BOOK OF ABSTRACTS

The 8th International Conference on Advanced Nanoparticle Generation and Excitation by Lasers in Liquids

MAY 24TH - 28TH, 2026 · CASTELLÓ, SPAIN

ANGEL CONFERENCE

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ANGEL26
CONFERENCE

WELCOME REMARKS

Welcome to Castellón, and welcome to Benicàssim, and to the Advanced Nanoparticle Generation and Excitation by Lasers in Liquids conference, ANGEL, a unique scientific gathering joining lasers and nanoparticles on the Mediterranean coast of Spain.

This conference brings together an international community of researchers working at the forefront of laser-based nanoparticle synthesis and characterization, a field that continues to grow in importance due to its wide-ranging applications in nanotechnology, materials science, and advanced functional systems. ANGEL represents a meeting point where fundamental science and emerging applications converge, fostering dialogue across disciplines and encouraging innovative approaches to current scientific challenges.

Over the coming days, you will experience a dynamic and stimulating programme, including oral presentations, poster sessions, and opportunities for discussion and collaboration. These sessions reflect the vitality of the field and highlight the importance of knowledge exchange, particularly for early career researchers who represent the future of this scientific community. The programme has been carefully structured to showcase the diversity of ongoing research, from nanoparticle generation mechanisms and characterization of the process to applications in catalysis, sensing or bio.

The single session format of ANGEL and the welcoming atmosphere of the hotel Intelier Orange aims to facilitate the biannual community gathering for 5 days. Coffee breaks, poster sessions, and social activities provide valuable opportunities to connect with colleagues, exchange ideas, and establish new collaborations that may shape future research directions.

Beyond the scientific programme, we hope you will also take the opportunity to enjoy Castellón, Benicàssim and its surroundings guided by the social activities proposed and continuing your own path. This coastal setting offers a unique blend of natural beauty, culture, and Mediterranean hospitality, providing the perfect backdrop for inspiration, reflection, and connection.

We hope that this conference will not only advance knowledge in the field of advanced nanoparticles generation and excitation in liquids but also strengthen the global ANGEL community network of researchers dedicated to pushing the boundaries of what is possible in this exciting and rapidly evolving discipline. By the end of ANGEL, we trust that new ideas, collaborations, and discoveries will emerge, contributing to the continued growth and impact of this field.

Prof. Gladys Mínguez Vega
University Jaume I

Junior Prof. Carlos Doñate Buendia
University Jaume I

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SPECIAL ISSUES

ANGEL participants are invited to contribute to the *Special Issues of Beilstein Journal of Nanotechnology* and *Discover Nano Journal*

BEILSTEIN JOURNAL OF NANOTECHNOLOGY

Laser material processing in liquids for nanoparticle synthesis.

Guest Editors:

- Prof. Gladys Mínguez-Vega, University Jaume I, Spain
- Dr. Benjamin Mochenhaupt, University of Duisburg-Essen, Germany
- Prof. Vicenzo Amendola, University of Padua, Italy

This Special Issue at Beilstein Journal of Nanotechnology addresses pulsed laser ablation and laser-based processing of nanoparticles in liquids as sustainable, surfactant-free routes to synthesize high-purity nanomaterials. It highlights experimental, theoretical, and computational advances in nanoparticle generation, characterization, applications, and composite integration for energy, biomedicine, catalysis, and manufacturing

This thematic issue is motivated by the **International Conference on Advanced Nanoparticle Generation and Excitation by Lasers in Liquids (ANGEL 2026)** in Spain, while welcoming contributions from the broader community. It follows a **previous thematic issue stemming from an earlier symposium**, published in the *Beilstein Journal of Nanotechnology*, reflecting the sustained growth and relevance of this research field.

Discover

Laser synthesis and processing in liquids towards functional nanomaterials

Guest Editors:

- Junior Prof. Carlos Doñate Buendia, University Jaume I, Spain
- Prof. Myong Yong, Gyeongsang National University, South Korea

This Special Issue in Springer Nature's journal Discover Nano focuses on laser synthesis and processing in liquids (LSPC) as a sustainable and versatile route for the fabrication of high-quality nanomaterials, aligning with the journal's broad scope in nanoscience, materials, energy, and biomedical applications. It aims to highlight recent advances in experimental, theoretical, and computational approaches that deepen the understanding of laser–matter interactions in liquid environments and the complex parameter space governing nanoparticle formation, structure, and productivity.

Contributions addressing functional nanomaterials and their applications in catalysis, sensing, energy conversion, and nanomedicine are particularly encouraged, alongside studies tackling challenges related to scalability and process optimization. This collection seeks to foster interdisciplinary collaboration and support the transition of LSPC from fundamental research toward practical and industrial implementation.

This thematic issue is motivated by the **International Conference on Advanced Nanoparticle Generation and Excitation by Lasers in Liquids (ANGEL 2026)** in Spain, while welcoming contributions from the broader community. It follows a **previous thematic issue stemming from an earlier symposium**, published in the Journal of Physical Chemistry, reflecting the sustained growth and relevance of this research field.

TUTORIAL

Pre-conference tutorial on the generation of nanoparticles by laser ablation in liquids will take place Sunday, May 24, at the Intelier Orange Hotel. The tutorial will be conducted by leading experts in the field and will include a hands-on component.

Alfred Vogel
University of Luebeck, Germany

Carlos Doñate
University Jaume I, Spain

Francis Rey Cortes
University Jaume I, Spain

Barbara Hissa
BJNano Editor, US

Leonid Zhigiliei
University of Virginia, US

Sergio Fernández Molina-Prados
University Jaume I, Spain

TUTORIAL SCHEDULE

	SUNDAY 24TH
09:00 - 10:00 h	Alfred Vogel
10:00 - 11:00 h	Carlos Doñate
11:00 - 11:30 h	COFFEE BREAK
11:30 - 12:30 h	Francis Rey Cortes
12:30 - 13:00 h	ANGELA
13:00 - 14:00 h	LUNCH BREAK
14:00 - 14:30 h	Barbara Hissa
14:30 - 15:30 h	Leonid Zhigiliei
15:30 - 18:30 h	**Practical workshop:** Arduino based colloidal concentration sensor
19:00 - 21:00 h	Welcome Reception

VENUE

The conference is held at the Intelier Orange Hotel, located in the vibrant coastal town of Benicàssim, just a short walk from the beach and surrounded by a wide variety of restaurants, cafés, and leisure areas in the immediate vicinity. ANGEL signs will be posted inside, helping to guide participants.

Benicàssim lies on the Mediterranean coast in the province of Castellón, approximately 90 km north of Valencia (around 1 hour by car), offering a perfect combination of seaside relaxation and easy access to major transport hubs.

The nearest airport is Castellón Airport (CDT), located about 30 minutes by car. Other international airports include Valencia Airport (VLC), approximately 1 hour away, Barcelona-El Prat Airport (BCN), around 2 hours and 30 minutes by car, and Adolfo Suárez Madrid-Barajas Airport (MAD), about 4 hours and 30 minutes away.

Local transport options include a nearby bus stop on Avenida Gimeno Tomás, just a 2-minute walk from the hotel. The Benicàssim Train Station is located approximately a 25-minute walk.

For wider rail connections, Castelló de la Plana Railway Station is just 20 minutes away by car, offering regional and long-distance services. Additionally, Valencia Joaquín Sorolla Railway Station, located about 1 hour away, provides high-speed AVE connections to major cities such as Madrid and Barcelona.



SOCIAL PROGRAM

Tuesday, May 26, 14:00 – 21:00: Valencia Tour

A cultural experience combining history, architecture, and free time to explore the city at your own pace.

Participants will travel by round-trip bus transfer from the hotel. The visit includes a guided tour through the historic city center, followed by free time for sightseeing, shopping, or enjoying the atmosphere.

In the afternoon, there will be a panoramic drive from the Torres de Serrano to the City of Arts and Sciences, including an exterior walk around the complex and the former Turia riverbed, now a beautiful urban park.

The excursion also includes free time in this area before returning to Benicàssim.



Wednesday, May 27, 18:15 – 19:00: Flute and Guitar Concert

Following the poster session, participants are warmly invited to attend a live concert featuring flute and guitar. This musical performance offers a relaxing and enriching atmosphere, providing an opportunity to unwind while enjoying a carefully curated repertoire.

The concert will feature guitarist Ana Archilés, whose artistic career combines performance and pedagogy, bringing a refined and expressive interpretation to the classical guitar repertoire. She will be joined by Italian flautist Francesco Mannis, an award-winning performer with an extensive international career, known for his refined musicianship and dedication to both performance and music education.



Wednesday, May 27, 20:00 – 22:00: Social Dinner

The Social Dinner offers participants the opportunity to enjoy a memorable evening by the Mediterranean in a relaxed and welcoming atmosphere.

The event will be held at PLAYACHICA, a vibrant beachfront venue located directly on the sand with beautiful views of the sea. Combining the elegance of a restaurant with the laid-back spirit of a beach club, it provides an ideal setting to unwind and connect with fellow attendees.

Guests will have the opportunity to experience Mediterranean gastronomy, with a menu inspired by local flavours and seasonal ingredients. The dinner will highlight the richness of the region's culinary traditions, offering a carefully prepared selection of dishes designed to be enjoyed in a convivial and sociable setting.

This evening aims to create a pleasant space for conversation, networking, and shared experiences, all within a unique seaside environment.



Thursday, May 28, 16:00 – 18:00: Benicàssim Tour

A delightful afternoon exploring the historic **Villas of Benicàssim** — a cultural experience combining architecture, history, and the charm of the town's seafront promenade.

Participants will enjoy a **walking tour** of the villas, where you will learn about the elegant summer residences built between the late 19th and early 20th centuries, their distinctive architectural styles, and the social history of Benicàssim as a prestigious holiday destination.



Friday, May 29, 09:00 – 12:00: Castellón Tour

A cultural experience combining the city's history, architecture, and vibrant local atmosphere.

Castellón is a dynamic city on the Mediterranean coast, home to the **Universitat Jaume I (UJI)** and known for its historic architecture, lively plazas, and rich cultural traditions. From beautiful Gothic and Baroque churches to bustling markets and inviting cafés, the city offers visitors an authentic taste of Spanish culture, complemented by its proximity to stunning beaches and natural landscapes in the province.



CONFERENCE PROGRAM

	MONDAY 25TH
09:00 - 09:15 h	ANGEL 26 Opening
09:15 - 09:45 h	Marcella Dell'Aglio
09:45 - 10:05 h	Leonid Zhigilei
10:05 - 10:25 h	Ramon Auer
10:25 - 10:45 h	Jaurel Kagho Zanguim
10:45 - 11:30 h	COFFEE BREAK
11:30 - 12:00 h	Anton Plech
12:00 - 12:20 h	David Amans
12:20 - 12:40 h	Gilles Ledoux
12:40 - 13:00 h	Maximilian Spellauge
13:00 - 14:30 h	LUNCH BREAK
14:30 - 15:00 h	Yoshie Ishikawa
15:00 - 15:20 h	Christoph Rehbock
15:20 - 15:40 h	Jan Lino Kricke
15:40 - 16:00 h	Anna Ziefuss
16:00 - 16:30 h	COFFEE BREAK
16:30 - 16:50 h	Żaneta Świątkowska-Warkocka
16:50 - 17:10 h	Kotaro Terao
17:10 - 17:30 h	Ryohei Yasukuni
17:30 - 17:50 h	William McMahon-Puce
18:00 - 19:00 h	FLASH TALKS
19:00 - 21:00 h	POSTER SESSION WITH COCKTAIL

	TUESDAY 26TH
09:00 - 09:30 h	Katharine Tibbetts
09:30 - 09:50 h	Angela de Bonis
09:50 - 10:10 h	Valentyn Volkov
10:10 - 10:30 h	Nikolai Tarasenko
10:30 - 11:00 h	COFFEE BREAK
11:00 - 11:30 h	Rafael Omar Torres Mendieta
11:30 - 11:50 h	Heinz Paul Huber
11:50 - 12:10 h	Sergio Molina-Prados
12:10 - 12:30 h	Alexander V. Bulgakov
12:30 - 12:50 h	Abdel Rahman Altakroury
12:50 - 14:00 h	LUNCH BREAK
14:00 - 21:00 h	**Activity – València Tour** Participants will travel at 14:00h comfortably by round-trip bus transfer included from the hotel.

	WEDNESDAY 27TH
09:00 - 09:30 h	Myong Yong Choi
09:30 - 09:50 h	Tommaso Del Rosso
09:50 - 10:10 h	Fabian G. Dorado Lopez
10:10 - 10:30 h	Oscar Bomati-Miguel
10:30 - 11:00 h	COFFEE BREAK
11:00 - 11:30 h	Guillermo Gonzalez-Rubio
11:30 - 11:50 h	Ana Maria Vilas Iglesias
11:50 - 12:10 h	Francis Rey Cortes
12:10 - 12:30 h	Sean O'Malley
12:30 - 12:50 h	Wiebke L. M. Narz
12:50 - 14:00 h	LUNCH BREAK
14:00 - 14:30 h	Soma Venugopal
14:30 - 14:50 h	Benjamin Mockenhapt
14:50 - 15:10 h	Jaime González
15:10 - 15:30 h	Cristiano Lo Pò
15:30 - 15:50 h	Theerthagiri Jayaraman
15:50 - 16:10 h	Tomáš Křenek
16:10 - 16:45 h	FLASH TALKS
16:45 - 18:15 h	POSTER SESSION
18:15 - 19:00 h	GUITAR AND FLUTE CONCERT
20:00 - 22:00 h	SOCIAL DINNER

	TUESDAY 28TH
09:00 - 09:30 h	Sadasivan Shaji
09:30 - 09:50 h	Marcello Condorelli
09:50 - 10:10 h	Sergei Kulinich
10:10 - 10:30 h	Indhulekshmi Prasad
10:30 - 11:00 h	COFFEE BREAK
11:00 - 11:20 h	Jithin Kundalam Kadavath
11:20 - 11:40 h	Silja-Katharina Rittinghaus
11:40 - 12:00 h	Emmanuel Haro-Poniatowski
12:00 - 12:20 h	Dongshi Zhang
12:20 - 12:40 h	Ivan Kazantsev
12:40 - 13:00 h	AWARD CEREMONY
13:00 - 13:20 h	ANGEL 26 CLOSING
13:20 - 14:30 h	LUNCH BREAK
16:00 - 18:00 h	**Activity – Benicàssim** Participants will enjoy a guided walking tour of the villas of Benicàssim.

	FRIDAY 29TH
09:00 - 14:00 h	**Activity – Visit to Castelló** Guided tour. A cultural experience combining the city's history, architecture, and vibrant local atmosphere.

Abstracts of

INVITED SPEAKERS

Laser-Induced Plasma: From Ultrapure Nanoparticle Synthesis to Nanoparticle-Enhanced Laser-Induced Breakdown Spectroscopy

Marcella Dell'Aglio [*a], Alessandro De Giacomo[*a*b]

[*a] *CNR-IFN (National Research Council - Institute for photonics and nanotechnologies), c/o Physics Department, University of Bari, Italy*

[*b] *Department of Chemistry, University of Bari, Italy*

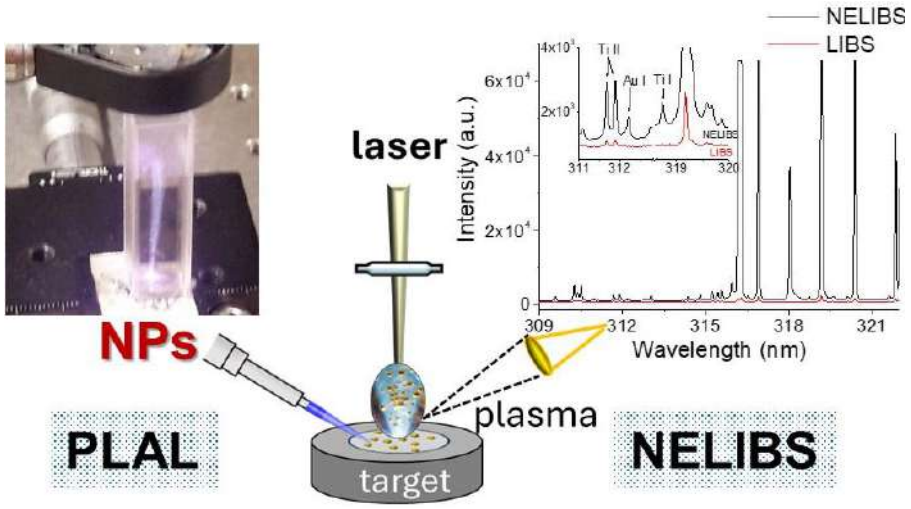
Laser-Induced Plasma (LIP) has gained increasing interest due to its high experimental flexibility and broad applicability in analytical chemistry, materials science, and nanomaterial production. LIP is generated by focusing a high-irradiance laser pulse on a sample, producing a high-temperature, high–electron-density plasma whose properties strongly depend on laser parameters, target material, and the surrounding environment [1]. By analysing plasma emission with high spectral and temporal resolution, fundamental plasma parameters and sample composition can be determined through Laser-Induced Breakdown Spectroscopy (LIBS), a micro-destructive, simultaneous multi-elemental technique capable of detecting also light elements.

When plasma is generated on samples immersed in liquids, Pulsed Laser Ablation in Liquid (PLAL) enables the green synthesis of ultrapure, stable nanoparticles without chemical precursors or contamination. Nanoparticle formation is driven by strong plasma confinement in the liquid [2]. Although the elementary processes sustaining plasma are the same as those of an expanding plasma in background gas, strong confinement and energy exchange with the liquid induce different competition between the elementary processes leading to nanoparticle nucleation and growth. Moreover, the plasma energy transfer to the liquid forms a long-lived cavitation bubble whose expansion and collapse finally allow the release of the nanoparticles into the liquid.

These ultrapure nanoparticles produced by PLAL have been exploited to enhance LIBS sensitivity through Nanoparticle-Enhanced LIBS (NELIBS) [3], without interfering elements except the metal of which the nanoparticle was made. NP-enhanced laser ablation is based on the interaction of the plasmonic system of metallic NPs with the ablated matter during the laser pulse irradiation with ns-laser pulses. When a laser is focused on a sample covered with a layer of NPs a matching between the electromagnetic field of the laser and the one generated on the NPs system occurs. This led to a field enhancement and consequently to a better atomization of the ablated matter and in turn, an enhancement of the emission intensity in the plasma emission spectrum, allowing the decrease of the detection limit. NELIBS enables sub-ppm trace element analysis in solids, liquids and, in particular, it overcomes the low sensitivity of conventional LIBS for biological matrices. Moreover, the single-shot analysis requires minimal sample quantities (few microliters in the case of liquids). NELIBS therefore has been successfully employed for elemental analysis on biological samples, including liquids, proteins and tissues as well as for retrieving information on the structure of NP-protein complex structures [4].

Finally, since the detection of nanoparticles by LIBS can be of great interest to the analytical chemistry community, both for the elemental analysis of the nanoparticles themselves and

for their potential use as tags in biomedical applications, the origin and characteristics of the atomic emission signal produced by NP vaporization during LIBS [5] have been also investigated, with particular attention to the effect of NP size—ranging from 5 to 100 nm—on the sensitivity of calibration curves.



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Acknowledgments:

This work was partially supported by the Italian Ministry of funded from European Union - Next Generation EU, Mission 4 Component 1" (CUP B53D2302546001, CUP H53D23007820001, CUP H53D23003930006, respectively)

Laser fragmentation in liquid – constructing a generic reaction map

Anton Plech[*a], Meike Tack[*b], Yogesh Pokhrel[*a], Sven Reichenberger[*b]

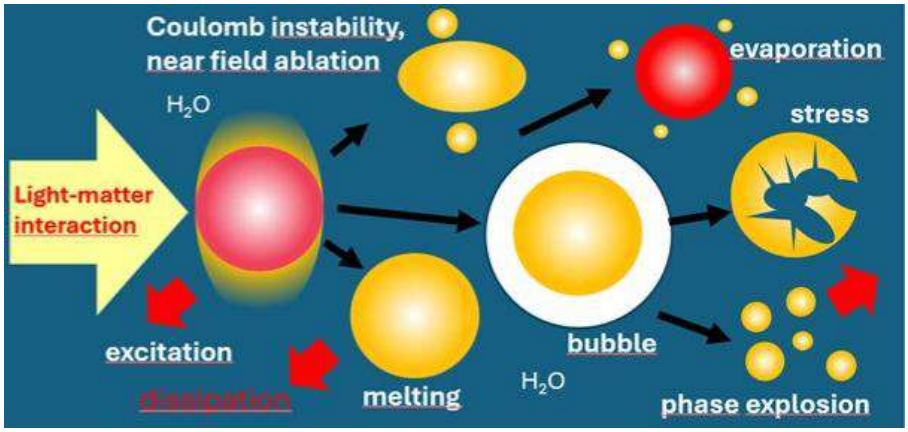
[*a] *Karlsruhe Institute of Technology, Germany.*

[*b] *University of Duisburg-Essen, Germany.*

Laser fragmentation in liquid (LFL) [1] is a process to complement laser ablation approaches to modify particles sizes, speciation and/or morphology of raw produced nanoparticles [2], but has recently been investigated as a de novo method for producing nanoparticles from industrial microparticles with excellent efficiency [3,4]. A fundamental understanding is paramount to rationalize the products to be expected and find clues for optimizing the process.

This presentation will discuss the possible reaction pathways of single-pulse irradiation of gold nanoparticles in water when excited by picosecond laser pulses [6] by applying advanced experimental methods [5] of pump-probe experiments with short-wavelength radiation and 100 ps time resolution [7] in comparison to large-scale simulations [8].

Both the applied laser fluence and the temporal delay after impulsive laser excitation serve as order parameter to disentangle the competing structural reactions and construct a map of possible intermediate and final states during the reaction. We will discuss the relevance of initial particle sizes [9,4], laser source [10] or ligand insertion [9].



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Acknowledgments:
We acknowledge fruitful discussions with A. Ziefuss, L. Zhigilei, H. Huang, S. Barcikowski, M. Spellauge, M. Levantino, and H. P. Huber. Beamline access at ESRF beamline ID09 is gratefully acknowledged. This work was funded by the German Science Foundation under contract 491072288 and by the Helmholtz Association program “From Matter to Materials and Life”.

Pulsed Laser Melting in Liquid from the Mixture of Photo-absorptive and non-photo-absorptive Raw Particles for Functional Sphere Fabrication

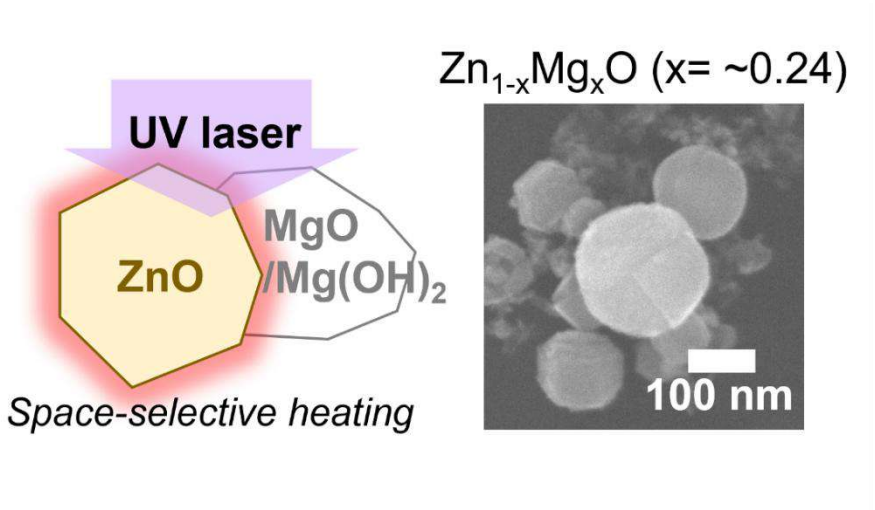
Yoshie Ishikawa[*a], Koichiro Saito[*a], Naoto Koshizaki[*b]

[*a] *Core Electronics Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Japan.*

[*b] *Graduate School of Engineering, Hokkaido University, Japan.*

Our group has been studying a technique, pulsed laser melting in liquid (PLML) to fabricate spherical submicrometer particles (SMPs). The SMP formation from simple single-component raw particles in the early stage of PLML research has been extended to that from the mixed particles composed of two or more components as raw particles. This process involves interesting phenomena such as interparticle reaction and alloying [1,2]. In this study we focus on the PLML processes to binary mixture of photo-absorptive and non-photo-absorptive raw particles and discuss the space selective heating due to the difference in photo-absorptivity and the effect of raw particle mixing conditions on SMP formation.

The mixture of photo-absorptive ZnO and non-photo-absorptive MgO or $Mg(OH)_2$ particles at various predefined-mixing ratios as raw particles were prepared with various methods; mechanical mixing using a planetary ball mill, co-precipitation from the mixed ionic solution of Zn^{2+} and Mg^{2+} via alkali solution addition, and pyrolysis of Zn and Mg acetylacetonate complex mixture. The mixture of raw particles dispersed in ethanol was irradiated with an ns pulsed laser at wavelength of 266 nm. Solid solution $Zn_{1-x}Mg_xO$ SMPs formed and the maximum solid solubility x= 0.24 of Mg in wurtzite ZnO was attained with laser irradiation of raw material particle mixture of ZnO and Mg $(OH)_2$ prepared by co-precipitation with Zn: Mg = 1:2 mixture molar ratio [3].



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Acknowledgments:
This work was supported by the grant from the Hosokawa Powder Technology Foundation.

Unravelling chemical reaction dynamics and mechanisms during laser synthesis and processing in liquid

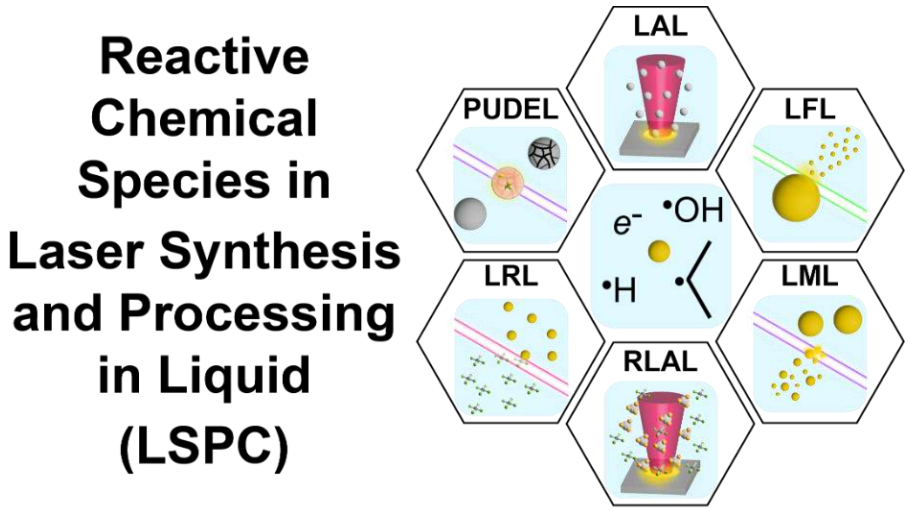
Katharine Tibbetts[*a]

[*a] *Virginia Commonwealth University, United States*

Laser synthesis and processing of colloids (LSPC) is often considered a "physical" synthesis method because the interaction of intense laser pulses with a target material induces physical changes in size and/or shape of the target. However, these physical changes are nearly always accompanied by chemical reactions involving the target material, liquid medium, or both. These reactions can produce nanoparticles with different compositions from the initial target or precursor material [1]. This presentation will highlight recent progress in my group towards elucidating chemical reaction pathways that occur during laser processing in liquids and how these reactions impact the properties of the product nanoparticles.

When LSPC is conducted in water, the laser interaction induces chemical decomposition of the water that produces a plasma containing predominantly hydrated electrons (e^-_{aq}) and hydroxyl radicals (OH•), along with additional reactive species such as hydrogen radicals (H•) and superoxide anion (O_2-•). Whereas the e^-_{aq} are strong reducing agents that can reduce metal ions in solution and create oxygen defects in metal oxide nanoparticles, the strong oxidizing agents OH• and O_2-• can oxidize ablated metal species and reduced metal atoms in solution. The effects of these reactive oxygen species (ROS) on nanoparticle properties and the use of chemical scavengers to suppress ROS formation will be discussed.

LSPC is often conducted in organic liquids to limit the oxidation reactions that occur in water due to the presence of ROS. Laser interaction with organic liquids induces a plethora of chemical reactions that produce many more reactive species and chemical byproducts than processing in water [2]. Moreover, ablated metal species can react with the generated organic radicals to produce carbon-coated nanoparticles. Characterization of organic byproducts of LSPC syntheses and use of chemical scavengers of organic radicals to identify populations of organic reactive species will be discussed.



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Emerging Frontiers and Innovative Applications of Ultrafast Laser Ablation

Venugopal Rao Soma[*a]

[*a] *School of Physics & DRDO Industry Academia – Centre of Excellence (DIA-COE, formerly ACRHEM), University of Hyderabad, India*

Ultrashort pulsed laser light-matter interaction is a captivating phenomenon with profound underlying physics/chemistry and depends on materials' properties. Additionally, this technique has potential in high-precision micromachining, surface functionalization, sensing, catalysis, structural coloring etc. The interaction of focused pulsed (picosecond/femtosecond duration) laser pulses with matter (in air and in a surrounding liquid) results in (i) novel phases of the matter, (ii) novel colloidal nanoparticles and surface nanostructures in a single experiment, and (iii) novel practical applications of the irradiated/prepared surfaces (anti-corrosion, hydrophobicity, hydrophilicity, complete absorption) [1-3].

We will discuss the effects of the interaction of short laser pulses with diverse materials such as metals (Ag, Au, Ag-Au-Cu), semiconductors (Si, Ge, GaAs, SiC, InP), 2-D materials (WS_2, MoS_2, MXenes), and high-entropy alloys [5-21]. We shall discuss the formation of functional nanomaterials/nanostructures resulting from this interaction, consequential in surface-enhanced Raman scattering (SERS)-based sensing applications, photonics, and in high-temperature coatings for defense applications.

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Laser-Induced Electrocatalysts for Sustainable Hydrogen Production and High-Value Chemical Conversion

Myong Yong Choi[*a]

[*a] *Department of Chemistry (BK21 FOUR), Research Institute of Advanced Chemistry, Gyeongsang National University, Republic of Korea.*

The development of cost-effective and durable electrocatalysts for hydrogen and ammonia production is central to advancing carbon-neutral energy technologies. This talk will highlight the recent advances in the development of multifunctional nanocatalysts and single-atom systems engineered via laser-assisted techniques for sustainable electrochemical energy conversion.

First, we introduce Ru@C nanospheres via pulsed laser ablation in liquid (PLAL). This catalyst exhibits exceptional bifunctionality for the hydrogen evolution reaction (HER) and hydrazine oxidation reaction (HzOR), enabling low-voltage overall hydrazine splitting (OHzS) with remarkable durability (>100 h). Integration into a Zn–hydrazine battery not only achieves a high energy efficiency of 90% but also facilitates self-powered hydrogen production, opening a pathway for on-site green H_2 generation.

Second, I will highlight a rapid and scalable CO_2-laser method for synthesizing dual single-atom catalysts (DSACs) of Ni and Co on MXene supports. The NiCo-DSAC/MXene catalyst demonstrates superior electrocatalytic nitrate reduction to ammonia via a low-energy pathway. Coupling this system with a Zn–NO_3^- battery simultaneously enables NO_3^- remediation, energy harvesting, and NH_3 production.

Together, these works demonstrate the power of laser-assisted strategies for tailoring catalytic interfaces and active sites at the atomic and nanoscale, offering a scalable route to integrated electrocatalytic–energy storage platforms for sustainable chemical production.

Synthesis of Noble Metal Alloy Nanocrystals via Ultrafast Pulsed Laser Irradiation of Colloidal Heterostructures

Guillermo González-Rubio[*a]

[*a] *Departamento de Química Física, Universidad Complutense de Madrid, Spain*

The synthesis of colloidal nanocrystals with complex composition represents an advanced strategy for creating nanomaterials with superior functionalities. [1,2] However, besides composition, control over dimensions, elemental distributions, crystalline defects, and surface chemistry is fundamental to governing their physicochemical properties and functionalities. Bottom-up wet-chemical routes can be exploited to design intricate multimetallic heterostructures with unprecedented quality.[3]

Unfortunately, alloy nanocrystal fabrication encounters high energy barriers for elemental mixing, due to unfavorable enthalpic contributions, large differences in reduction potentials, or atomic diffusion impediments. [1,4]

Ultrafast pulsed lasers emerge as a valuable tool to address this challenge thanks to their ability to heat colloidal nanocrystals to extremely high temperatures at ultrafast rates, thereby facilitating the overcoming of thermodynamic and kinetic barriers associated with combining different metals into discrete alloy nanocrystals.[5-7] Bottom-up wet-chemical routes are rationally designed to target multimetal nanocrystal heterostructures with defined compositions and dimensions, which are then excited with ultrafast pulsed laser irradiation to form partial or complete alloy nanocrystals.

Importantly, their colloidal stability is preserved during the alloying process. Thereby, multielemental alloys with defined numbers of atoms per nanocrystal and compositions can be successfully synthesized, incorporating metals such as Au, Pt, Pd, Ag, and Ir. The proposed methodology offers precise control over the synthesis of multimetallic nanocrystals, potentially facilitating their use in the development of advanced catalytic, sensing, and energy-production systems.

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Acknowledgments:
G.G.-R. acknowledges receipt of the Atracción de Talento grant from CAM (grant no. 2022-T1/IND-23908) and financial support from the European Research Council (ERC StG No. 101164205 Time4Nano).

Towards Precise Morphological Control of Magnetic and Catalytic Multielement Functional Nanoparticles

Rafael Omar Torres Mendieta[*a]

[*a] *Department of Chemical Sciences, University of Padua, Italy.*

Laser-based synthesis of nanoparticles (NPs) in liquids has evolved into a powerful platform for producing complex, multifunctional nanomaterials with exceptional purity and tunability. In particular, laser ablation in liquids (LAL), as well as its reactive variant, reactive LAL (RLAL), have opened unique pathways toward the production of multielement NPs, combining very appealing properties such as magnetic and catalytic functionalities within a single nano-object. This invited talk will discuss recent advances toward the precise morphological control of such multielement functional NPs, with emphasis on both existing synthetic approaches and application-driven material design, where precision is understood in terms of size, shape anisotropy, phase distribution, and spatial elemental organization.

The systematic correlations between laser parameters, liquid chemistry, and resulting NPs morphology and functionality will be analysed, including insights into ablation, plasma, and cavitation dynamics that govern multielement incorporation and phase evolution, highlighting the latest breakthroughs in the field and their implications.

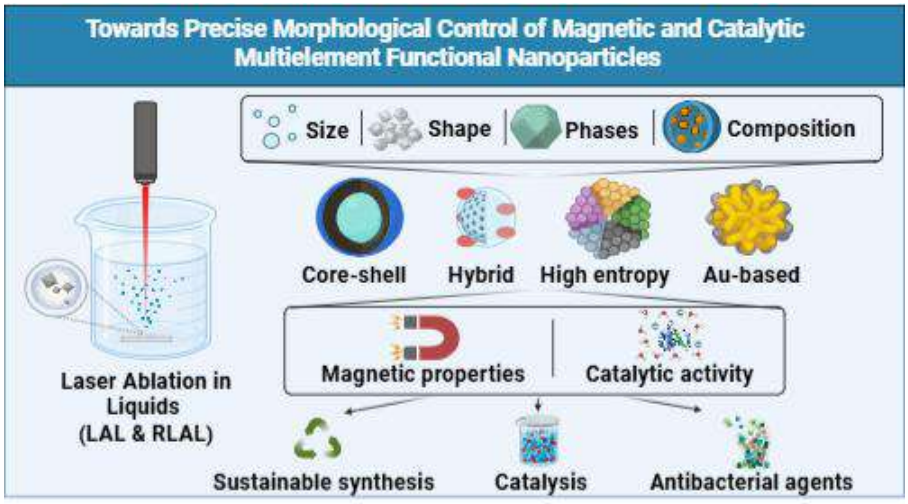
Particular attention will be devoted to the recently exponential developments in RLAL, which have turned it into a versatile route for producing multielement NPs, including magnetic-plasmonic and metal-oxide hybrid systems. By exploiting reactive species generated as a consequence of the ablation mechanism, this method enables the in-situ incorporation of multiple elements into individual NPs without the need for chemical precursors or surfactants.

Recent results include the synthesis of complex Au-based [1] and transition-metal-containing nanostructures [2], as well as NPs derived from non-traditional solid and liquid sources such as complex multilayered targets [3] and industrial effluent residues [4], underscoring the potential of laser techniques for sustainable and circular nanomaterial production. Emerging structure-property relationships further reveal how tailored morphologies enable tuneable magnetic-plasmonic coupling and functional performance across catalytic, environmental, and biomedical interfaces.

In this context, the talk will further deepen the impact of NPs morphological control on catalysis, a field with broad cross-sectorial implications, and demonstrate how the replacement of hazardous reducing and stabilizing agents by light introduces a new sustainable dimension to nanomaterial synthesis.

This light-driven approach, enabled by LAL and RLAL, elevates laser-based NPs synthesis from a fabrication strategy to a genuine design paradigm, one that continues to expand through multielement integration [5], high-entropy nanoalloys [6], recyclable catalytic platforms [7], and stimuli-responsive antibacterial agents [8]. Ultimately, the ability to precisely tailor NPs morphology and composition using light alone positions laser synthesis

in liquids as a key enabler for the rational engineering of complex, multifunctional, and application-ready nanomaterials.



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Surface Enhanced Raman Spectroscopy (SERS) Sensors of Ultra-sensitivity, Stability and Signal Enhancement by Laser Patterning in Nanocolloids

Sadasivan Shaji[*a*b]

[a*] *Facultad de Ingeniería Mecánica y Eléctrica (FIME), Universidad Autónoma de Nuevo León, México.* [b*] *Centro de Innovación, Investigación y Desarrollo en Ingeniería y Tecnología (CIIDIT), Universidad Autónoma de Nuevo León, México.*

SERS is a fast and effective technique for trace level detection of various types of molecules with high sensitivity using their characteristic vibrational features. We demonstrate an innovative and cost-effective method for fabricating ultrasensitive and stable SERS sensors with different surface morphologies. Laser surface patterning of a thin layer of silver (Ag) or silver-copper (Ag-Cu) films in laser ablated Ag, Au and bimetallic (AgAu) nanocolloids resulted surface nanostructuring and *in-situ* incorporation of nanoparticles based plasmonic nanostructures, leading to enrichment of SERS sensitivity by electromagnetic enhancement and synergistic effect of metal/bimetallic nanoparticles.

The sensors showed excellent SERS response for visible and near infrared Raman excitation wavelengths with femtomolar sensitivity and quantitative detection capability. The sensors exhibit good SERS signal homogeneity and uniformity. The SERS spectra are reproducible after one month of storage, validating sensor's shelf life and stability. SERS sensors are utilized for the detection of different water contaminants (Pb, Arsenic, SDS) as well as various dyes and biomolecules (Glucose, Uric acid, L-Cystine). This method for SERS sensor fabrication is a simple, fast, and scalable one for generating nanostructured surface morphologies and expanding plasmonic resonances for ultrasensitive, wide field molecular identification and quantification.

Abstracts of

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Heat transfer, melting, resolidification, and defect generation in short-pulse laser processing of nanoparticles in liquids

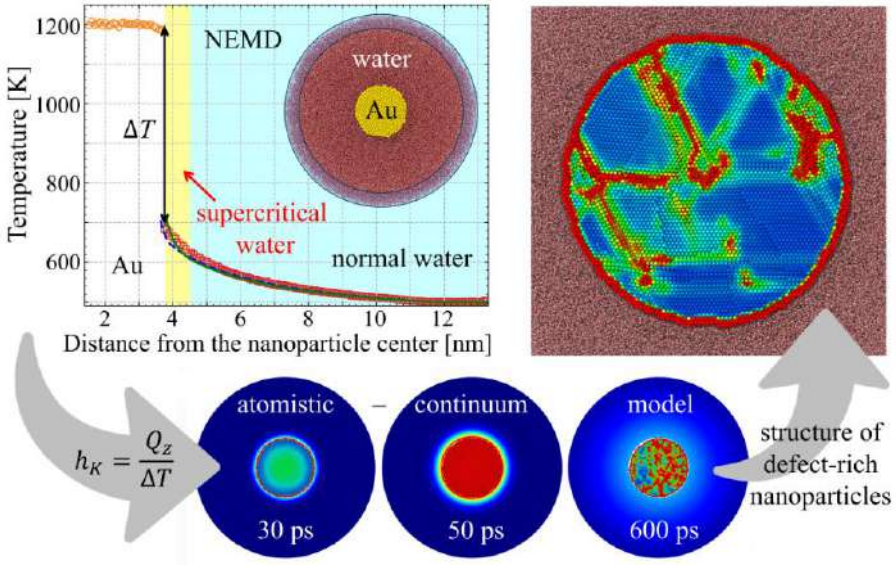
Leonid V. Zhigilei[*a]
[*a] *University of Virginia, USA.*

The heat transfer from a colloidal nanoparticle rapidly heated by a short laser pulse to the surrounding liquid environment plays a central role in laser-based nanoparticle processing techniques aimed at modifying particle shape, size, and internal structure. In particular, the strongly enhanced catalytic activity of metal nanoparticles produced by laser synthesis in liquids [1] is commonly attributed to a high density of crystal defects [2], which, in turn, can be linked to the extreme cooling rates experienced by nanoparticles embedded in a liquid environment [3,4].

In this presentation, the mechanisms of heat transfer and defect formation in short-pulse laser processing of nanoparticles in liquids are investigated using atomistic and continuum-level simulations of Au nanoparticles in water [5]. The relative contributions of heat transfer across the nanoparticle–liquid interface (thermal boundary conductance) and diffusional heat dissipation in the surrounding liquid are examined, with particular attention to regimes in which water adjacent to the hot Au surface is heated to, or above, its critical temperature. Molecular dynamics simulations reveal that the formation of a layer of supercritical water strongly modifies heat transfer across a planar Au–water interface, while the high interfacial curvature of nanoparticle–water interfaces enhances thermal boundary conductance, suppresses nanobubble formation, and maintains efficient heat transfer even at high temperatures.

The results of the atomistic simulations of steady-state interfacial heat transfer are incorporated into a hybrid atomistic-continuum model that combines a continuum description of heat diffusion in the water environment with atomistic modeling of laser-induced structural and phase transformations in the nanoparticle. Simulations performed with this hybrid model predict that Au nanoparticles irradiated by 10 ps laser pulses in water undergo rapid cooling on time scales of ~100 ps for 7 nm particles and several hundred picoseconds for 20 nm particles. At sufficiently high laser fluences, the nanoparticles experience complete melting followed by resolidification under conditions of deep undercooling.

Solidification under these conditions produces nanoparticles with nanocrystalline structures featuring high densities of planar defects (twins, stacking faults, and grain boundaries). These findings provide a mechanistic basis for understanding the enhanced catalytic activity frequently reported for nanoparticles synthesized or processed by laser irradiation in liquids.



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Acknowledgments:
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Optical Signatures of Redeposition Informed by Molecular Dynamic Simulations

Ramon Auer [*a], Chaobo Chen [*b], Maximilian Spellauge [*a], Daniel J. Förster [*a], Leonid V. Zhigelei [*b], Heinz P. Huber [*a]

[*a] *Laser Center HM, Munich University of Applied Sciences HM, Germany*

[*b] *Department of Materials Science and Engineering, University of Virginia, USA*

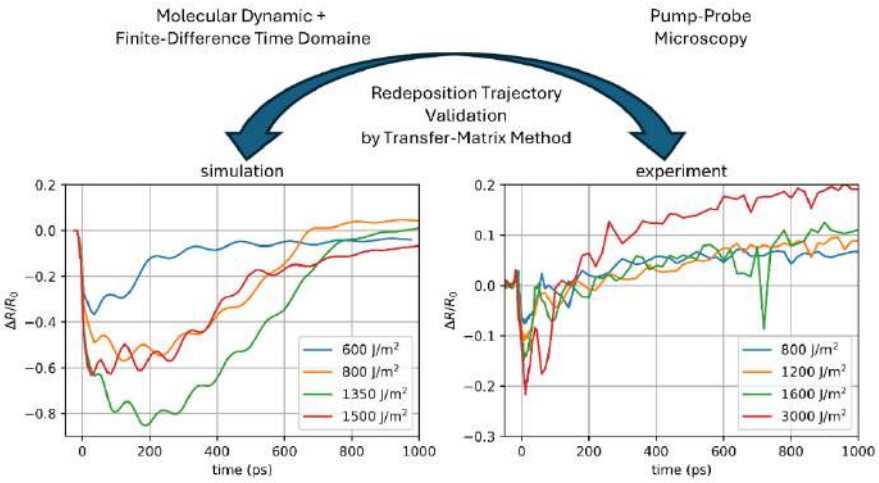
Laser ablation in liquids (LAL) enables the generation of ligand-free nanoparticles from nearly any solid, yet its scalability is constrained by limited productivity and energy efficiency [1]. A major loss channel is redeposition: atomistic simulations predict that a significant fraction of the initially ejected material does not escape into the liquid but returns to the target, reducing the effective ablation volume [2]. Direct time-resolved experimental access to redeposition remains limited because transient Newton rings, which serve as clear signatures of spallation in air, are not observable in liquids [3]. We therefore validate MD-predicted optical properties using transient measurements of the relative reflectance change.

Building on an experimentally validated MD–experiment framework for $Fe_{0.5}Ni_{0.5}$ ablation in air, where spallation and phase explosion were linked to transient optical responses [4], we extend the approach to LAL. MD simulation outputs are coupled to finite-difference time-domain (FDTD) electrodynamic calculations to predict time-dependent effective optical properties of the evolving near-surface region. These are parameterized as a minimal, time-dependent multilayer system and propagated using a transfer-matrix method (TMM) to compute the reflectance at 520 nm under normal incidence. The analysis focuses on the first 2 ns, where MD-in-liquid studies predict the strongest redeposition signatures [2]. Model predictions are compared to spatially resolved pump–probe microscopy (PPM) data providing 500 fs temporal and micrometer spatial resolution.

For four representative fluences, the MD–FDTD–TMM model reproduces the main features of the measured $\Delta R/R_0(t)$ transients and separates contributions from redeposition-induced ablation-layer motion, early liquid pressure-wave signatures, and the onset of cavitation and bubble dynamics. Inclusion of redeposition explains an early positive reflectivity component not attributable to cavity formation alone. Retrieved trajectories show redeposition onset on sub-nanosecond timescales and near completion by ~2 ns, with fluence-dependent maximum lift-off amplitudes of several tens of nanometers. The same MD–FDTD–TMM analysis further yields early shock velocities and bubble-related optical contributions.

This study establishes a consistent simulation–experiment framework for redeposition by transferring an experimentally validated MD approach from air to liquid environments, enabling optical validation of redeposition trajectories without Newton rings, and identifying a quantitative temporal window for multi-pulse excitation schemes.

This enables optimization of sub-nanosecond double-pulse delays to suppress redeposition, thereby reducing bimodal nanoparticle size distributions and promoting a more monomodal size distribution [5].



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Application of Machine-Learning and Automatic Data Analysis to Nanomaterials Synthesis Prediction by Laser Ablation in Liquid

Jaurel Kagho Zanguim [*a], Yi Luo [*b], Tobias Schlöder [*b], Manuel Tsotsalas [*b], Daniel Forrer [*a], Pascal Friederich [*b], Vincenzo Amendola [*a]

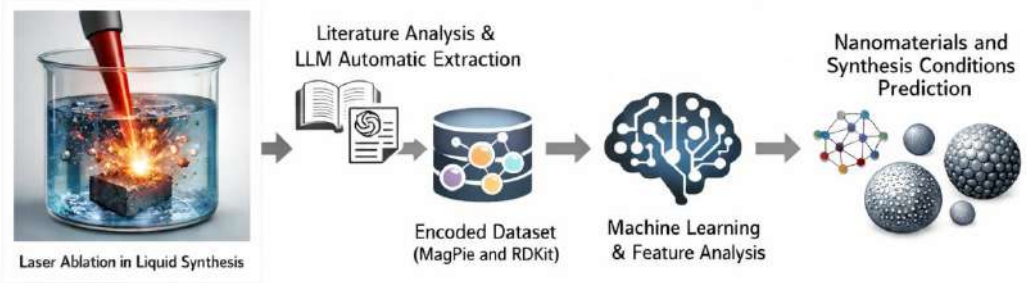
[*a] *University of Padova, Italy*

[*b] *Karlsruhe Institute of Technology (KIT), Germany*

Laser-generated nanomaterials [1, 2] have so far been promising in a gamut of applications leveraging their peculiarities such as purity, unconventional phases and controlled defectivity. Nevertheless, in view of performing data-driven discovery [3] to predict, design and identify new and optimal laser-generated nanomaterials, this research work focuses on building a first comprehensive database for the laser ablation in liquid (LAL) synthesis technique. Where applicable, through an AI-assisted Python software, specific parameters on LAL are automatically extracted from scientific literature by means of a GPT-based [4] large language model (LLM) leading to a preliminary database for LAL.

This database is then processed for a machine-understandable representation for LAL targets, solvents, and solutes. The PubChem, RDKit and magpie cheminformatics libraries [5, 6] were used to encode material properties of solvents, solutes and LAL targets. Starting from the fully encoded dataset, we perform feature visualization and feature importance analysis to understand the importance of various synthesis parameters for the prediction of machine learning model outputs. We further perform machine learning classification predictions for type of morphology and chemical class of nanoparticles.

In order to complement the feature importance analysis towards output prediction, we perform a detailed Shapley analysis of machine learning features [7] for all classification tasks effected. This leads to insights on the relationship between features of the dataset and prediction of various classes of nanoparticles. [3, 5, 6, 7] The ML model aims at identifying potential laser-generated candidate nanomaterials for specific applications, such as in catalysis, photonics, nanomedicine and nanomagnetism.



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Energy balance in nanosecond laser fragmentation

David Amans [*a], Mehdi Fawaz [*a], Prahlad Kumar Baruah [*a*b], Thaïs Favier [*a], Thierry Biben [*a], Samy Merabia [*a]

[*a] *Université Claude Bernard Lyon 1, CNRS, UMR5306, Institut Lumière Matière, France*

[*b] *Department of Physics, Pandit Deendayal Energy University, India*

The investigation of laser–colloid interactions is of significant scientific interest due to their considerable application potential across a wide range of irradiation regimes. These applications span from medical hyperthermia at low fluence [1], to the production of nanoparticles with controlled sizes via laser fragmentation at high fluence [2], as well as the controlled generation of defects (PUDEL) for catalytic applications [3].

In this study, we have focused in particular on the fragmentation mechanisms induced by nanosecond laser pulses, highlighting the possibility, in this regime, of obtaining sharp and monomodal size distributions. We aimed to characterize energy transfer, from the deposition of energy into gold nanoparticles by a nanosecond pulse (5 ns) to the formation of a bubble around these particles. A specific feature of nanosecond-pulse excitation is that the characteristic time for plasma formation is shorter than the pulse duration. The nascent plasma absorbs part of the laser pulse. However, the contribution of the energy absorbed by the plasma to bubble formation remains poorly characterized, even though plasma screening is a well-identified issue in laser ablation in liquids.

To address energy balance in nanosecond laser fragmentation, we combined two experiments: the first was designed to obtain reliable statistics on the maximum size of laser-generated bubbles, and thus on the associated energy required for solvent vaporization; the second aimed to evaluate the extinction cross section of the laser-generated plasma.

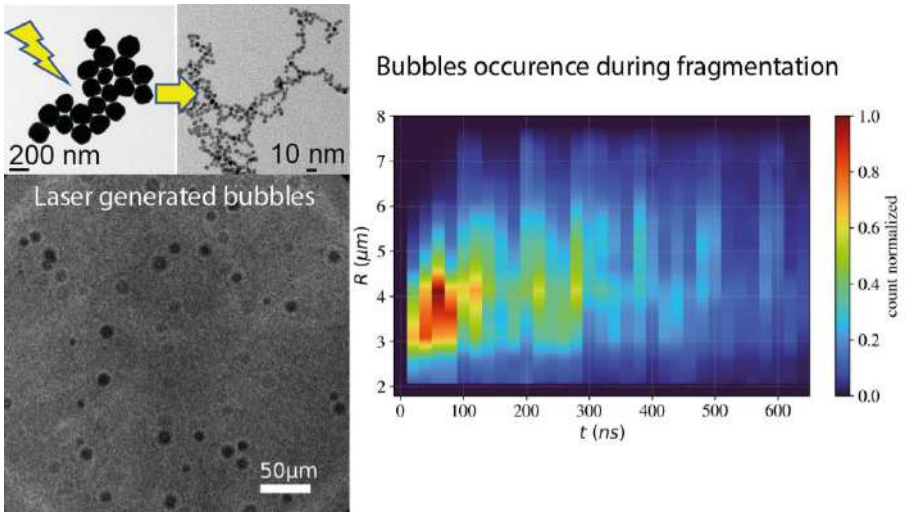
We designed a pump–probe setup to acquire shadowgraph images of small micrometer-scale bubbles generated by the laser–nanoparticle interaction, using an improved methodology relative to previous work by Stavitch and co-workers [4]. By analyzing thousands of images collected at different delays, we characterize the temporal evolution of the bubble size distribution and, consequently, the distribution of the maximum bubble radius, assuming a universal law for bubble dynamics deduced from previous measurements [5].

The procedure was applied to a low-concentration solution of 200 nm gold nanoparticles to avoid bubble–bubble interactions. For a fluence of 50 J/cm^2 at 355 nm, the maximum bubble radius is 5.2 µm (median of the distribution, with a standard deviation of 1.7 µm), necessitating 56 pJ of energy for water vaporization. In the meantime, by measuring the time dependence of the transmitted pulse energy into the colloidal solution, we can follow the time evolution of the fragmentation events.

After complete fragmentation of the pristine 200 nm particles, the size distribution of the resulting particles reveals a monodisperse population centered at 4 nm (standard deviation 0.7 nm), independent of the applied fluence over the range from a few J/cm^2 to 50 J/cm^2.

The monodisperse distribution indicates that the fragmentation process is a single-step event, directly producing 4 nm particles from the 200 nm particles. As the solution is continuously composed of two particle populations, namely 200 nm and 4 nm particles, it is therefore possible to deduce, from the temporal evolution of the pump attenuation into the colloid solution during fragmentation, the contribution of the plasma to pump extinction.

From these experiments, we deduce that the extinction cross section of the laser-generated plasma is at least 1.5 µm^2, i.e., about 30 times larger than the absorption cross section of a 200 nm particles in water as predicted by Mie theory. Interestingly, for a fluence of 50 J/cm^2, the energy absorbed by both the gold nanoparticles and the laser-generated plasma remains much higher than the energy required for water vaporization, suggesting that the vaporization mechanism is only weakly governed by heat transfer, or that heat transfer is a slow process compared to the bubble formation dynamics.



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Acknowledgments:

This work has benefited from financial support from the ANR through the CASTEX project (ANR project # 21-CE30-0027).

Cavitation around irradiated gold particles

Gilles Ledoux[*a], Julien El Hajj[*a], Samy Merabia[*a]

[*a] *Université Claude Bernard Lyon 1, CNRS, Institut Lumière Matière, France.*

Gold nanoparticles, due to their plasmonic properties, are of great interest for hyperthermia applications. In this context, the particles are heated by laser in order to heat the surrounding medium. However, the transfer process is still poorly understood, as are the boiling conditions around these particles. In this work, we used atomistic simulation combined with a two-temperature model to evaluate the evolution of the water temperature around gold particles with and without a silica layer. In parallel we explored experimentally the conditions to obtain explosive boiling bubbles around bare gold nanoparticles in water under tension.

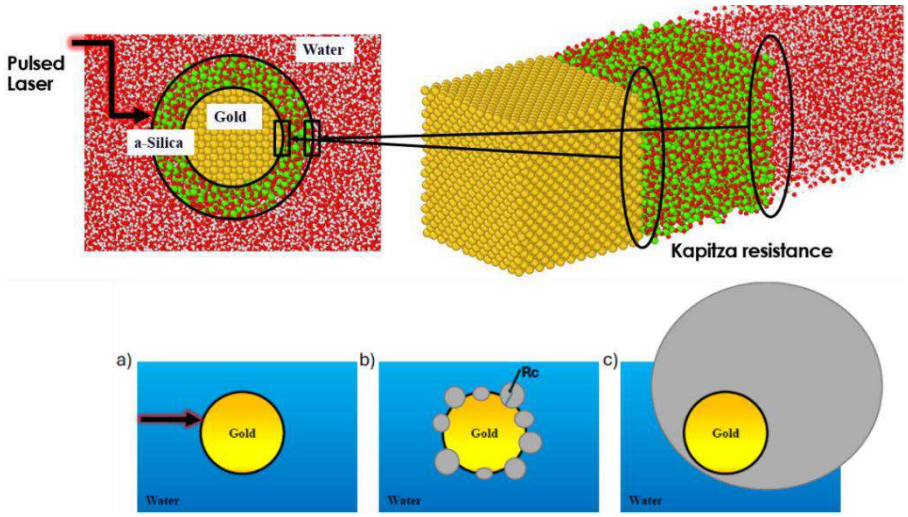
We employ a finite element modeling approach to investigate heat transfer in laser-heated gold-core amorphous silica-shell nanoparticles suspended in water, integrating atomistic molecular dynamics (MD) simulations with the two-temperature model (TTM) and Mie theory, while leveraging the Bruggeman approximation for absorbance calculations. Our analysis focuses on the thermal dynamics, particularly the influence of silica porosity. Heat transfer from the nanoparticles to the surrounding water is governed by interfacial thermal resistances—known as Kapitza resistances—at both the core-shell and shell-water interfaces, which critically shape the overall heat transfer behavior (Figure).

To quantify these effects, we use MD simulations to calculate interfacial heat transfer and derive key parameters, including the effective thermal conductivity of thin films and phonon-phonon interactions at the gold-silica and silica-water interfaces [1]. We also explore the impact of laser pulse duration on the nanoparticles' thermal response, examining how heat generation in water evolves over time, and investigate the role of coating thickness in either confining heat within the nanoparticle or facilitating its transfer to the water.

Additionally, we assess the influence of electron-phonon coupling at the core-shell interface and compare our findings with bare gold nanoparticles to identify conditions under which silica-coated gold nanoparticles exhibit superior performance as nanoheaters [2].

Experimentally, 200nm diameter gold particles stabilized by a phosphate buffered saline 0.1mM solution with a low controlled concentration are introduced in a homemade dynamic cell where the solution can be brought under mechanical tensions up to ~-100MPa. A nanosecond pulsed laser is shinned in the solution with slowly increasing energy. Once the laser energy is sufficient, the local temperature of the liquid becomes high enough so that it boils. Since the water is kept under tension the boiling bubbles grow and stabilize and becomes optically detectable.

The comparison between the experimental results and the models is in good agreement and consistent with the theory of homogeneous nucleation. Indeed, the cavitation bubble will only grow when the boiling temperature is reached at a distance corresponding to the critical nucleation radius as schematized in the figure.



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Acknowledgments:

This work was supported by the French National Research Agency (ANR) through the CASTEX project (ANR-21-CE30-0027).

Fundamentally Higher Energy Efficiency of Microparticle Fragmentation in Liquids compared to Laser Ablation in Liquids

Maximilian Spellauge [*a*b], Ramon Auer [*a], Meike Tack [*b], Florentine Limani [*a], David Redka [*a], Sven Reichenberger [*b], Anna R. Ziefuss [*b], Barcikowski Stephan [*b], Huber Heinz P[*a]

[*a] *Laser Center HM, Munich University of Applied Sciences HM, Germany*

[*b] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE) University of Duisburg-Essen, Germany*

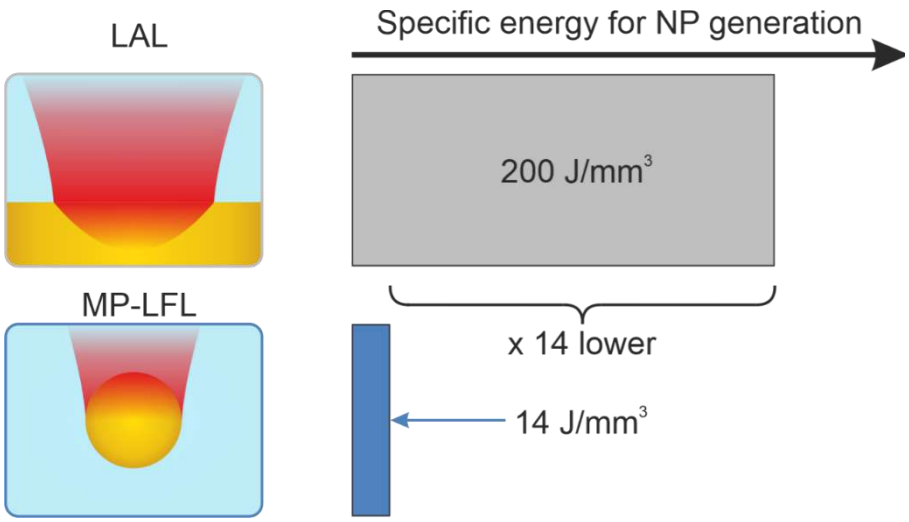
Laser-based nanoparticle (NP) synthesis in liquids is realized by laser ablation in liquids (LAL) or laser fragmentation in liquids (LFL). For LAL, the energy-efficiency of NP generation has recently been quantified on an absorption-corrected, single-pulse basis [1]. In contrast, the energy efficiency of microparticle laser fragmentation in liquids (MP-LFL) remains largely unkonwn. Most MP-LFL studies rely on ensemble-level irradiation, where multiple MPs are irradiated and the absorbed laser energy per MP cannot be determined. As a result, a quantitative, absorbed-energy-based comparison between MP-LFL and LAL is still lacking, despite increasing interest in fragmentation-based routes for scalable NP production [2].

Here, we present a quantitative study of the energy efficiency of ultrashort-pulsed MP-LFL and compare it to LAL. Single gold MPs with a diameter of 1.2 µm are fragmented by single 10 ps laser pulses in water, enabling determination of the absorbed laser energy. Time-resolved pump-probe microscopy combined with post-fragmentation NP analysis resolves fragmentation mechanisms, energy partitioning, and energy efficiency, allowing comparison of MP-LFL energetics with established LAL energetics.

MP-LFL initiates fragmentation at an absorbed peak fluence of 37 mJ/cm^2, which is approximately five times lower than to absorbed ablation threshold of bulk gold in water of 200 mJ/cm^2 [1]. Energy-partition analysis shows that 83% of the absorbed laser energy is converted into cavitation bubble energy, while at least 1% contributes to the surface energy of the generated NPs. Despite this small fraction, the conversion of absorbed laser energy into NP surface energy is about an order of magnitude more efficient in MP-LFL than in LAL. When evaluated in terms of absorbed energy density required for NP generation, MP-LFL requires 14 J/mm^3, approximately an order of magnitude less energy than state-of-the-art LAL, which requires 200 J/mm^3.

This efficiency gain originates from the MP geometry. Analogous to ultrashort-pulses LAL [3], our results show that MP-LFL proceeds via two fragmentation pathways: photothermal phase explosion of a thin surface layer, producing NPs with diameters ranging from a few nanometers up to about 70 nm, and photomechanical fracture of the molten MP volume. yielding a NP fraction with diameters of approximately 85 nm to 150 nm. In MP-LFL, however, the finite MP geometry confines the energy and hence reduces thermal conduction losses. Moreover, pressure-wave focusing within the MP amplifies the photomechanical contribution to fragmentation.

These results position picosecond MP-LFL as a fundamentally more energy-efficient approach for scalable NP production than LAL.



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Acknowledgments:

The authors gratefully acknowledge funding of this project by the Deutsche Forschungsgemeinschaft (DFG) under project number 562785215.

Laser fragmentation and extraction processes in organic microparticle dispersions

Christoph Rehbock[*a], Friedenauer Tina [*a], Spellauge Maximillian [*a*b], Vosough Maryam [*c], Thom Cedric [*d], Meckelmann Sven W.[*d], Heinz P. Huber[*b], Torsten C. Schmidt[*c], Oliver J. Schmitz [*d], Stephan Barcikowski [*a]

[*a] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany.*

[*b] *Munich University of Applied Sciences HM, Germany.*

[*c] *Instrumental Analytical Chemistry, University of Duisburg-Essen, Germany.*

[*d] *Applied Analytical Chemistry University of Duisburg-Essen, Germany.*

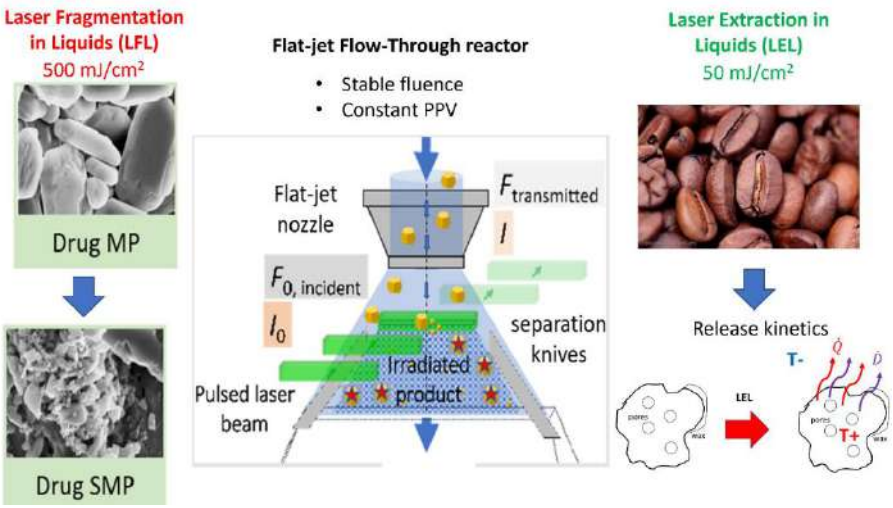
Laser synthesis and processing of colloids is a versatile technique for synthesizing nanoparticles from microparticles and bulk materials. It is well-established for inorganic materials, such as metals or semiconductors. However, LSPC of organic dispersions is still in its infancy. Previous works included the laser fragmentation of metal complexes and organic dyes or the downsizing of drugs to improve solubility and bioavailability [1].

Recently, irradiation of coffee powder dispersions at low fluence below 50 mJ/cm^2 indicated changes in the extraction process [2]. However, the major downside of these studies was that they were conducted in batch setups that not only impaired mechanistic understanding due to the undefined numbers of laser pulses per particle (PPP) but were also unsuitable for scale-up.

In this work, we used a liquid-jet flow-through reactor to process organic microparticle suspensions, while the number of PPP could be precisely tuned, and jet-curvature-related fluence gradients were eliminated. During the processing of the model drugs naproxen, prednisolone, ketoconazole, and megestrol acetate, we demonstrate a fragmentation efficiency (yield of sub-micrometer particles (SMP) determined by SEM and analytical sedimentation analysis), 100 times higher than in batch reactors, as well as enhanced solubility at minimal chemical degradation (< 1%) [3]. In further experiments using curcumin as a model material and energy-efficient 1 PPP processing, we found enhanced productivity with microparticle mass concentration (up to 0.3 g/h) and the potential for conversion of all microparticles into SMP at optimized illumination conditions.

This was complemented by mechanistic examinations of the fragmentation process using pump-probe microscopy monitoring shockwave and bubble formation dynamics on single microparticles. These findings highlight the prevalence of photomechanical fragmentation mechanisms with minimized global heating [4]. In more recent experiments, we irradiated coffee powder dispersions in a liquid-jet flow-through reactor at low fluence (< 70 mJ/cm^2) conditions where the specific surface area is unaffected by the laser, but unique extraction profiles of volatile organic compounds, determined by GC-MS, are generated, and low acidity is found in the liquid.

These findings indicate a previously rarely documented process of laser-matter interaction based on laser extraction in liquids (LEL), altering mass release kinetics in complex organic mixtures, adding a powerful new approach to food processing [5].



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Enhancing High-Power Pulsed Laser Fragmentation in Liquids Through Spatial Laser Beam Shaping and CFD-Supported Flow Jet Optimization

Jan Lino Kricke [*a], Zongwen Fu [*a], Uwe Janoske [*b], Carlos Doñate-Buendía [*c], Bilal Gökce [*a]

[*a] *Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering, University of Wuppertal, Germany.*

[*b] *Chair of Fluid Mechanics, School of Mechanical Engineering and Safety Engineering, University of Wuppertal, Germany.*

[*c] *GROC-UJI, Institute of New Imaging Technologies, Universitat Jaume I, Spain.*

Pulsed laser fragmentation in liquids (PLFL) stands out as a facile, versatile, and environmentally friendly synthesis method for monomodal ligand-free nanoparticles (NPs) [1]. It allows for precisely tailoring their size, structure, morphology, and composition, and thus gains increasing attraction. However, low PLFL productivities still represent a bottleneck towards industrial-scale throughput in the gram-per-hour scale [2].

To this end, strategies like employing free-flowing setups, coupled with high-power laser sources, were recently introduced [3,4]. Yet, PLFL of materials with high fragmentation fluence thresholds remains challenging and may be accompanied by pronounced laser-liquid interactions and large byproduct formation, attributed to high microparticle educt sizes with poor absorptivity.

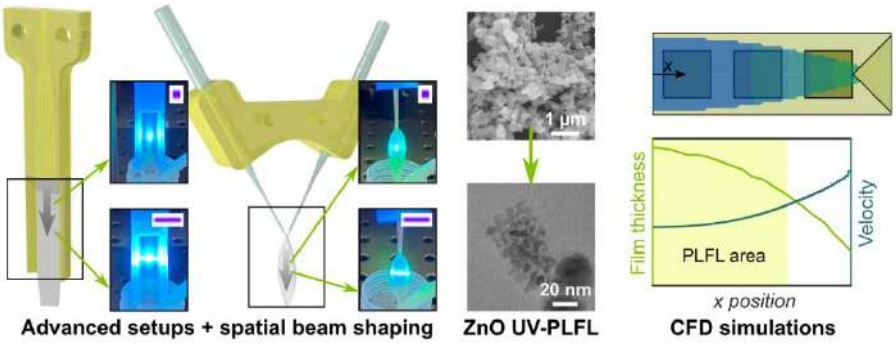
In this contribution, two novel free-flowing setups are introduced for PLFL and comprehensively compared with a benchmark flow setup that creates a circular jet cross-section. Their performance is exemplified in the synthesis of ZnO NPs in deionized water, which renders them attractive for manifold applications, yet approaching the <10 nm size regime stays difficult.

The novel setups provide flat liquid jets for increased flow rates (up to 370 ml/min) at minimal liquid surface curvatures, limiting laser self-focusing even at high fluences of up to 700 mJ/cm^2. Combined with spatial laser beam shaping of the flat-top UV laser beam to increase the relative irradiated area with respect to the liquid jet width, considerable advances are realized. At constant energy inputs of 50 mJ, the mean particle size is reduced by more than twofold to just 6.7 nm at improved monodispersity (PDI = 0.24) while yielding doubled microparticle conversion rates of up to 65 % without prior size separation treatments or stabilizer presence.

Moreover, the novel setups reduce the accumulated colloid heating and evaporation loss by a factor of six and two, respectively, manifesting their potential to leverage PLFL for industrial implementation. For the first time, the experimental results are supported by numerical computational fluid dynamics (CFD) simulations to determine the critical flow properties such as the liquid velocities, film thicknesses, and surface curvatures.

The synergistic approach demonstrates the synthesis of stabilizer-free ZnO NPs of unprecedented small size, competitive to conventional NP synthesis techniques.

It provides a robust concept with great potential to improve the PLFL productivity regardless of the selected NP material without demanding more sophisticated lasers towards a scalable and continuous process.



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From Picosecond to Nanosecond Fragmentation: Achieving Record Yield, Throughput, and Tunable Surface Chemistry in Single-Pulse Microparticle LFL

Anna Ziefuss[*a], Nadine Stratmann [*a], Lars Krenz [*a], Benjamin Mockenhaupt[*a], Maximilian Spellauge[*b], Ramon Auer [*b], Heinz P Huber [*b], Kathrine Tibbetts[*c], Stephan Barcikowski [*a]

[*a] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE) University of Duisburg-Essen, Germany*

[*b] *Laser Center HM, Munich University of Applied Sciences HM, Germany; Department of Chemistry, Virginia Commonwealth University, USA*

[*c] *Department of Chemistry, Virginia Commonwealth University, USA*

As one of the key laser-based synthesis and processing methods, microparticle laser fragmentation in liquids (MP-LFL) enables the generation of ligand-free nanoparticles (NPs) from a wide range of materials. In the ultrashort-pulsed regime (fs-ps), MP-LFL is governed by stress confinement, leading to an interplay between photothermal and photomechanical processes, including spallation, pressure focusing, and shock-induced fracture.(1) While these mechanisms are well described and provide valuable mechanistic insight, single-pulse mass conversion of the MPs to NPs typically remains incomplete due to near-surface energy deposition.(2)

This presentation contrasts the ultrashort-pulsed regime with ns MP-LFL, which follows a fundamentally different energy-coupling pathway. Owing to the longer pulse duration, thermal diffusion during the laser pulse extends far beyond the optical penetration depth and may approach the characteristic MP dimension. Matching the thermal penetration depth to the MP size provides nearly homogeneous heating, thereby enabling a novel single-pulse MP-LFL approach. Using silver MPs as a model system, ns MP-LFL enables highly efficient photothermal fragmentation (Fig. 1a), yielding sub-10 nm NPs with near-quantitative single-pulse conversion, record mass yields, and gram-per-hour throughput (Fig. 1a), under steady-state conditions, in liquid flow. (3)

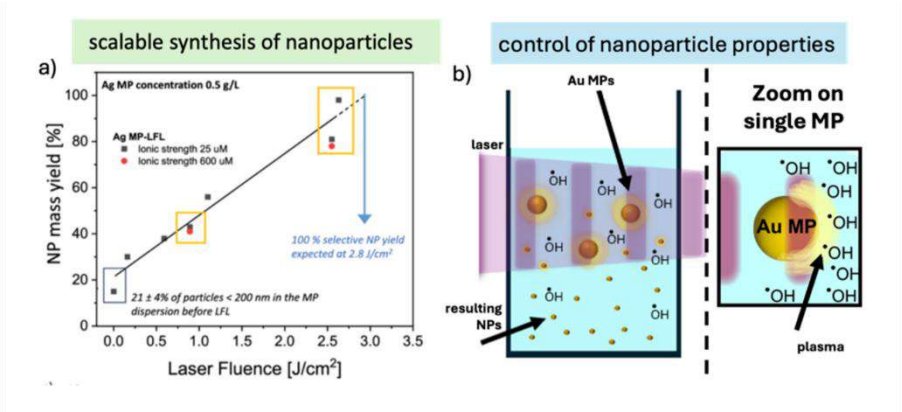
Beyond the unparalleled fragmentation yield, surface chemistry and chemical interactions play an important role in MP-LFL under both ps and ns excitation. Fluence-dependent chemical effects observed during ps MP-LFL of gold directly link NP formation to solvent-mediated reaction pathways, demonstrating that chemical processes occur on time scales relevant to laser–matter interaction. These findings indicate that transient species generated at the particle–liquid interface can influence fragmentation dynamics beyond purely thermal or mechanical effects (Fig. 1b). (4)

In the ns regime, such chemically mediated interactions become particularly relevant due to the longer pulse duration, which increases the temporal overlap between laser irradiation and transient chemical or electronic processes. If reactive species or charge carriers are generated during irradiation, they can interact with the laser field while fragmentation is still ongoing, thereby modulating effective energy coupling.

This presentation explores these effects using electronically active materials as model systems, exemplified by lanthanum hexaboride (LaB_6). Owing to its exceptionally low work

function, LaB_6 readily emits electrons during nanosecond irradiation, providing direct experimental access to electron-mediated energy dissipation channels. By probing and modifying the chemical environment using selected electron acceptors, such as persulfate, electronic surface processes are identified as a key factor governing fragmentation efficiency.

Overall, the results presented here illustrate how fragmentation efficiency and chemically mediated interactions jointly govern MP-LFL across pulse-duration regimes, highlighting the interplay among pulse duration, chemical environment, and energy coupling during laser fragmentation in liquids.



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We acknowledge financial support by the German Research Foundation (DFG) for funding the large-scale scientific instrument High-Power UV Laser Fragmentation System (project number 491146928). AZ acknowledges support from the DFG research grant (project number 262558940 and 405553726). We further thank Tobias Bessel for his assistance in designing and aligning the ns-laser set-up.

Time-Resolved Separation of Melting and Reduction Pathways in Pulsed Laser Irradiation of CuO Nanoparticles in Liquids

Żaneta Świątkowska-Warkocka[*a], Mohammad Sadegh Shakeri[*a], Katharine Moore Tibbetts[*b]

[*a] *Institute of Nuclear Physics Polish Academy of Sciences, Poland*
[*b] *Virginia Commonwealth University, United States*

Pulsed laser irradiation of nanoparticle suspensions, also commonly referred to as pulsed laser melting (PLML), provides a versatile, reagent-free route to nanomaterial restructuring driven by laser-induced melting-solidification dynamics [1]. In oxide colloids, however, this process does not simply result in fragmentation or growth but instead produces a solvent-dependent competition between physical reshaping and chemical reduction that cannot be resolved by endpoint characterization alone [2-4].

Here we show that continuous in situ optical absorption spectroscopy enables direct, time-resolved separation of these coupled pathways during picosecond pulsed laser irradiation of CuO nanoparticles in organic solvents. Distinct absorption signatures independently track rapid de-agglomeration and reshaping through changes in optical scattering, and oxide-to-metal conversion through the emergence of a characteristic plasmonic response. In a non-oxygenated solvent, metallization proceeds efficiently and follows a strongly nonlinear fluence dependence, consistent with a multistep reduction mechanism. In contrast, an oxygen-containing solvent promotes fast de-agglomeration while stabilizing oxide-rich particles, suppressing plasmonic signatures over the same processing window.

The experimental observations are further rationalized by thermal modeling and reactive atomistic simulations, which link the observed optical kinetics to localized melting, ultrafast quenching, and solvent-specific interfacial chemistry. Together, these results establish absorption-based in situ diagnostics as a powerful approach for resolving laser-driven nanoparticle transformations in liquids and demonstrate that solvent choice acts as a mechanistic control parameter governing melting dynamics, redox kinetics, and final phase composition under pulsed laser irradiation.

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Acknowledgments:

This research was supported by the Kościuszko Foundation Exchange Program to the United States. We gratefully acknowledge Poland's high-performance infrastructure PLGrid, ACC Cyfronet AGH, for providing computer facilities and support within computational grant No. PLG/2025/018879.

Effect of Laser Repetition Rate on the Reaction Kinetics in Metal Nanoparticle Synthesis by Laser-Induced Reduction

Kotaro Terao [*a], Kazutaka Fujita [*a], Shigeki Yanagida [*a], Shinichi Fukuda [*b], Rikuto Kuroda [*b], Takahiro Nakamura[*b]

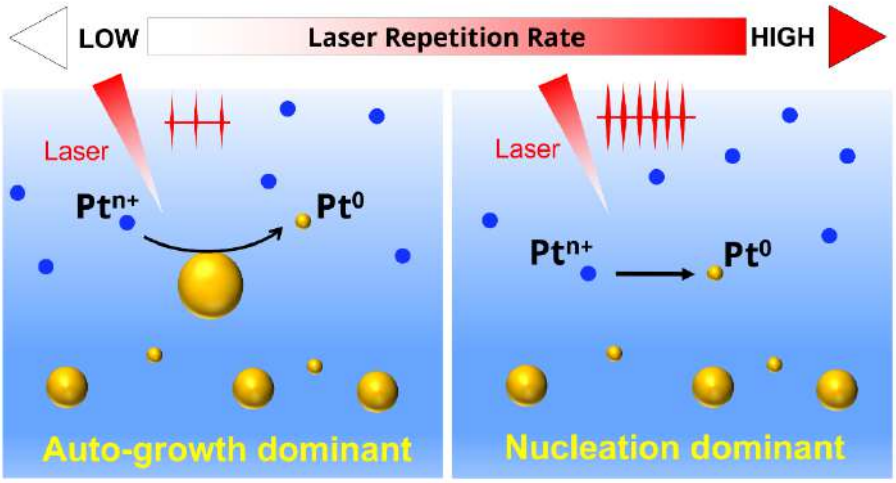
[*a] *TDK Corporation, Japan*

[*b] *Illuminus Inc., Japan*

Laser-induced reduction (LIR) is one of the promising methods for synthesizing metal nanoparticles (NPs) from precursor solutions using pulsed laser irradiation without chemical reducing agents [1-3]. To control particle size and productivity in NP synthesis using LIR, it is essential to elucidate the reaction process and kinetics during laser irradiation. However, studies on the reaction process and kinetics of LIR have so far focused only on the synthesis of gold (Au) NP [2,3]. In this study, we investigated the effect of laser repetition rate on the reaction kinetics during nanoparticle synthesis using LIR and further compares the results by targeting Au and platinum (Pt) NP synthesis to examine differences between the elements.

Aqueous precursor solutions of Au and Pt were irradiated with a tightly focused laser beam (pulse energy of 7 mJ, pulse duration of 100 fs, wavelength of 800 nm), and the time evolution of absorbance associated with nanoparticle formation was monitored by time-resolved in situ UV–Vis absorption spectroscopy. In the experiment, the pulse repetition rate was varied from 10 to 1000 Hz. The evolution curves were fitted to the Finke–Watzky (F–W) two-step kinetic model (nucleation A → B, rate constant k_1; autocatalytic growth A + B → 2B, rate constant k_2) to extract the rate constants [4].

Reaction kinetics of both Au and Pt systems were well described by the F–W model, but they exhibited distinct features. The Au system was dominated by the autocatalytic growth term (k_2), whereas the Pt system exhibited a relatively large primary nucleation term (k_1). Moreover, the k_1-dominated behavior in Pt became more pronounced at higher pulse repetition rate. These findings advance mechanistic understanding of LIR across elements and suggest that tuning laser parameters can shift the balance between nucleation and crystal growth, providing a kinetics-based route to control NP size and morphology. In the presentation, we will also explain the effects of laser energy on the reaction mechanism and discuss the k_1-dominated behavior in Pt.



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Effects of Surface Properties on the Optical Characteristics of Organic Nanoparticles Fabricated by Laser Fragmentation in Liquid

Ryohei Yasukuni [*a], Daisuke Tominaga [*a], Naoto Masuda [*a], Tomosumi Kamimura [*a *b]

[*a] *Osaka Institute of Technology, Japan.*

[*b] *Institute of Laser Engineering, Osaka University, Japan.*

Background:

Organic nanoparticles (NPs) exhibit unique photoluminescent properties distinct from both bulk crystals and isolated molecules. Their low toxicity and minimal environmental impact make them potential candidates for optical device applications. However, the specific influence of surface properties on these characteristics remains largely unexplored. Laser fragmentation in liquid provides a surfactant-free method to fabricate NPs by irradiating pulsed laser light onto bulk crystals in pure water. In this study, we investigated the effect of the surface properties of organic NPs on their optical properties by adding a surfactant to a NPs dispersion and observing the changes in their fluorescence spectra.

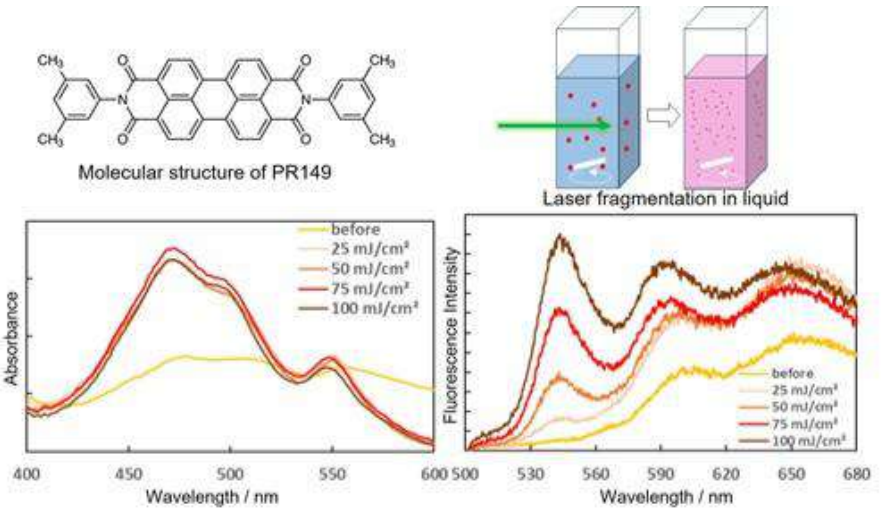
Experimental:

Bis(3,5-dimethylphenyl)-3,4,9,10-perylenetetracarboxylic diimide (PR149) was used as a model compound. Bulk crystals were dispersed in pure water and an aqueous sodium dodecyl sulfate (SDS) solution (final concentration: 16 mM) at a concentration of 0.006 mg/mL. A 2 mL aliquot of the dispersion was placed in a 1 cm optical cuvette and stirred. The sample was irradiated with a Nd:YAG laser (wavelength: 532 nm, pulse width: 6–8 ns, repetition rate: 10 Hz, fluence: 20 mJ/cm^2). Absorption and fluorescence spectra were recorded before and after irradiation.

Results and Discussion:

Laser irradiation of PR149 dispersions in both pure water and SDS solution led to an increase in absorbance, confirming the formation of NPs. While the absorption spectra were nearly identical in both media, the fluorescence spectra exhibited significant differences. In pure water, the NP emission was dominated by excimer fluorescence, characteristic of the crystalline state. In contrast, the presence of SDS induced a new fluorescence peak at shorter wavelengths, resembling the emission of isolated molecules (monomers).

Dialysis membrane filtration confirmed that PR149 did not dissolve in the SDS solution. These results suggest that the adsorption of surfactant molecules onto the NP surface disrupts the molecular packing at the crystal-liquid interface, resulting in monomer-like fluorescence. This structural change is likely driven by the reduction in surface free energy resulting from the surfactant adsorption. The presentation will further discuss the influence of surfactants on the crystalline phases of these NPs and on the efficiency of the fragmentation.


Molecular structure of PR149
Laser fragmentation in liquid
Absorbance
Wavelength / nm
before
25 mJ/cm²
50 mJ/cm²
75 mJ/cm²
100 mJ/cm²
Fluorescence Intensity
Wavelength / nm

Identifying Optimal Laser Fluence of Pulsed Laser Ablation Synthesis of Silicon Nanoparticles Via Optimisation Of UV-Vis Absorption

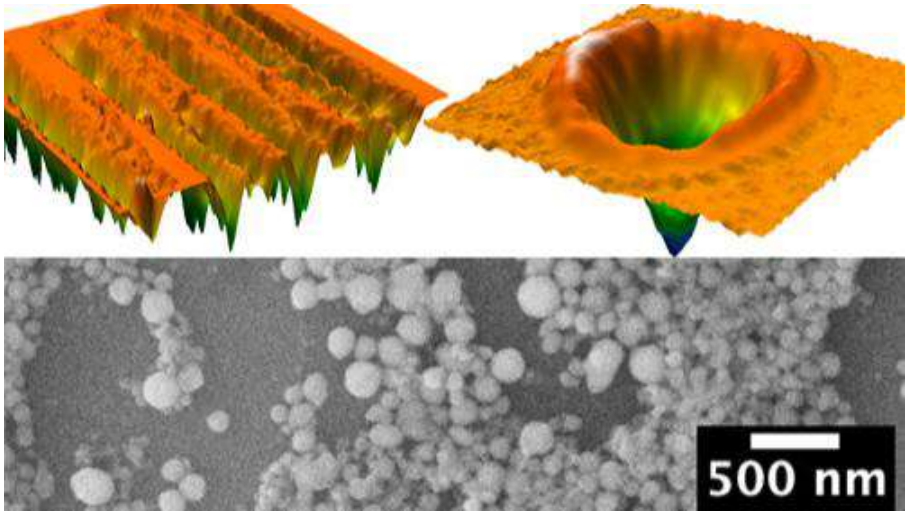
William McMahon-Puce [*a], Haoran Mu [*a], Sauliu Juodkazis [*a], David Moss [*a], James Chon [*a]
[*a] *Swinbrune University of Technology, Australia*

Due to the unique optical properties, silicon nanoparticles (SiNPs) could have a diverse range of potential applications in biomedical imaging, and optically addressable quantum systems. We synthesise SiNPs via femtosecond pulsed laser ablation in liquid (fs-PLAL) using a 1030 nm laser source (≈ 200 fs pulse duration, 200 kHz repetition rate) focused through a near-infrared-enhanced objective (Mitutoyo M Plan Apo NIR 5×, NA = 0.14) onto a silicon wafer immersed in 5 mL of deionised water. The use of pulsed laser melting in liquid (PLML) is also explored in this work to improve the surface quality of SiNPs.

We identify a peak SiNP synthesis rate of approximately 0.311 μg min^{-1} at fluences in the range of 20-30 J cm^{-2} [1], which is comparable to other reported productivity rates [2]. The identified fluence range corresponds to a regime that balances efficient material removal with reduced bubble-induced shielding. Analysis of ablation volumes showed that while single-pulsed ablation [1,2] crater volumes increase with laser fluence, both multi-pulsed ablation crater [3,4] volumes and measurable SiNP volumes peak near 25 J cm^{-2} before decreasing. This decrease is attributed to the formation of cavitation bubbles that scatter incoming pulses and reduce ablation efficiency [3,4]. By comparing the measured SiNP volume to the effective material removal per-effective-pulse, we define an optimal fluence regime where this difference is minimised.

Quantitative nanoparticle yield was determined using UV-Vis extinction spectroscopy combined with optimisation via minimisation, enabling extraction of both SiNP concentration and particle size distribution within the optical extinction regime (r ≈ 20-200 nm). Unlike the nanoparticle population estimates from electron/optical microscopy images, which are statistically limited, or dynamic light scattering (DLS) which inherently overestimates particle size due to signal dominance from larger particles, this approach treats the measured extinction spectrum as an inverse problem. Calculated Mie-theory extinction spectra [5] for individual particle sizes are combined to reproduce the experimental spectrum, yielding an estimate of the entire particle population and the total synthesis yield.

The peak SiNP productivity is expected to be improved using high-speed scanning systems (e.g. galvo mirrors) to reduce pulse overlap and avoid cavitation bubble interference [6]. These results provide practical guidance for tuning of fs-PLAL parameters for high throughput, optically optimised SiNP production and stablish UV-Vis based optimisation via minimisation technique as a reliable tool for nanoparticle yield estimation.



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TUESDAY 26TH

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Influence of Laser Pulse Regime on the Structure and Properties of Bimetallic and Hybrid Nanoparticles

Angela De Bonis[*a], Antonio Santagata[*b]

[*a] *Dipartimento di Scienze di Base e Applicate, Università della Basilicata, Italy*

[*b] *CNR-ISM, Italy*

Bimetallic nanoparticles and hybrid metal–oxide systems have attracted growing interest due to their ability to combine the functionalities of single-component materials, enabling enhanced catalytic, optical, and electronic properties. These performances arise from synergistic interactions at metal–metal and metal–oxide interfaces, as well as from the possibility of controlling composition and structure at the nanoscale. We studied the synthesis of silver-based bimetallic nanoparticles and hybrid metal–oxide nanostructures produced by laser ablation in liquid (LAL), with particular emphasis on the influence of laser pulse duration on ablation mechanisms and nanoparticle formation pathways.

A systematic comparison between nanosecond (ns) and femtosecond (fs) laser ablation regimes provides insight into the transition from predominantly thermally driven processes to ultrafast, non-equilibrium dynamics. Femtosecond laser ablation enables highly confined energy deposition, limiting heat diffusion into both the target and the surrounding liquid. This regime favors the formation of smaller nanoparticles with narrower size distributions and improved structural and compositional homogeneity. In contrast, ns laser ablation is dominated by thermal effects and prolonged plasma–liquid interactions, which facilitate particle growth, coalescence, and oxidation, leading to larger nanoparticles with broader size distributions and more complex surface chemistry.

An extensive multi-technique characterization was employed to correlate laser parameters with the resulting nanoparticle properties. UV–Vis absorption spectroscopy provided insight into the optical response of the colloids, revealing plasmonic features and band-edge modifications associated with nanoparticle size, structure, and interfacial interactions. Transmission electron microscopy (TEM) enabled direct visualization of nanoparticle morphology and size distributions, while X-ray photoelectron spectroscopy (XPS) provided information on elemental composition and chemical states, highlighting different degrees of oxidation and metal–oxide interaction.

This approach offers valuable guidelines for the rational design of advanced nanomaterials for applications in catalysis, sensing, energy conversion, and environmental and biomedical technologies.

Tunable Laser Nanostructuring for van der Waals Materials

Valentyn Volkov [*a], Ivan Kazantsev [*a], Gleb Tikhonowski [*a], Gleb Tselikov [*a], Aleksey Arsenin [*a]

[*] *Emerging Technologies Research Center, XPANCEO, United Arab Emirates*

Two-dimensional (2D) layered transition metal dichalcogenides (TMDCs) have attracted tremendous research interests due to their unique properties for developing new-generation electronic and optoelectronic devices [1]. Nanostructures made from transition metal dichalcogenides represent unique platform for nanophotonics due to its high dielectric constants and nontrivial excitonic physics.

The important feature of TMDCs nanoparticles (NPs) that distinguishes them from pure all-dielectric silicon NPs is the possibility of realization of Mie-exciton coupling regime that boosts light-matter interaction at the nanoscale manifesting itself in resonant enhancement of second harmonics generation [2], light scattering [3] and photothermal response [4]. However, it is worth noting that despite the recent significant progress in the field of dichalcogenide nanophotonics, the problem of nanostructuring of TMDCs remains open. On the one hand, it can be solved using standard technological approaches (such as lithography, ion beam etching).

However, these methods have several limitations. For instance, they do not facilitate the production of spherical TMDCs nanoparticles. Meanwhile, various theranostic approaches rely on resonant spherical nanoparticles (NPs). These NPs enable both the visualization of nanoparticles within biological tissues and the treatment of malignancies through nanoparticle-enhanced phototherapy.

This study addresses the challenge of nanostructuring vdW materials by showcasing, for the first time, the remarkable versatility of the femtosecond laser synthesis method for producing colloidal nanoparticles (NPs) from vdW materials and perovskites. Our approach enables precise control over the morphology, size, composition, and optical properties of NPs, achieving high colloidal stability and maintaining the original crystalline structure of over 50 vdW materials [5].

We have demonstrated that laser synthesis can produce a diverse array of nanostructures, including fullerene-like, polygonal, and pyramidal shapes from transition metal dichalcogenides (TMDCs), single-crystalline NPs from M(A)Xenes, and crystalline nanocubes from perovskites. Additionally, it was shown that the size of colloidal vdW nanoparticles can be varied from 10 to 150 nm. Molecular dynamics simulations further elucidate the crystallization processes involved, revealing that both heterogeneous and homogeneous nucleation mechanisms contribute to the formation of these nanostructures, with the size and core-shell ratio being dependent on the cooling rate.

The successful demonstration of this method not only provides a new tool for fabricating vdW-based NPs but also opens vast potential for further innovations in scientific research and technological applications. The ability to create such diverse and well-defined nanostructures paves the way for advancements in numerous fields and offers exciting prospects for future exploration beyond the current applications of layered materials.

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Laser ablation of bilayer targets in liquid for fabrication of alloyed and doped nanoparticles and surface structures

Nikolai Tarasenko[*a], Vladislav Kornev[*a], Mikhail Nedelko[*a], Natalie Tarasenka[*b]

[*a] *B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Belarus*

[*b] *University of Strathclyde, Glasgow, United Kingdom*

Alloyed and doped nanostructures have attracted a particular interest in recent years because their electronic, optical, and magnetic properties can be tuned by varying their composition and size, finding wide application in electronics, biomedicine, and catalysis [1]. However, preparation of such nanostructures with attaining a composition control poses a persistent challenge.

This work focuses on the development of a method of doped and alloyed nanoparticles (NPs) fabrication based on laser ablation of bilayer targets in liquids. This approach allows simultaneous ejection of the components of both layers into plasma, followed by multicomponent NPs formation. We demonstrate the application of this approach for the synthesis of selected alloyed (Si1-xSnx) and doped (ZnO:Co) NPs. Doping silicon with tin provides a possibility of regulating the lattice parameters, energy band structure and mobility of charge carriers, resulting in not only bandgap narrowing, but also changing a type of its conductivity, from indirect to direct [2].

The doped ZnO structures, including cobalt-doped ZnO thin films, are developed for the potential applications in magnetoelectric and magneto-optical devices, light emitters and detectors, and as passive laser Q-switches [3]. Zinc oxide is a wide-bandgap semiconductor, promising for these applications due to its chemical stability, low toxicity, and low cost.

The developed synthesis procedures include scanning of focused Nd:YAG laser radiation (1064 nm) or its second and forth harmonics in the ablation mode over the surface of Sn-Si or Co-ZnO bilayer targets immersed in a cuvette with a liquid (ethanol). In case of Si1-xSnx nanostructures, laser processing of a silicon wafer with a thin tin film deposited on its surface has been performed. For the Co-doped ZnO, the layers of ZnO and Co NPs have been deposited on a glass substrate followed by laser irradiation of bi-layer films.

It has been demonstrated that the formation of nanocrystalline SiSn layers on the Si substrate can be achieved under optimized laser parameters (laser fluence and wavelength, laser beam spatial structure, irradiation duration). In addition, under higher laser fluence the formation of composite silicon-tin NPs has also been observed in the solution above the processed target. The obtained particles have an optical band gap in the range of 0.72 - 0.73 eV, which is consistent with the literature data for the Si1-xSnx alloy with a direct band gap.

At lower fluences, the main mechanisms of the indicated composite nanostructures formation are assumed to be laser-induced processes of rapid heating, subsequent joint melting and recrystallization.

This regime has been efficient for incorporation of Co atoms into the ZnO structure. LIBS analysis performed to quantify the Co content in the sample after laser processing revealed the formation of films with a fairly uniform distribution of cobalt ions within the ZnO matrix with a dopant concentration of approximately 5%. The incorporation of Co ions into the ZnO structure has also been confirmed by Raman spectra and X-ray diffraction analysis.

Thus, the conducted studies demonstrated the possibility of fabrication of alloyed and doped NPs and surface structures during laser processing of bilayer targets in liquid. The obtained results are of interest for the further development of laser ablation methods addressing practical issues of multicomponent nanostructures synthesis with controlled size and composition.

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Acknowledgments:
The work was supported by the National Academy of Sciences of Belarus under project Convergence 2.2.07 and by the Belarusian Foundation for Fundamental Researches under Grant F25INDA-005.

Energetics of ultrashort pulse laser processing in air and in liquids

Heinz Paul Huber[*a], Maximilian Spellauge[*a], David Redka[*a], Ramon Auer[*a], Meike Tack[*c], Anna Ziehfuss[*c], Sven Reichenberger[*c], Stephan Barcikowski[*c], Bilal Gökce[*b]

[*a] *Laser Center HM, Munich University of Applied Sciences HM, Germany.*

[*b] *Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering, University of Wuppertal, Germany.*

[*c] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany.*

Material removal by ultrashort-pulse laser ablation follows complex photomechanical and photothermal pathways, with phenomena such as spallation and phase explosion. [1-3]. While this mechanistic picture is well established, it does not provide a quantitative measure of energy conversion into material removal. Establishing such a framework enables an energetic comparison of laser ablation in air, laser ablation in liquids, and laser fragmentation in liquids.

For this purpose, energetics is quantified in terms of the absorbed energy to ablate a given volume, for convenience expressed in units of J/mm^3. This allows direct comparison with thermodynamic energies for heating, melting, and evaporation and indicates possible and impossible pathways. For most metals, semiconductors, and dielectrics, melting and evaporation occur at approximately 5 J/mm^3 and 50 J/mm^3, respectively. Furthermore, heating from room temperature to the evaporation temperature requires roughly 5 to 10 J/mm^3.

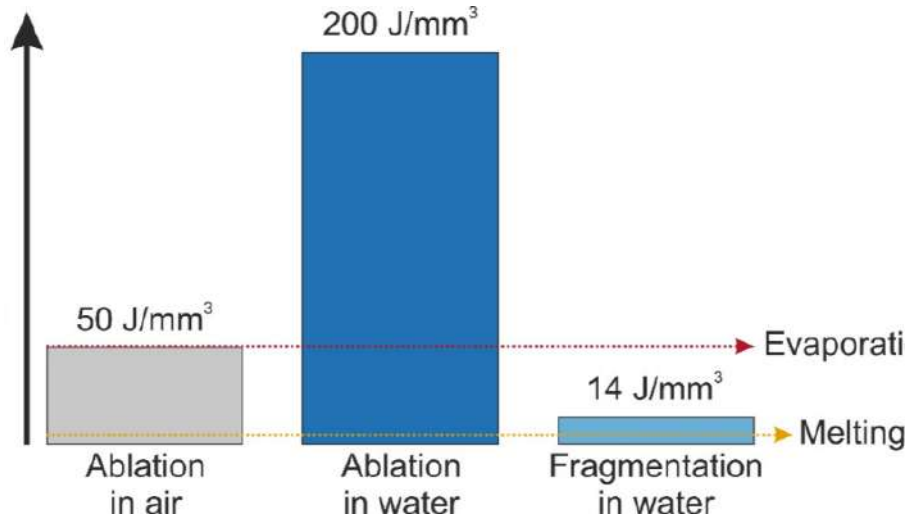
These values reflect that atoms in materials are bound by a few electron volts per atom and that most materials exhibit fairly constant atomic densities on the order of 10^{23} 1/cm^3. The unit J/mm^3 can be converted into energy-specific ablation volumes in µJ/µm^3, commonly used in laser micromachining, and into power-specific productivities in g/h/W, which are frequently employed to characterize the performance of laser-based nanoparticle generation.

To quantify the energetics experimentally, the absorbed pulse energy and the ablated volume are determined under single-pulse conditions to avoid multi-pulse effects such as heat accumulation, incubation, shielding, or redeposition. The ablated volume is obtained from precise spatial measurements of ablation craters with depths of only a few nanometers.

Applying this approach to single ultrashort pulses in air, the energetics were determined for the metals Al, Cu, and AISI304 [4] as well as Au [5]. At the fluences and pulse durations of maximum efficiency, absorbed energies per ablated volume of approximately 30, 150, 200 and 50 J/mm^3 were obtained, respectively. These values indicate that ultrashort-pulse laser ablation mechanisms such as spallation and phase explosion require energies ranging from the evaporation energy up to two to three times this value.

Extending this energetic analysis to laser ablation in liquids and laser fragmentation in liquids reveals pronounced differences compared to ablation in air. For laser ablation of Au in water, the absorbed energy per ablated volume increases to approximately 200 J/mm^3 [5]. This increase is attributed to the redeposition of ablated material. In contrast, laser fragmentation of Au microparticles in water exhibits a reduced energy per ablated volume compared to laser ablation in liquids, with a value of approximately 14 J/mm^3, well below those observed for laser ablation in air [6]. This reduction is attributed to the confined geometry of the microparticle.

Taken together, these results place laser ablation in air, laser ablation in liquids, and laser fragmentation in liquids on a common energetic scale. They show that the liquid environment fundamentally increases the energetic cost of material removal, while geometric confinement in microparticle fragmentation allows ablation energetics approaching those of laser ablation in air. This provides a quantitative basis for assessing and optimizing the efficiency of laser processing and the productivity of nanoparticle generation.



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Acknowledgments:
This work was supported by the Deutsche Forschungsgemeinschaft (DFG) under projects 491072288, 428315411, 528706678, and 562785215.

Enhanced Gold Nanoparticle Production via Waterfall Pulsed Laser Ablation System

Sergio Fernández Molina-Prados[*a], *Jan Lino Kricke*[*b], *Garvit Shaarma*[*b], *Zongwen Fu* [*b], *Bilal Gökce*[*b], *Gladys Mínguez-Vega*[*a], Carlos Doñate-Buendía[*a]

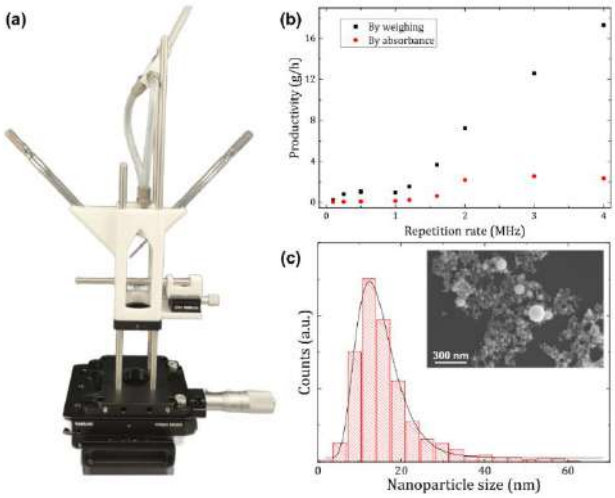
[*a] *GROC-UJI, Institut de Noves Tecnologies de la Imatge (INIT), Universitat Jaume I, Spain.* [*b] *Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering, University of Wuppertal, Germany.*

Pulsed laser ablation in liquid (PLAL) is a versatile nanoparticle (NP) synthesis technique [1], yet its productivity is often limited by the laser interactions with the liquid resulting in optical nonlinearities, plasma and cavitation bubble shielding. In this work, an air ablation-waterfall system is presented as an effective platform to increase colloidal gold NPs production by combining air ablation with the waterfall liquid collection. The waterfall system employs a thin, stable laminar water sheet that enables to capture NPs produced by ablation in air, supressing laser-liquid and laser-cavitation bubble interactions that are the bottleneck for productivity maximization in PLAL [2,3].

Fluid dynamics studies were performed to ensure a turbulence-free laminar flow that yields a highly transparent and low scattering liquid waterfall. Based on the generation of a stable waterfall liquid layer, advanced processing chamber geometries were designed and fabricated using prototyping techniques as FDM 3D printing, allowing fast iteration and optimization of the system, Figure 1(a). Systematic laser ablation experiments on gold targets demonstrated that precise control of the inter-distance between the laminar water sheet and the metallic surface plays a decisive role in maximizing ablation efficiency. Under optimized conditions with a 10 ps, 100W, 1064 nm laser source, a gold removal rate of up to 17.3 g/h was achieved, with a colloidal NP collection in the waterfall of at least 2.6 g/h, Figure 1(b)-(c).

These results indicate that the proposed waterfall approach provides a robust platform to investigate laser ablation regimes that bridge characteristics of air and liquid processing, with the potential to combine efficient material removal with direct nanoparticle collection in liquids

Figure 1: (a) Waterfall processing chamber fabricated by FDM 3D printing. (b) Au NPs productivity as a repetition rate function. (c) Waterfall Au NPs size distribution. Scanning electron microscope image in the insert.



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Spatial Beam Shaping in Nanoparticle Generation in Liquids by Lasers: Two Approaches for Size Control and Productivity Increase

Alexander V. Bulgakov [*a], Oleksandr Gatsa [*a], Rémi Bérard [*a], Abdel Rahman Altakroury [*b], Shabbir Tahir [*b], Farbod Riahi [*b], Zongwen Fu [*b], Carlos Doñate-Buendía [*c], Stephan Barcikowski [*d], Bilal Gökce [*b]

[*a] *FZU - Institute of Physics of the Czech Academy of Sciences, Czech Republic.*

[*b] *Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering, University of Wuppertal, Germany.*

[*c] *GROC·UJI, Institute of New Imaging Technologies, Universitat Jaume I, Spain.*

[*d] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany*

Pulsed laser ablation in liquids (PLAL) is a well-established technique to produce high-purity colloidal nanoparticles (NPs) which often possess superior properties compared to other synthetic approaches. In particular, PLAL generation of compositionally complex NPs can be precisely controlled. However, industrial applications of PLAL-produced NPs are still limited, mainly due to the low productivity of the method. Also, control of the NP size distribution remains a challenge for PLAL. Here we address these two limitations by spatial shaping of the used laser beams employing two shaping approaches, splitting the beam into several sub-beams [1,2] and converting the original Gaussian beam into a donut-shaped one [3].

A picosecond IR laser of variable pulse energy and repetition rate was used to produce metal (Au) and alloy (FeNi and CrFeCoNiMn) NPs in liquid (water or ethanol). The laser beam was split by diffractive optical elements with different splitting ratios from 2 to 81. We demonstrate that the splitting approach allows bypassing the PLAL-generated cavitation bubble, the main limiting factor for NP productivity, both temporally (optimal ablation conditions can be achieved at lower laser repetition rates) and spatially (lower beam scanning speeds are needed). The achieved productivity increase factor, compared to standard single-beam PLAL, was about 2.8 for two sub-beams, ~4 for 11 sub-beams, and ~ 15 for 49 sub-beams. The roles of the inter-pulse distance and inter-pulse time in reducing the cavitation bubble shielding effect were investigated in a wide range of PLAL conditions. The obtained results suggest that the NP productivity at the industrial level of g/h can be routinely achieved by the multi-beam PLAL approach using compact kW-class lasers and simple inexpensive scanning systems.

The potential to modify the size distribution of NPs synthesized by PLAL is demonstrated using a donut-shaped laser beam. Through comparative experiments on picosecond laser ablation of various materials (metals, oxides, alloys) in water with Gaussian and donut-shaped laser beams, we observed a significant reduction in particle size, narrowing of the size distribution width, and an improvement in sphericity when utilizing the donut-shaped beam. We also performed time-resolved shadowgraph imaging of the laser-induced cavitation bubble, revealing a toroidal structure that overruns the ring-shaped ablation site, compared to the quasi-hemispherical bubble covering the ablation spot produced by the

Gaussian beam. These results indicate that donut-shaped laser pulses offer a promising approach for precise control over the size and shape uniformity of PLAL-produced NPs.

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Acknowledgments:

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R. Bérard acknowledges support from the Rayleihlab project, Co-funded by the European Union (Physics for Future – Grant Agreement No. 101081515), Institute of Physics of Czech Academy of Sciences, and Czech Academy of Sciences.

High-throughput nanoparticle synthesis enabled by 49-beam nanosecond laser ablation in liquids

Abdel Rahman Altakroury [*a], Rémi Bérard [*b], Oleksandr Gatsa[*b], Zongwen Fu[*a], Carlos Doñate-Buendía[*c], Alexander V. Bulgakov [*b], Bilal Gökce[*a]

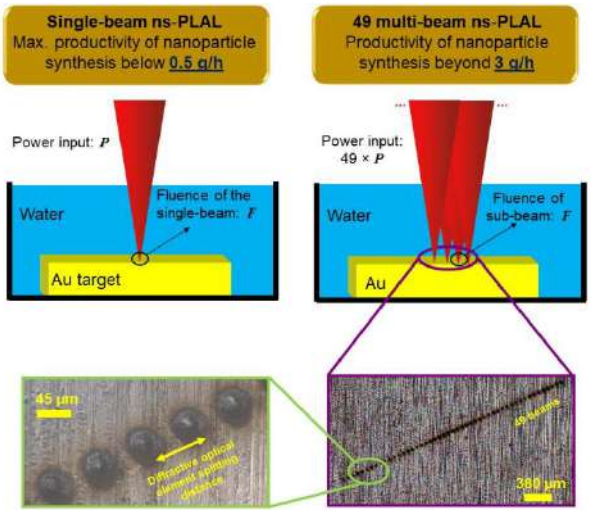
[*a] *Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering, University of Wuppertal, Germany*

[*b] *FZU - Institute of Physics of the Czech Academy of Sciences, Czech Republic*

[*c] *GROC·UJI, Institute of New Imaging Technologies, Universitat Jaume I, Spain*

We report an efficient synthesis of gold nanoparticles (NPs) via nanosecond pulsed laser ablation in liquid (ns-PLAL) using a multi-beam diffractive optical element (DOE). The flat-top raw beam is divided into 49 sub-beams. Single-beam experiments were first conducted to determine the fluence threshold and optimal fluence enabling optimized tuning of the sub-beam fluence in multi-beam experiments. By combining a low repetition rate (10 kHz) and a large interpulse spacing with the DOE, cavitation bubble shielding of the subsequent pulses is minimized, maximizing energy delivery to the target and enhancing productivity.

This approach enables the use of laser powers up to 300 W (far beyond the single-beam breakdown limit), resulting in a maximum productivity of ~3.3 g/h. Importantly, the demonstrated productivity is achieved using high-power ns laser systems, which are considerably more cost-effective and industrially established than ultrashort-pulse sources. In this context, the 49-beam ns-PLAL concept provides an economically attractive and scalable route for nanoparticle production. NPs generated under single-beam and 49-beam irradiation were analyzed and compared at identical fluence per spot. The 49-beam configuration produces a systematic shift toward larger median particle sizes. However, the addition of NaCl effectively suppresses this size growth during 49-beam ablation, enabling size-quenching without a significant reduction in productivity.



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Pulsed laser driven fixation of CO2 into advanced functional nanomaterial for photonic and biological applications

Tommaso Del Rosso [*a], Tahir Tahir [*a], Guilherme Conceição Concas [*a], Mariana Gisbert [*a], Nicola Daldosso [*b], Francesco Enrichi [*b], Anastasia Chillá [*c], Anna Laurenzana [*c]

[*a] *PUC-Rio, Brasil.*

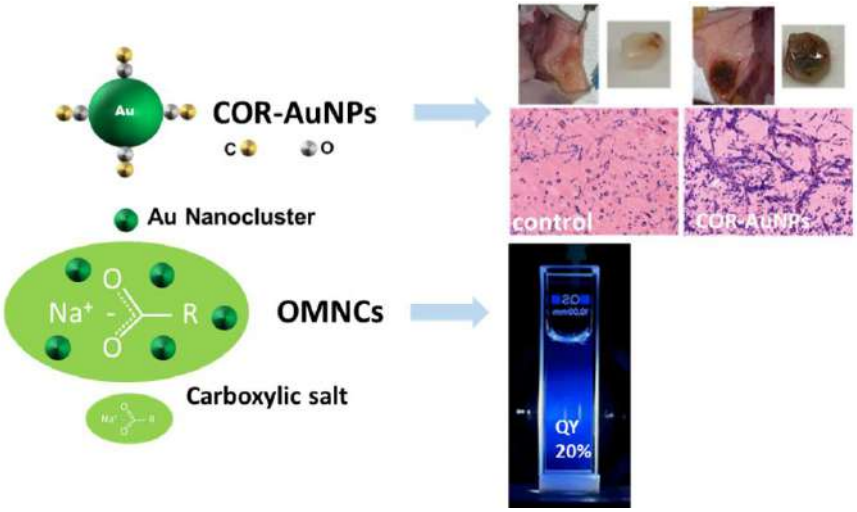
[*b] *Universitá di Verona, Italy.*

[*c] *Universitá di Firenze, Italy.*

CO_2 reduction reaction is up today exploited for the synthesis of value-added feed-stocks in gaseous or liquid form. Here we report an example of CO_2 reduction reaction leading to the production of advanced functional nanomaterial by the use of pulsed laser irradiation of a gold target in water. The presence of CO_2 derivatives in water during the ablation process, leads to C_2 and C_3 coupling with the production of organic material with the typical fingerprint of the CO_2 reduction reaction.

Moreover, the presence of carbon monoxide complexed to the surface of AuNPs is observed also when the pulsed laser irradiation is performed at the deionized water-air interface suggesting that, at least for the case of gold target, this common ablation environment leads to the production of gold nanoparticles which are not fully ligand-free, as reported by the traditional literature. By the pulsed laser driven CO_2 reduction reaction, we are able to obtain ultra-small AuNPs (diameter < 3 nm) and photoluminescent organometallic nanocomposites (OMNCs) with a quantum-yield of the about 23% in the blue spectral region [1].

The CO_2 reduction reaction controls, through the formation of gold-carbonyl groups, also the biological effects of the produced nanomaterial in endothelial colony forming cells, with the possibility to switch from anti-angiogenic to pro-angionenic regulators. In the latter case, the biomolecular signaling indicates the ability to behave as carbon monoxide releasing gold nanoparticles (COR-AuNPs), inducing a strong pro-angiogenic activity, demonstrated by both *in vitro* and *in vivo* experiments [2].



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Acknowledgments:

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Brasil (CAPES)- Finance Code 001. Funding from FAPERJ and CNPq are also acknowledged. The research leading to these results has received funding from AIRC under IG 2020 - ID. 24381 project (P.I. Fibbi Gabriella). The authors would like to thank also the Multiuser Laboratory of High-Resolution Microscopy (LabMic) at the Universidade Federal de Goiás for the transmission electron microscopy measurements.

Laser-Generated BODIPY Nanoparticles in Water: Surfactant Effects and J-Aggregate Formation

Fabian Guillermo Dorado Lopez[*a] [*b], Cristophe Lefumeux[*a], Jean-Frederick Audibert [*c], Zhengyu Zhang[*d], Rachel Meallet[*a]

[*a] *Institute of Molecular Sciences of Orsay (ISMO), Paris-Saclay University, France.*

[*b] *Nara Institute of Science and Technology, Japan.*

[*c] *Supramolecular and Macromolecular Photophysics and Photochemistry Laboratory (PPSM), France.*

[*d] *CentraleSupélec, France.*

Fluorescent materials are required for many applications such as sensors, diagnostic assays and bio-imaging reagents. Specifically, in bio-imaging, the optimization of the brightness could be achieved by gathering fluorescent molecules into nanoparticles [1]. BODIPY, a family of dyes, have shown excellent properties for bio-imaging, such as high fluorescent quantum yields and absorption coefficients, in addition to high photo-stability [2]. Laser fragmentation in liquids (LFL) is a promising technique for the development of fluorescent nanoparticles, which have already been applied for few organic fluorescent materials such as vanadyl phthalocyanine, pentacene and perylene diimide [3].

In this study, an unfocused nanosecond pulse laser (InnoLas SpitLight 600, 532 nm Nd:YAG, 8 ns, 10 Hz) has been used to synthesize mesityl-BODIPY (MB) nanoparticles in water. The effect of different concentrations of surfactant (Pluronic F127) and laser fluences (10 to 180 mJ/cm^2) have been studied, and changes of the spectral properties along the range of laser fluence and surfactant concentration have been observed.

Among these properties, we found the evolution of a J-aggregate band from 20 to 100 mJ/cm^2 when the concentration of surfactant was equal to or higher than the critical micelle concentration (CMC), demonstrating that the use of surfactant in LFL not only improves the colloidal stability, but it can also contribute in the tuning of optical properties of fluorescent organic nanoparticles.

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Acknowledgments:

This work was supported by the French National Research Agency (ANR) under the “Investments for the Future” program (ADI 2023, IDEX Paris-Saclay ANR-11-IDEX-003), together with funding from Université Paris-Saclay and CNRS. Additional support from the doctoral schools ED n°571 “2MIB” (Université Paris-Saclay) and Nara Institute of Science and Technology is acknowledged. The authors also thank Prof. Gilles Clavier for providing the BODIPY material.

Development of All-in-One Magnetic and Radiopaque Hybrid Nanoparticles by Pulsed Laser Ablation in Liquids for Dual MRI/CT Imaging

Oscar Bomati-Miguel [*a*b], Rocio Litran Ramos [*a*b], Ruth Lahoz [*c], Eva Natividad [*c], Jose Manuel Delgado [*a*b], Manuel Piñero de los Ríos[*a]

[*a] *Departamento de Física de la Materia Condensada, Universidad de Cádiz, Spain.*

[*b] *Instituto de Investigación en Microscopía Electrónica y Materiales, Universidad de Cádiz, Spain.*

[*c] *Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, Spain.*

Methods:

In this study, iron-based hybrid nanoparticles incorporating high atomic number elements were synthesized using a physical top-down method based on Pulsed Laser Ablation in Liquids (PLAL). [1-4] Nanosecond pulsed laser ablation (λ = 1064 nm) was performed on ceramic targets of $YbFeO_3$, FeLaO3, $FeTaO_4$ and γ-Fe_2WO_6 immersed in distilled water or ethanol. The work was designed to examine (i) the influence of the liquid medium on the structural, chemical and magnetic properties of the nanoparticles; (ii) the relative performance of ytterbium, tantalum and tungsten as radiopaque components; and (iii) different surface functionalization strategies using polyethylenimine (PEI), glutathione (GSH) and cysteamine (CYS), applied via in situ and ex situ routes. Structural and chemical characterization was carried out by X-ray diffraction, transmission electron microscopy (TEM/HRTEM) and X-ray photoelectron spectroscopy. Magnetic properties were evaluated by SQUID magnetometry. MRI transverse relaxivity and CT attenuation were assessed in phantom studies, and in vitro biocompatibility was evaluated using Jurkat T human leukemia cells.

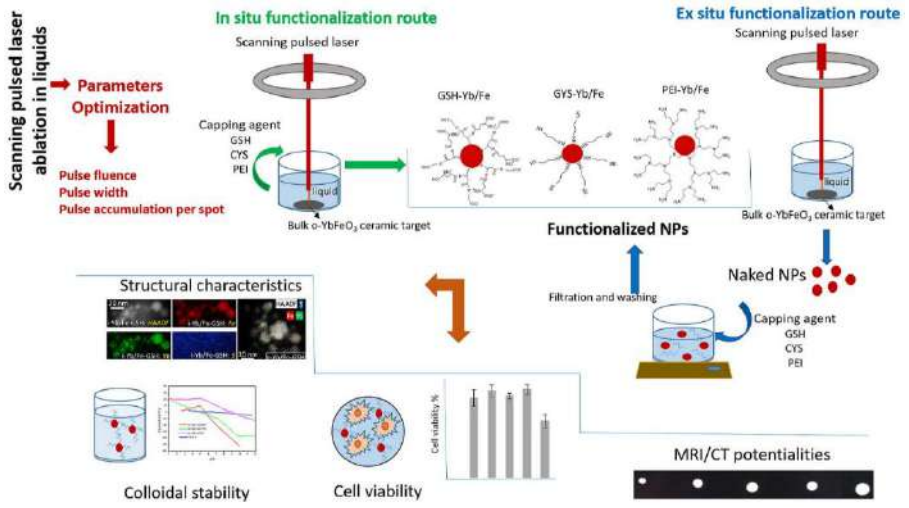
Results:

The liquid environment was found to strongly influence nanoparticle formation. In Yb-Fe and Ta-Fe systems, ablation in water led predominantly to the formation of paramagnetic hydroxide phases, which showed limited MRI contrast efficiency. Ablation in ethanol, by contrast, promoted the formation of metastable, non-stoichiometric oxide phases. In the Yb-Fe system, nanoparticles synthesized in ethanol exhibited ferromagnetic behavior not observed in the corresponding bulk material, enabling T_2-weighted MRI contrast while maintaining the radiopaque contribution of ytterbium. [2-4]

To improve CT attenuation in clinically relevant energy ranges (~120 kVp), the study was extended to the tungsten-iron system, taking advantage of tungsten's K-edge at 69.5 keV. PLAL of γ-Fe_2WO_6 in ethanol produced spherical, amorphous nanoparticles with homogeneous elemental distribution. The amorphous structure facilitated surface functionalization. A comparison of functionalization approaches showed that ex situ methods, particularly using thiol-containing ligands (GSH and CYS), resulted in improved colloidal stability (hydrodynamic diameters below 150 nm), near-neutral physiological behavior and cell viabilities above 85% after 24 h. In situ functionalization resulted in higher levels of carbonaceous by-products and reduced biocompatibility. [4]

In phantom studies, W-Fe nanoparticles functionalized with GSH or CYS exhibited transverse relaxivity values comparable to those reported for commercial superparamagnetic iron oxide agents and X-ray attenuation coefficients higher than those obtained for equivalent iodine concentrations.[4]

Conclusions:
The results indicate that PLAL in ethanol is a suitable method for the synthesis of iron-based hybrid nanoparticles combining magnetic and radiopaque properties. The progression from crystalline ytterbium-based systems to amorphous tungsten-based nanoparticles allowed the simultaneous achievement of effective MRI contrast and enhanced CT attenuation. Within the scope of this study, thiol-functionalized W-Fe nanoparticles demonstrated physicochemical and imaging properties that support their further investigation as dual-modal MRI/CT contrast agents.



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Acknowledgments:

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Synthesis and antibacterial performance of laser-generated Pd/CuO bimetallic nanoparticles

Ana Maria Vilas Iglesias[*a], Mónica Fernández-Arias[*a], Mohamed Boutinguiza[*a*b], Daniel Rodríguez[*c*d*e], Eugenio Solla[*f], Tània Vilella[*c*d], Jesús del Val[*a], Antonio Riveiro[*a*b], Javier Gil[*c*d*g], Juan Pou[*a*b]

[*a] *CINTECX, LaserON Research Group, E.E.I, Universidade de Vigo; Galicia Sur Health Research Institute (IIS Galicia Sur), SERGAS-UVIGO, Spain*

[*b] *Galicia Sur Health Research Institute (IIS Galicia Sur), SERGAS-UVIGO, Spain*

[*c] *BBT and CIEFMA Research Groups, Department of Materials Science and Engineering and Research Center for Biomedical Engineering, Barcelona-Tech (UPC), Universitat Politécnica de Catalunya, Spain.*

[*d] *Barcelona Research Center in Multiscale Science and Engineering, Barcelona-Tech, Universitat Politécnica de Catalunya, Spain.*

[*e] *Centro de Investigación Biomédica en Red—Bioingeniería, Biomedicina y Nanomedicina (CIBER-BBN), Instituto de Salud Carlos III, Spain.*

[*f] *Servicios de Apoyo a la Investigación (SAI), Universidade da Coruña, Spain.*

[*g] *School of Dentistry, Universitat Internacional de Catalunya, Spain.*

Antimicrobial resistance (AMR) represents one of the most critical global health challenges of the 21st century, driving the search for alternative antimicrobial strategies [1,2]. In this context, metallic nanoparticles (NPs) have emerged as promising candidates to combat resistant infections due to their unique physicochemical and biological properties [3–5]. Among them, silver nanoparticles have been extensively investigated [6–10]; however, recent studies suggest that certain bacterial strains may also develop resistance to silver-based nanomaterials [11,12]. Consequently, research is focusing on bimetallic nanoparticles, which can achieve better antibacterial activity thanks to the synergy that takes place between their two monometallic components [13,14].

Various techniques exist for the synthesis of metallic nanoparticles, although chemical methods remain the most commonly employed [15]. Nevertheless, laser ablation of solids in liquids (LASL) has gained increasing relevance as a clean and sustainable alternative, enabling the production of high-purity nanoparticles without chemical precursors that may generate toxic by-products. This advantage gains more and more importance when nanoparticles are expected to be used in biomedical applications [16–19].

In this work, copper/copper oxide (Cu/CuO) and palladium (Pd) monometallic nanoparticles were synthesized by laser ablation in deionized water and subjected to a laser re-irradiation process to obtain copper–palladium bimetallic nanoparticles.

The formation of nanoparticles of the intermetallic alloy Cu_3Pd was confirmed through an extensive characterization using transmission electron microscopy (TEM), selected area electron diffraction (SAED) and high-resolution transmission electron microscopy (HRTEM). The formation of this intermetallic was attributed to interactions between the laser and both types of nanoparticles during the re-irradiation process. To evaluate their antimicrobial potential, CuO, Pd, and Pd/CuO nanoparticles were immobilized onto titanium discs and tested against Staphylococcus aureus, also monitoring ion release during the first 24 hours. Ultimately, cytotoxicity of the nanoparticles was assessed using the HFF-1 human fibroblasts cell line.

The bimetallic Pd/CuO nanoparticles demonstrated a significant antibacterial effect against S. aureus while exhibiting no cytotoxic effects on fibroblasts. The results suggest that ion release plays a key role in the antibacterial performance of the synthesized nanoparticles. Overall, the combined laser ablation and re-irradiation processes represent a promising and biocompatible approach for developing Pd/CuO bimetallic and antimicrobial nanomaterials.

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Acknowledgments:
The authors wish to thank the technical staff from CACTI (University of Vigo), SAI (University of Coruña) and Dr. J.A. Jiménez from CENIM-CSIC for their assistance with some of the characterization techniques.

This work was partially supported by the Government of Spain (PID2020-117900RBI00 (MCIU/AEI/FEDER, UE), FPU21/04488, EQC2018-004315-P (AEI/FEDER UE), RED2018-102803-T, project PID2021-125150OB-I00), and Xunta de Galicia (ED431C 2023/25).

Laser-Synthesized Carbon Quantum Dots as Multifunctional Platforms for Biomedical Sensing and Therapy.

Francis Rey Cortes[*a], Eva Falomir[*b], Gladys Mínguez-Vega[*a]

[*a] GROC-UJI, Institut de Noves Tecnologies de la Imatge (INIT), Universitat Jaume I, Spain.

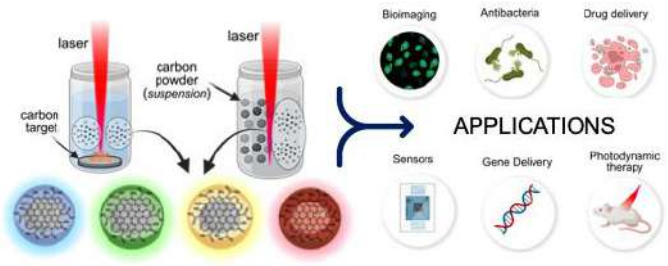
[*b] Department of Inorganic and Organic Chemistry, Universitat Jaume I (UJI), Spain.

This work investigates carbon quantum dots (CQDs) synthesized via pulsed laser fragmentation in liquids (PLFL), highlighting laser-based synthesis as a versatile, eco-friendly, and high-purity method with strong potential for biomedical applications [1]. To address the gap between CQD synthesis and real-world use, the study focuses on exploiting the physicochemical properties of laser-synthesized CQDs for sensing and drug delivery.

PLFL-produced CQDs were first functionalized with aminophenylboronic acid (APBA) to create a fluorescence-based, non-enzymatic glucose sensor. A novel laser-assisted post-modification step improved water dispersibility and enabled efficient functionalization. The resulting CQDs-APBA exhibited blue-shifted, stable fluorescence with a quantum yield of 35% and showed a sensitive, selective fluorescence turn-off response to glucose, achieving a detection limit of 165 µM and reliable performance in real saliva samples [2].

The biomedical utility of these CQDs was further demonstrated by encapsulating them in biocompatible PEI–TPP nanoparticles for delivery of the anticancer drug sorafenib (SRF). The CQDs-TPP/SRF system showed effective drug loading, enhanced anticancer and anti-angiogenic activity, successful cellular uptake, and the ability to inhibit and penetrate solid tumors in preliminary in vitro and in vivo models, while enabling fluorescence-based tracking.

Overall, the study demonstrates that PLFL-synthesized CQDs are promising multifunctional fluorescent probes for non-invasive sensing and drug delivery, with significant potential for further optimization and broader biomedical applications.



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Pulse Duration Effects on the Fate of AuNP-Loaded Nano-Polymersomes

Regina Salzer[*b], Cory Trout[*a], *Sean O'Malley*[*a*b], Julianne Griepenburg[*a*b]

[*a] *Rutgers University - Camden, Department of Physics, United States*

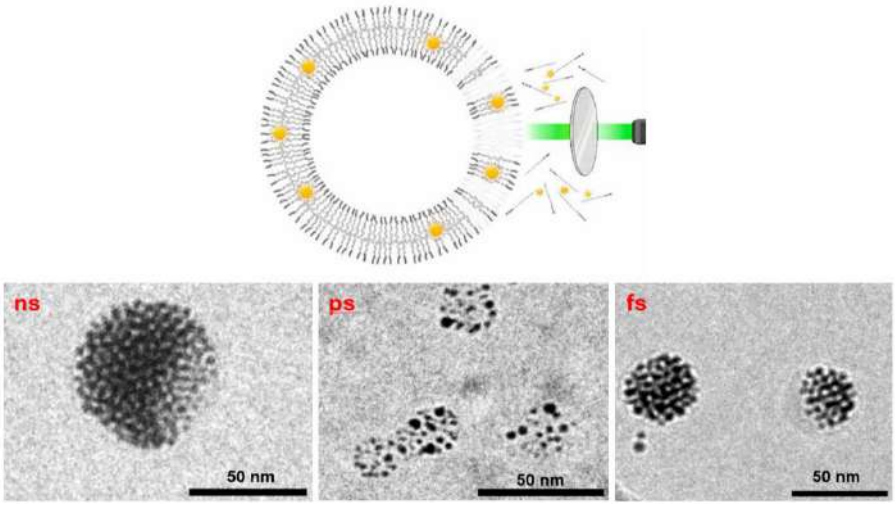
[*b] *Rutgers University - Camden, Center for Integrative and Computational Biology, United States*

Polymersomes represent a versatile synthetic vesicle platform with a wide range of potential applications in areas such as drug delivery and nanoreactors. A critical step in their utility is the ability to achieve controlled release of the encapsulated cargo. Light serves as a particularly advantageous release stimulus due to its capacity for spatiotemporal precision. However, the diblock copolymers that self-assemble into the polymersome membranes are not inherently photosensitive. To address this limitation, gold nanoparticles (AuNPs) are incorporated into the membrane. Their strong plasmonic response under irradiation facilitates membrane disruption and enables the release of encapsulated content.

Initial work on the micron scale demonstrated that exposure to 532 nm femtosecond laser pulses could induce transient pores in the membrane while maintaining vesicle integrity, or cause complete rupture, depending on fluence. [1] The current work presents a similar AuNP-loaded polymersome system but scaled down to the more biologically relevant nano-regime which introduces greater challenges in characterizing its photo-responsiveness.

Dynamic light scattering measurements show that these nanoscale particles exhibit both enhanced responsiveness to femtosecond irradiation and increased resistance to surfactants. [2] Cryo-TEM imaging has been extensively employed to visualize AuNP distribution within the polymersome membrane and to study their structural fate following irradiation, offering insights into the underlying photomechanical mechanisms that bring about disruption.

This work also explores the differential response of the polymersomes to laser pulses across 3 time-domains (femtosecond, picosecond, and nanosecond), highlighting behaviors in each regime. While dodecanethiol functionalized AuNPs have been predominantly used in these studies, additional results are presented involving AuNPs produced via pulsed laser ablation in liquid (PLAL) and functionalized with varying alkane chain lengths. [3] These PLAL-produced particles offer greater flexibility in tuning ligand length, which in turn influences key properties such as nanoparticle organization within the membrane.



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Acknowledgments:

The authors acknowledge Dr. Matthew R. Libera and Dr. Tsengming Chou (Laboratory for Multiscale Imaging, Stevens Institute of Technology, USA) for cryo-TEM support (NSF Award #1827557). J. C. G. acknowledges NSF LEAPS-MPS Award #2213408 and support from the GEERF II Opportunity Meets Innovation Challenge Grant administered by the New Jersey Office of the Secretary of Higher Education and the U.S. Department of Education.

Photoluminescent, surfactant-free Ag-Au alloy nanoclusters from laser fragmentation in liquids with amphoteric pH buffering and redox sensing functions

Wiebke L. M. Narz [*a], Milen Nachev [*b], Bernd Sures [*b*c], Wolfgang J. Parak [*d], Stephan Barcikowski [*a], Christoph Rehbock [*a]

[*a] *Universität Duisburg-Essen, Technische Chemie I, Germany.*

[*b] *University of Duisburg-Essen, Aquatic Ecology and Centre for Water and Environmental Research (ZWU), Germany.*

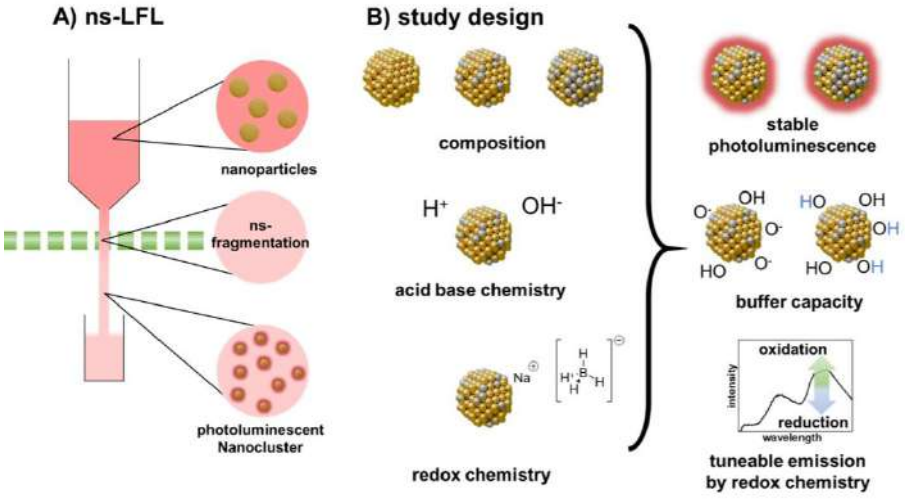
[*c] *University of Duisburg-Essen, Research Center One Health, Research Alliance Ruhr, Germany.*

[*d] *University Hamburg, faculty of Physics and Chemistry, Center for Hybrid Nanostructure (CHyN), Germany.*

The photoluminescence (PL) of metal nanoclusters (NCs) with diameters of 1-3 nm originates from their quantized electronic structure and is extremely sensitive to their chemical environment. While ligand-stabilized noble metal NCs have been widely investigated, the behaviour of surfactant-free, colloidal NCs under varying chemical conditions remains largely unexplored. Laser fragmentation in liquids (LFL) represents a versatile method for the surfactant-free synthesis of photoluminescent AuNCs [1], and previous studies have revealed a correlation between surface charge density (SCD) and PL emission [2].

In this work, monodisperse gold and gold-silver alloy NCs (≈ 1.4 nm) were synthesized via nanosecond laser fragmentation in liquids (ns-LFL). Comprehensive structural and optical analyses, including high-resolution TEM, analytical ultracentrifugation, UV-Vis, and fluorescence spectroscopy, confirmed narrow size distributions and distinct, composition-independent PL signatures attributed to core and surface states. Acid-base titrations revealed amphoteric surface behaviour with high buffering capacity (up to 5 nmol cm^{-2}), exceeding that of larger gold nanoparticles by a factor of 6.5. The NCs remained colloidally stable under both strongly acidic and basic conditions, adjusting their surface charge density without affecting fluorescence intensity.

Redox-active agents selectively modulated emission intensities, evidencing a strong coupling between PL and electron transfer processes at the NC interface. These results demonstrate that surfactant-free Au and AgAu NCs combine exceptional chemical robustness with redox-tuneable optical properties, making them promising candidates for nanoscale sensing and adaptive photonic applications. Furthermore, ns-LFL proves to be a robust and versatile method for production of not only gold nanoclusters but also well-defined alloy nanoclusters.



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Acknowledgments:

DFG project DFG PA 794/28-1

Pulsed laser-induced defects and dopants enhance catalytic activity of transition metal oxides

Benjamin Mockenhapt[*a], Dana Schellenburg[*a], Sven Reichenberger[*a], Stephan Barcikowski[*a]

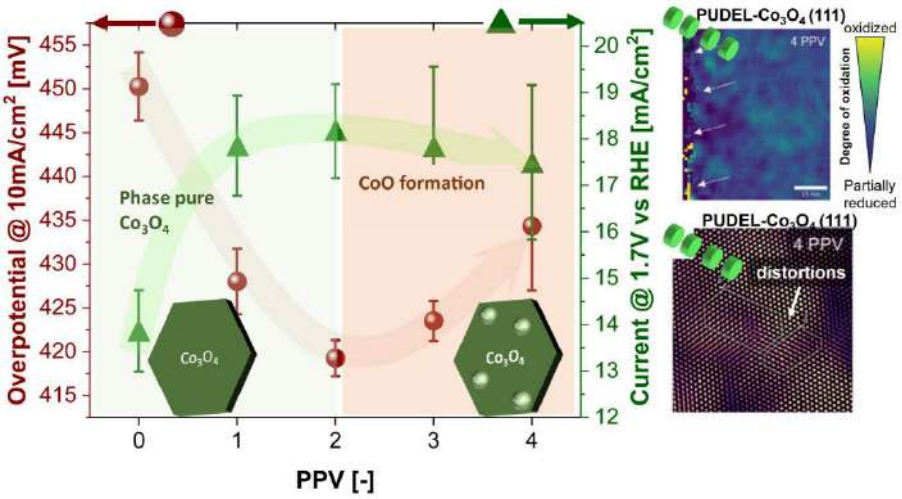
[*a] *Technical Chemistry I, University of Duisburg-Essen and Center for Nanointegration Duisburg-Essen (CENIDE), Germany.*

Pulsed Laser Defect Engineering in Liquids (PUDEL) is a powerful technique both for fundamental catalyst research and for catalyst performance enhancement.[1, 2] As previously shown, PUDEL enables tuning of the density of active surface states with single laser pulses: the catalyst is rapidly heated by individual pulses, inducing fast diffusion processes and lattice restructuring, while heat transfer into the surrounding liquid kinetically "freezes" these metastable structural states before they can transform into the next thermodynamic phase.[1,3,4]

Studies on $CoFe_2O_4$ spinels correlated improved catalytic performance in cinnamyl alcohol oxidation with an increased fraction of octahedral Co^{3+} sites, generated by pulse-by-pulse laser treatment.[5] Furthermore, iron could be incorporated into undoped Co_3O_4 by pulse-by-pulse treatment of spherical Co_3O_4 in Fe-containing solution.[2] In all cases, the laser-induced structural changes correlated with trends in catalytic activity.[2,3,5] However, these investigations mainly used spherical particles with multiple crystal orientations and facets, complicating fundamental interpretation and theoretical modelling. To gain a deeper understanding of the activity-boosting mechanisms, Co_3O_4 platelets grown along <111> directions were investigated as a more well-defined model system in PUDEL treatments.

When PUDEL was performed in pure water, the formation of CoO_x sites and lattice distortions was observed by HR-STEM and EPR analysis (Fig. 1 b)).[1] In contrast, PUDEL of the same material in a VCl_3 precursor solution introduced vanadium as a heteroatom into the spinel structure, while EPR suggested the formation of high-spin Co^{2+} on octahedral sites, analogous to the previously observed changes in the inversion parameter in PUDEL-treated $CoFe_2O_4$. In both cases, the Co_3O_4 platelets were partially reduced.[1,6]

The resulting structure- and composition-dependent activity trends were reflected not only in the electrocatalytic oxygen evolution reaction (OER, Fig. 1 a)) but also in thermal catalytic alcohol oxidation, indicating that similar laser-induced surface states can promote both electro- and thermocatalytic pathways.[1,6] Overall, these studies demonstrate that pulsed laser post-processing of particle suspensions not only supports fundamental understanding of the origin of catalyst activity, but also enhances intrinsic catalytic performance, offering a versatile tool for rational catalyst design.



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Acknowledgments

The authors also gratefully acknowledge the Deutsche Forschungsgemeinschaft (DFG) for its financial support under project 388390466 – CRC/TRR 247 (Sub-project C05).

High-Performance Photocatalytic Transparent Thin Films Enabled by Laser-Synthesized Noble Metal Nanoparticles

Jaime González Cuadra[*a], *Sergio Molina-Prados*[*b], Gladys Mínguez Vega[*b], *Nuno Gonçalves*[*c], Tito Trindade[*c], *Rui Miguel Novais*[*a], João Labrincha[*a], Juan Carda[*d]

[*a] *Department of Materials and Ceramic Engineering / CICECO–Aveiro Institute of Materials, University of Aveiro, Portugal.*

[*b] *GROC-UJI, Institute of New Imaging Technologies, Universitat Jaume I, Spain.*

[*c] *Department of Chemistry / CICECO–Aveiro Institute of Materials, University of Aveiro, Portugal.*

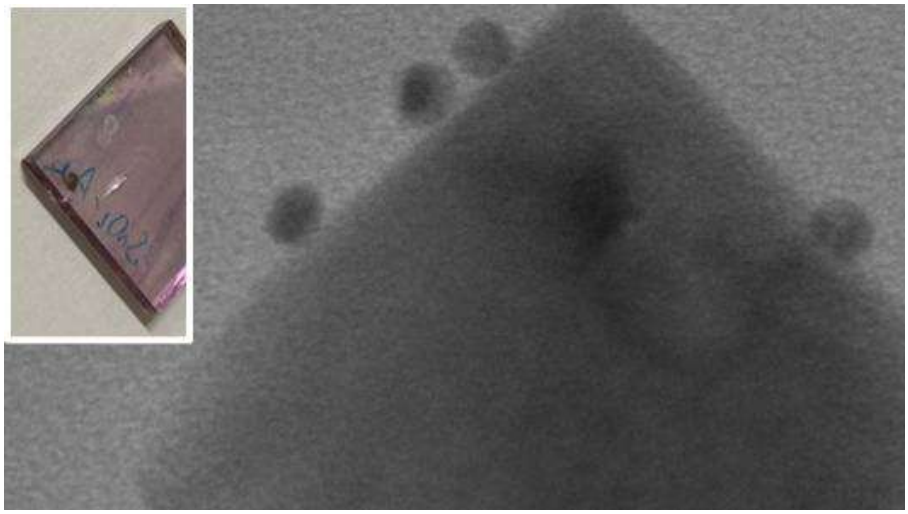
[*d] *Department of Inorganic and Organic Chemistry, Universitat Jaume I, Spain.*

The development of efficient, sustainable, and easily recoverable photocatalytic systems remains a critical challenge for advanced oxidation processes aimed at environmental remediation. In this work, we report the fabrication of high-performance transparent photocatalytic thin films based on wide-bandgap semiconductor oxides (TiO_2 and SnO_2) functionalized with noble metal nanoparticles (Ag and Au) synthesized by pulsed laser ablation in liquids (PLAL). This laser-based approach enables the production of ultra-pure, surfactant-free nanoparticles with controlled size and high colloidal stability, offering a green and scalable alternative to conventional chemical routes [1].

Transparent semiconductor thin films were deposited on glass substrates by spray pyrolysis, followed by the surface immobilization of laser-synthesized noble metal nanoparticles through a physical assembly process. Structural and morphological analyses confirmed the formation of compact, homogeneous films with thicknesses below 300 nm and high optical transparency (>80%). The presence of Ag and Au nanoparticles on the semiconductor surface led to the formation of Schottky heterojunctions, as evidenced by XRD, Raman spectroscopy, TEM, and XPS analyses, without altering the bulk crystal structure of the oxide layers [2].

The incorporation of noble metal nanoparticles significantly enhanced photocatalytic performance under UV irradiation by improving charge carrier separation and suppressing electron–hole recombination. TiO_2–Ag thin films achieved nearly complete degradation of Rhodamine B, while SnO_2–Au films reached high degradation and mineralization efficiencies for ciprofloxacin using remarkably low catalyst loadings. Reactive species trapping experiments confirmed hydroxyl and superoxide radicals as the dominant oxidative agents. Additionally, the immobilized thin-film architecture ensured excellent stability, reusability, and negligible metal leaching.

Overall, this work demonstrates that the combination of laser-synthesized noble metal nanoparticles with transparent oxide thin films constitutes a robust and versatile platform for high-efficiency photocatalysis, with strong potential for scalable water treatment and antimicrobial surface applications.



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Acknowledgments:

This work was supported by the Spanish Ministry of Science and Innovation (MCIN/AEI) through projects PID2020-116719RB-C43 and PID2019-110927RB-I00, as well as funding from the Generalitat Valenciana (PROMETEO/2020/029) and Universitat Jaume I (UJI-B2019-37). Additional support was provided by CICECO – Aveiro Institute of Materials (FCT/MCTES, PIDDAC: UIDB/50011/2020, UIDP/50011/2020, LA/P/0006/2020). Technical support from the scientific facilities of Universitat Jaume I is also acknowledged.

Laser ablation of a fork (stainless steel) and water splitting application

Cristiano Lo Pò [*a], Stefano Boscarino [*a], Francesco Ruffino [*a], Silvia Scalese [*b]

[*a] *University of Catania, Italy*

[*b] *CNR IMM Section of Catania, Italy*

Hydrogen (HER) and Oxygen (OER) evolution reactions play a fundamental role in the field of green sustainability, because they are key reactions for water electrolysis. The high-performance materials are platinum for HER, while iridium and ruthenium oxides for OER. These materials are precious and rare, thus in economic terms, earth abundant and non-pollutant electrocatalysts should be employed. A valuable alternative is provided by nickel-iron alloy and compounds since the synergistic effects of these two transition metals is proved and observed in literature.

This work takes place in a framework of circular economy and environmentally friendly perspective since the starting point is the commonly used stainless steel for food and catering, in particular a fork. Stainless steel already contains iron and nickel, plus an additional amount of chromium and carbon and is safe (non-toxic) since we use it every day to eat.

In this work, Pulsed Laser Ablation in Liquid (PLAL) is used for a dual purpose: produce nanoparticles and modify the stainless-steel target surface.

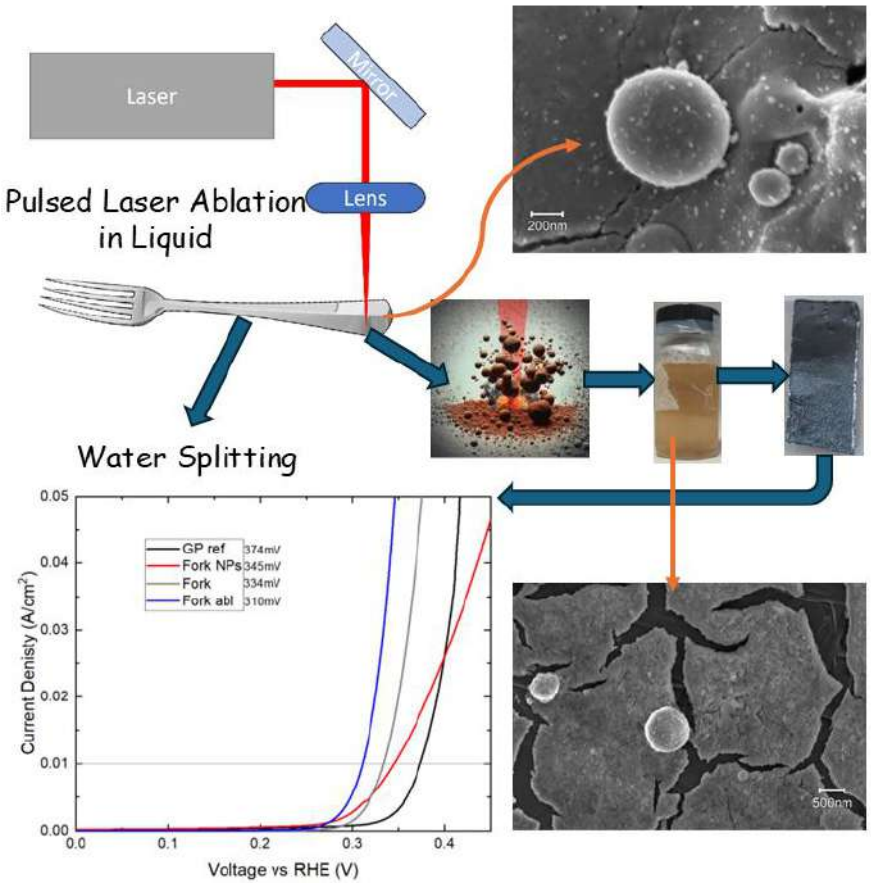
PLAL is performed using a Nd: YAG ns-pulsed laser in water over a common stainless steel 18/10 fork (λ=1064 nm, 10ns, 5W, 10Hz) for 10 minutes, the target is manually moved to achieve a complete surface modification.

Morphological, structural and compositional characterizations have been performed by Scanning Electron Microscopy (SEM), Atomic Force Microcopy (AFM), Raman Spectroscopy, UV-Vis Spectrophotometry, Energy dispersion X-Ray (EDX).

Electrochemical measurements have been performed in an electrolyte consisting of 1 M KOH. A three-electrodes setup has been used with platinum wire as the cathode and a saturated calomel electrode (SCE) as the reference electrode. Water splitting activity was investigated using Cyclic Voltammetry (CV), Linear Sweep Voltammetry (LSV) and Electrochemical Impedance Spectroscopy (EIS).

The produced nanoparticles were used for the decoration of an inert carbon substrate, and the catalytic activity was investigated in HER and in OER processes, with low catalyst loading (in the order of 40μg/cm^2).

In the other side, the stainless-steel target modified after the ablation process strongly increase its performance both toward hydrogen and oxygen production at the standard current density of 10mA/cm^2.



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This work was funded by European Union (Next Generation EU), through the MUR-PNRR project SAMOTHRACE (Grant No. ECS00000022).

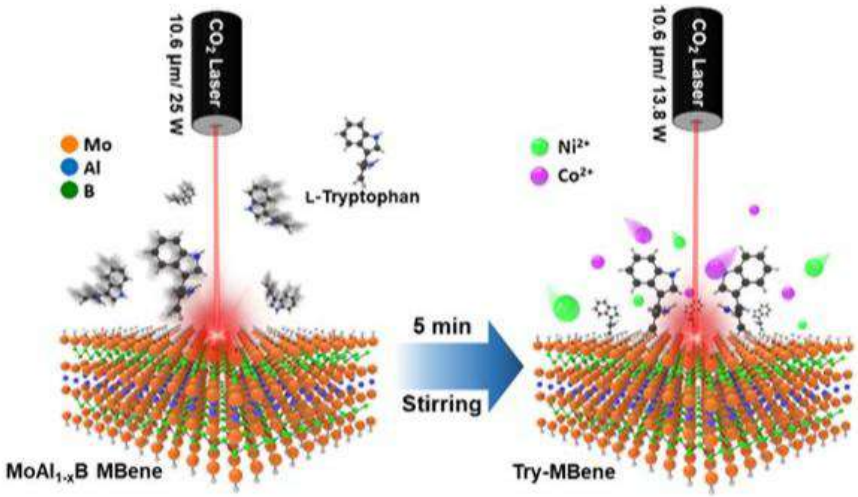
Dual Single-Atom Stabilization on MBene Using a CO_2 Laser for Electrochemical Nitrate Reduction to Ammonia Production

Theerthagiri Jayaraman[*a], Juhyeon Park[*a], Seongbo Lee[*a], Gyeong-Ah Kim[*a], Wonji Go[*a], Myong Yong Choi[*a]

[*a] *Department of Chemistry (BK21 FOUR), Research Institute of Advanced Chemistry, Gyeongsang National University, Republic of Korea.*

Dual single-atom (DSA) catalysts hold great potential, but their synthesis complexity remains a key challenge. Achieving strong interactions between single atoms (SAs) and the support is the main goal in SA catalysis for ensuring robust isolated SA–host interactions. To address this, we introduce a continuous-wave CO_2 laser irradiation strategy that stabilizes SAs in 3 min and demonstrates the feasibility of MBene as a new two-dimensional borides host. Selective acid/oxidant etching expands delaminated $MoAl_{1-x}B$ MBene sheets, exposing Mo-B rich basal planes, while L-tryptophan functionalized $MoAl_{1-x}B$ immobilizes Co and Ni DSAs via electron-rich metal–N and metal–O sites under CO_2 laser irradiation (λ = 10.6 μm, power = 25 W).

The CoNi-DSA/MBene impressively increases electrochemical nitrate reduction reaction (NO_3RR) activity, achieving an NH_3 production rate of 32.36 ± 0.56 mg h^{-1} cm^{-2} at −0.8 V versus RHE. Beyond NO_3RR, CoNi-DSA/MBene is employed as the cathode in a Zn–NO_3^- battery, offering advanced energy solutions with NH_3 production. This study underpins the potential of CO_2 laser processing as a new avenue for the rational design of multifunctional SA catalysts in energy technologies.



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Recently revealed potentials of laser ablation in liquids for energy-saving formation of functional nanomaterials

Tomáš Křenek [*a], Lukáš Vála [*a], Markéta Veselá [*a]
[*a] *University of West Bohemia, Czech Republic.*

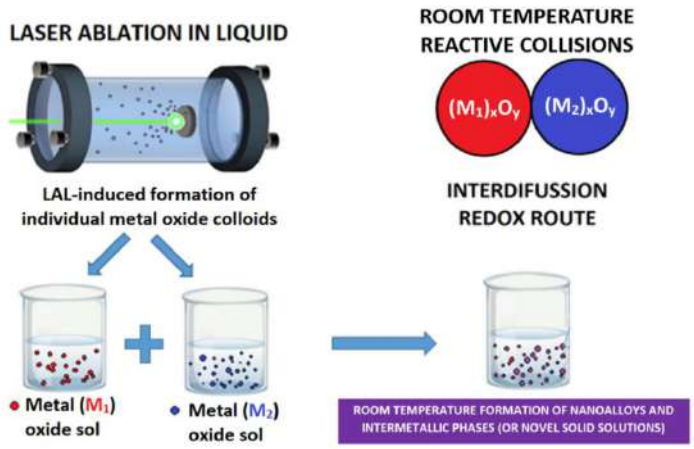
Laser ablation in liquids (LAL) has been developed into efficient technique producing various colloidal nanoparticles with applicable properties in e.g. biodetection, antibacterial agents, gas sensing, SERS detection and photocatalysis.

Aim of this contribution is present our recent research revealing advantages of LAL for synthesis of functional materials in terms of the following aspects: (i) functionalization of porous surfaces by nanoparticles via electrostatic attraction, (ii) LAL-induced high-pressure structures with enhanced e.g. photocatalytic activity, (iii) room temperature reactive interactions between two different sols yielding metal silicides.

(i) One of the typical problems faced in the catalytic applications of colloidal nanoparticles is their instability towards aggregation, which decrease the catalytic properties. A strong effort is devoted to achieving a higher colloidal stability by various stabilizers which are, however, usually not environmentally friendly and such freely moveable nanocatalysts can enter biogeochemical cycles (ecosystem, human body, etc.). It is therefore an attractive idea to make use of the electrostatic adsorption of nanoparticles on porous/rough surfaces. This concept has been proved with various photocatalytic and antibacterial/bioactive nanoparticles which allows facile formation of functionalized surfaces for catalytic and implant application [1].

(ii) Highly thermodynamically non-equilibrium conditions of LAL are beneficial for formation of high-pressure structures which could exhibit improved e.g. photoactive characteristics. LAL-induced FeS-derived nanoparticles contains high-pressure orthorhombic FeS phase which represent so far unreported example of high-pressure structures produced by LAL. High-pressure form of FeS exhibits significantly higher photocatalytic activity compared to its stable phase, which encourage next research of catalytic properties of LAL-induces high-pressure phases [1].

(iii) In spite of advanced research on functional colloidal inorganic nanoparticles and their reactivity, room temperature reactive interactions between two different colloids have remained challenging so far. Simple room temperature mixing of ethanol TiO- and SiO-derived colloids allows the formation of TiSi2, which is the first-ever case of room temperature reactive interactions between two colloidal species. Inclusion of TiSi2 in colloidal mixture significantly enhanced its photocatalytic efficiency for solar-light organics degradation [2]. Such room temperature colloidal reactive interaction has been proofed also for next combination of metastable oxides such as MnO+SiO, Cu2O+SiO, whose products (Mn/Cu silicides and silicates) exhibit desirable balance between compatibility and antibacterial effect and thus find application as efficient agents for functionalization of orthopaedic and dental implant surfaces.



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THURSDAY 28TH

ANGEL26
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Defect-engineering in 2D layers for semiconductor SERS sensing

Luisa D'Urso[*a], Antonio Brancato[*a], Marcello Condorelli[*a], Enza Fazio[*b], Giuseppe Forte[*a], Giuseppe Compagnini[*a]

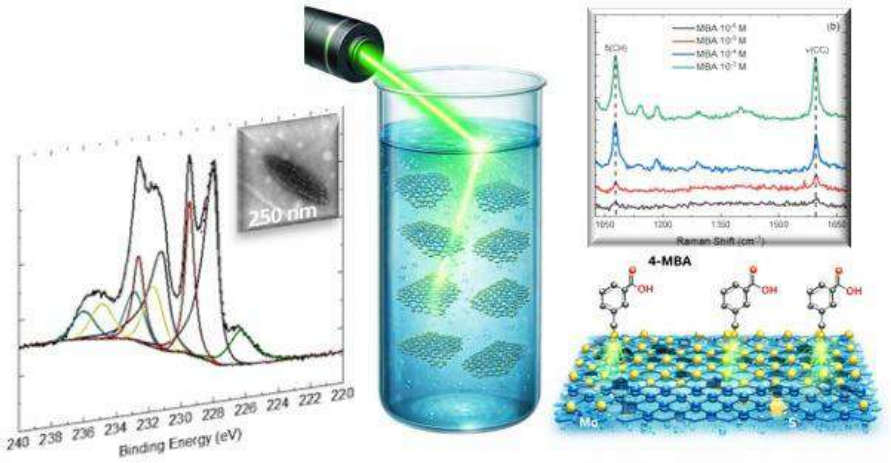
[*a] *University of Catania, Italy*

[*b] *University of Messina, Italy*

Surface-enhanced Raman scattering (SERS) offers exceptional molecular sensitivity; however, the poor stability and limited reproducibility of noble-metal-based substrates, which dominate current SERS platforms, significantly restrict their practical implementation. In this study, we investigate non-plasmonic alternatives based on two-dimensional hexagonal boron nitride (hBN) and molybdenum disulfide (MoS_2). We introduce a reagent-free pulsed laser irradiation-in-liquid strategy to controllably generate defects, thereby tailoring the electronic structure of these 2D materials through the formation of sulfur and boron vacancies.

Laser-modified MoS_2 exhibits a markedly enhanced SERS response compared with its pristine counterpart, with the enhancement strongly correlated with increased defect density and the emergence of the conductive 1T phase. These features promote more efficient charge transfer between the substrate and adsorbed molecules. A comparable defect-induced enhancement is also observed in hBN layers. SERS measurements were performed using 4-mercaptobenzoic acid (4-MBA) as a probe molecule at various concentrations under 532 nm excitation.

Density functional theory calculations further support the experimental results, revealing improved energy-level alignment between the modified 2D semiconductor platforms and the probe molecule. Overall, our findings demonstrate that phase and defect engineering of two-dimensional materials represents a reliable and scalable approach for the development of reproducible, non-plasmonic SERS substrates, offering a promising alternative to noble metals for sensitive chemical and biosensing applications.



Acknowledgments:
The authors L. D., M.C. and G. C. acknowledge funding and support by PRIN 2022 LANCIA. M.C. and PRIN PNRR 2022 ELATED. Piaceri 2024–2026 NANO-STRENGHT is acknowledged by L. D. This work was also supported by the PON project Bionanotech Research and Innovation Tower (BRIT), funded by the Italian Ministry of Education. V. S. acknowledges funding from the European Union (NextGeneration EU), through the MUR-PNRR project SAMOTHRACE (ECS00000022).

Laser Prepared ZnO–SnOx Hybrid Nanomaterial for Room-Temperature NH_3 Sensing

Sergei Kulinich[*a], Ali AlJulaih[*a], Ranyi Zheng[*a], Masaki Hashida[*a], Satoru Iwamori[*a]
[*a] *Tokai University, Hiratsuka, Japan*

We report on a ZnO–SnO_x hybrid nanomaterial produced via laser ablation of the corresponding metals in water and its application in gas sensing. We demonstrate that this hybrid nanomaterial can be conveniently prepared by sequentially ablating Zn and Sn metal plates in water using a nanosecond-pulsed YAG laser.

The resulting ZnO–SnO_x nanomaterial was characterized for its surface and phase composition and then annealed to reduce metallic Sn inclusions and promote the formation of a uniform composite. When compared with its individual components (ZnO and SnO_x nanomaterials, which primarily responded to ethanol [1,2]) the novel hybrid ZnO–SnO_x material exhibited enhanced selectivity and sensitivity toward ammonia.

Notably, the sensor responded to concentrations as low as 10 ppm, with a response and recovery times of approximately 70 s and 220 s, respectively. These findings highlight the potential of this hybrid material for further optimization and improvement of its room-temperature gas-sensing performance.

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S.K. acknowledges support from the Amada Foundation (grant nos. AF-2024231-B3 and AF-2024261-Z1).

Hybrid nanostructures of Cu_2BiI_5 with SnS nanoparticles as thin film photodetector

Indhulekshmi Prasad[*a], Bindu Krishnan[*a], David Avellaneda Avellaneda[*a], Josue Amilcar Aguilar Martinez[*a], Shaji Sadasivan[*a]

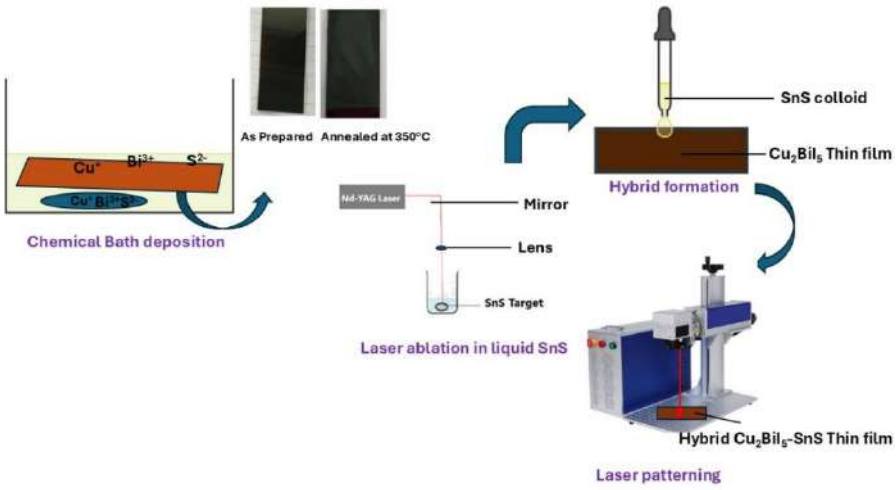
[*a] *Facultad de Ingeniería Mecánica y Eléctrica, Universidad Autónoma de Nuevo León, México.*

Hybrid nanostructures of rudorffite Cu_2BiI_5 thin films with SnS nanoparticles are successfully fabricated and investigated for photodetector applications. Cu_2BiI_5 thin films were obtained via iodization of chemically deposited Cu_3BiS_3 precursor films SnS nanocolloids were synthesized by laser ablation of a SnS target in liquid and incorporated onto the Cu_2BiI_5 thin film surface to form the hybrid architecture.

Laser surface patterning was performed, and its influence on the structure, morphology, and optoelectronic properties of the hybrid films was systematically studied. X-ray diffraction (XRD) analysis showed the formation of phase-pure ruffoffite Cu_2BiI_5. X-ray photoelectron spectroscopy (XPS) verified the elemental composition and chemical states. Surface morphology, laser-induced surface structures and the respective elemental mapping were examined using scanning electron microscopy (SEM) employed with energy-dispersive X-ray spectroscopy (EDX), confirming the distribution of Cu, Bi, I, Sn, and S on the surface of the hybrid films. T

he Cu_2BiI_5/SnS hybrid system exhibited enhanced light absorption and improved charge separation due to favourable band alignment at the heterointerface and laser-induced surface modification. Photoresponse measurements revealed improved optoelectronic characteristics for the devices fabricated using the laser-patterned hybrid films compared to pristine Cu_2BiI_5, indicating efficient photogenerated charge transport and reduced recombination losses due to the SnS nanoparticles.

These results highlight the potential of laser-patterned Cu_2BiI_5/SnS hybrid thin films as a promising, lead-free material for advanced optoelectronic and photodetection applications.



Acknowledgments:
This work was supported by the Secretaría de Ciencia, Humanidades, Tecnología e Innovación (SECIHTI, Mexico), which provided a doctoral fellowship to Indhulekshmi Prasad.

Laser-Assisted Dual-Alloyed Au/AgAu-Decorated CuAg Nanostars and AuAg@AgCu Nanoflowers for Broadband SERS Detection of Arsenolite, Microplastics, and Synthetic Colorants

Jithin Kundalam Kadavath[*a], *Bindu Krishnan*[*a,*b], *René Fabián Cienfuegos Pelaes*[*a*b], *David Avellaneda Avellaneda*[*a], *Nora Aleyda Garcia Gomez*[*c*d], *Selene Sepúlveda Guzmán*[*a*b], *Sadasivan Shaji*[*a*b]

[*a] *Facultad de Ingeniería Mecánica y Eléctrica (FIME), Universidad Autónoma de Nuevo León, México.*

[*b] *Centro de Innovación, Investigación y Desarrollo en Ingeniería y Tecnología (CIIDIT)- Universidad Autónoma de Nuevo León, México.*

[*c] *Facultad de Ciencias Químicas (FCQ), Universidad Autónoma de Nuevo León, México*

[*d] *Centro de Investigación en Biotecnología y Nanotecnología (CIBYN), Universidad Autónoma de Nuevo León, México.*

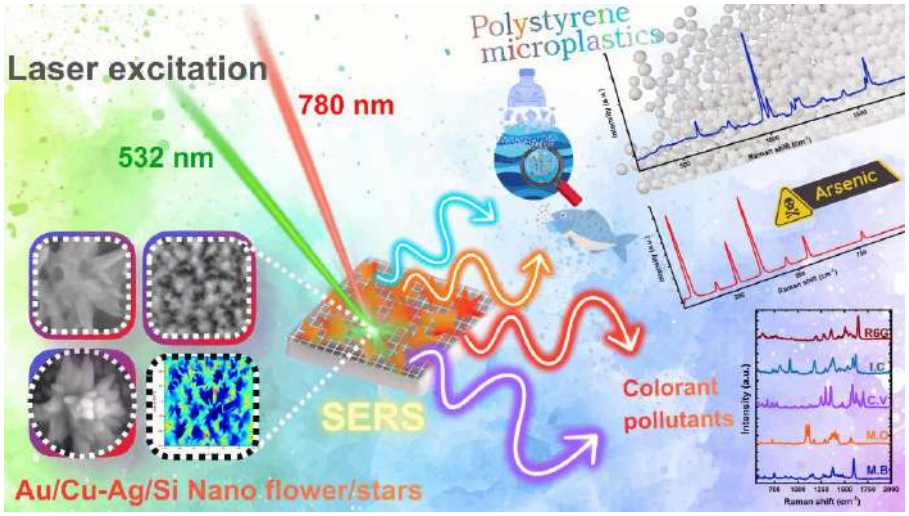
Growing environmental and public health risks associated with trace-level pollutants demand robust, ultra-sensitive, and broadband analytical platforms capable of reliable detection across diverse chemical classes. Laser-engineered alloyed plasmonic nanostructures on silicon are presented as versatile surface-enhanced Raman scattering (SERS) substrates that enable ultrasensitive, reproducible, and multi-wavelength detection of inorganic toxic compounds like As_2O_3, microplastics, and synthetic dyes.

The platforms are fabricated via an environmentally benign laser-assisted surface engineering/alloying strategy combined with plasma sputtering, yielding hierarchical AuAg-decorated Ag–Cu nanourchins and nanostars with dense three-dimensional plasmonic hotspot networks. Sharp tips, branched features, and interparticle junctions generate strong electromagnetic confinement, while synergistic Ag–Au and Cu–Ag alloy domains ensure broadband plasmonic coupling compatible with both visible (532 nm) and near-infrared (780 nm) excitation.

The resulting substrates enable trace-level detection of rhodamine 6G down to 5×10^{-14} M, arsenolite (As_2O_3) to 10^{-13} M under 532 nm excitation, and polystyrene microplastics at concentrations as low as 2×10^{-3} g L^{-1}, representing one of the lowest reported detection limits for arsenic oxide.

In parallel, the same SERS platforms achieve ultrasensitive and charge-independent detection of both cationic (methylene blue, rhodamine 6G, crystal violet) and anionic (indigo carmine, methyl orange) dyes, with detection limits reaching 10^{-15} M. Surface decoration with bimetallic AuAg nanoparticles and sputtered Au significantly enhances signal uniformity, suppresses oxidation, and improves structural integrity.

Excellent signal reproducibility (RSD < 9%) and long-term stability over five weeks highlight the robustness of these laser-fabricated substrates. The combination of green fabrication, multi-wavelength operability, chemical durability, and record-level sensitivity positions these alloyed plasmonic SERS platforms as powerful tools for environmental monitoring, food safety, and trace-pollutant analytics.



Acknowledgments:

Jithin Kundalam Kadavath is grateful to SECIHTI -Mexico for providing a doctoral fellowship. Sadasivan Shaji is thankful to SECIHTI -Mexico for research funding of project CB 2017-2018, No: A1-S-21684.

Laser-Generated Nanoparticles for Metal Additive Manufacturing: Influence of Size and Chemistry

Silja-Katharina Rittinghaus[*a], Jan Niklas Petenati[*a], Garvit Sharma[*a], Daniel Borchert[*a], Hamed Shokri[*a], Prasanth Bondi[*b], Yangyiwei Yang[*b], Bai-Xiang Xu[*b], Bilal Gökce[*a]

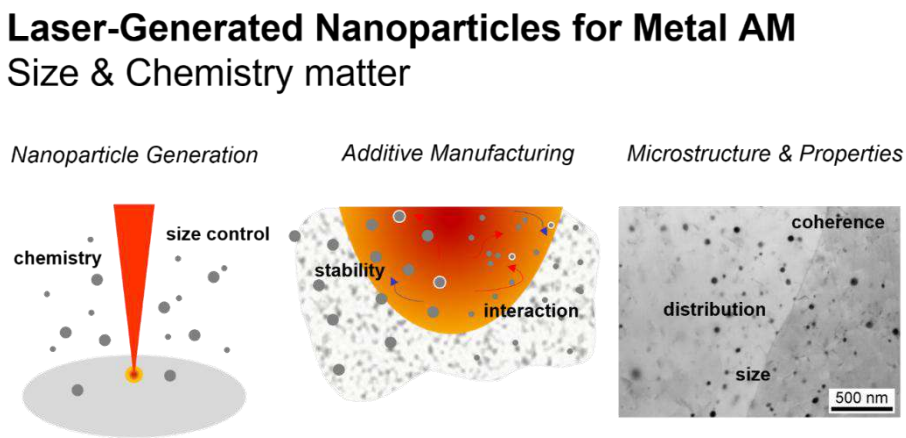
[*a] *Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering, University of Wuppertal, Germany.*

[*b] *Mechanics of Functional Materials, Technical University of Darmstadt, Germany.*

Although metal additive manufacturing (AM) enables the fabrication of complex geometries with tailored mechanical and thermal properties, but precise microstructural control remains challenging. One promising approach is to integrate laser-generated nanoparticles into metal powders to enhance strength, hardness, and high-temperature performance. Oxide nanoparticles are particularly relevant for oxide dispersion strengthening (ODS), where their uniform distribution inhibits grain growth and improves creep resistance [1].

The effects of nanoparticles depend critically on their size and intrinsic chemical composition. Smaller particles promote stronger interactions with the metal matrix and refine grains, while the particle chemistry governs in-situ reactions that can form complex phases. However, open questions remain regarding nanoparticle stability and the precise evolution of nanoscale features during processing. Agglomeration and heterogeneous distribution present major challenges [2], as clustered particles can result in localized weaknesses.

The precise characterization of nanoparticle distribution in dense metal components remains demanding and requires advanced imaging and analytical methods. This presentation discusses strategies to control nanoparticle size, chemistry, and dispersion, with a focus on ODS alloys. Recent experimental and simulation results illustrate ways to minimize agglomeration, understand in-situ reactions, and optimize microstructural evolution. The presentation also highlights perspective applications and future directions for high-performance nanostructured metals.



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Simultaneous PLAL and sol-gel techniques for the synthesis of nanostructured glasses and gelatins

Emmanuel Haro-Poniatowski[*a*b], Fátima Cabello[*a], Marina García-Pardo[*a], Rosalia Serna[*a], Fernando Chacón-Sánchez[*a], Johann Toudert[*a], Luis Escobar-Alarcón[*c]

[*a] *Laser Processing Group, Instituto de Óptica, IO, CSIC, Spain.*

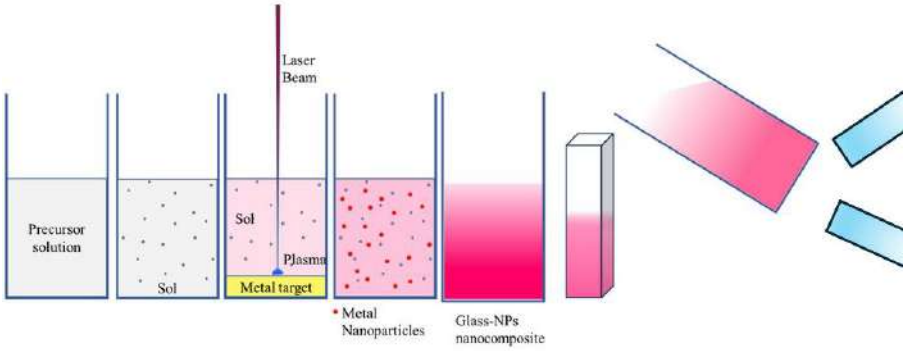
[*b] *Departamento de Física, Universidad Autónoma Metropolitana Iztapalapa, México.*

[*c] *Departamento de Física, Instituto Nacional de Investigaciones Nucleares, México.*

Here we report on the synthesis and characterization of glasses and gelatins with embedded nanoparticles using a combination of the Sol-Gel and laser ablation techniques [1, 2]. This procedure allows us to fabricate nanostructured materials in bulk and thin film form in a straightforward manner. Tetraetilorthosilicate (TEOS) and water with hydrochloric acid as a catalyzer are used to produce the starting solution to synthesize the glasses. Gelatins were prepared using commercial transparent gelatin and hot water.

Laser ablation was performed in the nanosecond regime using a Nd:YAG laser emitting at 1064 nm, with an energy of 100 mJ at 10 Hz repetition rate focused in a 2mm diameter laser spot. The ablation time ranged from 5 to 15mn. The noble metal target is immersed in a vessel in the corresponding (organic or inorganic) solution. After gelation the glasses and gelatins are dried appropriately and after this process blocks or thin films are obtained.

The optical properties of nanostructured glasses and gelatins with embedded noble metal nanoparticles show the typical absorption of the surface plasmon resonance. Finally, the possibility of implementing hybrid organic-inorganic sensors using these nanostructured materials is discussed.



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Femtosecond laser nanomanufacturing for multifunctional optical modulation

Dongshi Zhang*a
*a Shanghai Jiao Tong University, China.

Femtosecond (fs) laser nanomanufacturing is a versatile technique for fabricating nanostructures (e.g., laser induced periodic surface structures (LIPSS)) and synthesizing nanomaterials, an exciting “one stone with two birds” method. Generally, they are separately studied, with few focus on their combinations. In this work, some new insights are gained after combining them together for a hierarchical nanomanufacturing, with a focus on their potential applications for optical modulation, information encryption and decryption (Figure 1) [1-3].

White Cyphochilus insulanus beetles, exhibiting both environmental camouflage display and radiative cooling functions, serve as a good prototype for biomimetic fabrication. As inspired, this work presents a femtosecond (fs) laser-based biomimetic fabrication strategy that takes full use of the synthesized radiative cooling nanomaterials for a groundbreaking stimuli-responsive infrared (IR) impressionistic camouflage display.

The proposed technique is capable of readily transforming various substrates (quartz glass and metals including Ti, Al, Zr, and W) into self-assembled porous networks (aerogels) consisting of oxygen-vacancy-rich oxide nanoparticles. Surprisingly, the emissions of all as-prepared porous particle-networks in the radiative-cooling long-wavelength infrared (LWIR) band are above 95%, with the SiO2 aerogels reaching a maximum of 99.6% [4].

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[4] Liao J, Li Z, Zhang D. Bionic femtosecond laser manufacturing for impressionistic camouflage infrared display

Laser-Fabricated Nano-Inks from 2D Materials for Aerosol Jet Printing

Ivan Kazantsev [*a], Gleb Tikhonowski [*a], Sofer Zdenek [*b], Gleb Tselikov [*a], Aleksey Arsenin [*a], Valentyn Volkov [*a]

[*a] *Emerging Technologies Research Center, XPANCEO, United Arab Emirates*

[*b] *Department of Inorganic Chemistry, University of Chemistry and Technology Prague, Czech Republic*

Van der Waals (vdW) nanoparticles (NPs) represent a versatile class of functional nanomaterials with tunable optical, electronic, and mechanical properties, making them attractive for advanced additive manufacturing. In a recent study, single-step femtosecond pulsed laser ablation in liquids (fs-PLAL) was used to synthesize spherical, additive-free vdW nanoparticles exhibiting exceptional colloidal stability across diverse solvents, including water. This laser-based approach was used by Tselikov et al. to enable the synthesis of nanoparticles from more than 50 different vdW materials, underscoring its universality and scalability.[1] This stability arises from an intrinsic surface charging mechanism, providing strong electrostatic repulsion that prevents agglomeration without the need for chemical surfactants.

The ability to prepare pure, stable colloids expands opportunities for environmentally friendly additive manufacturing workflows and ensures compatibility with chemically sensitive substrates. We demonstrate the direct use of these vdW nano-inks in high-resolution aerosol jet printing, achieving uniform, well-defined patterns on multiple substrates with no sedimentation of inks during prolonged operation.

The spherical morphology of the nanoparticles ensures reliable jetting and consistent deposition quality, which is essential for precision patterning applications. Using this approach, we also printed SERS-active substrates on various materials, including aluminum foil, paper, and PET, and evaluated their performance, confirming their functionality for sensing applications. Beyond advanced printing, the exceptional stability enables integration into simple writing tools, such as marker pens, facilitating rapid, equipment-free prototyping of functional surfaces.

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Abstracts of **POSTERS**

ANGEL26
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Hybrid Micro-Nano Filler Strategy for Thermally Conductive Photopolymers using Plal-Synthesized Alumina Nanoparticles

Ana Damnjanović [*a], Lluís Martínez-León [*a], Gladys Mínguez-Vega [*a], Carlos Doñate Buendia [*a], Leonor Hernández [*b], Pablo A. Prieto-Díaz [*b], Nikita Konovalov Shishov [*a], Jesús Lancis [*a]

[*a] *GROC UJI - Photonics Research Group, Universitat Jaume I, Spain*

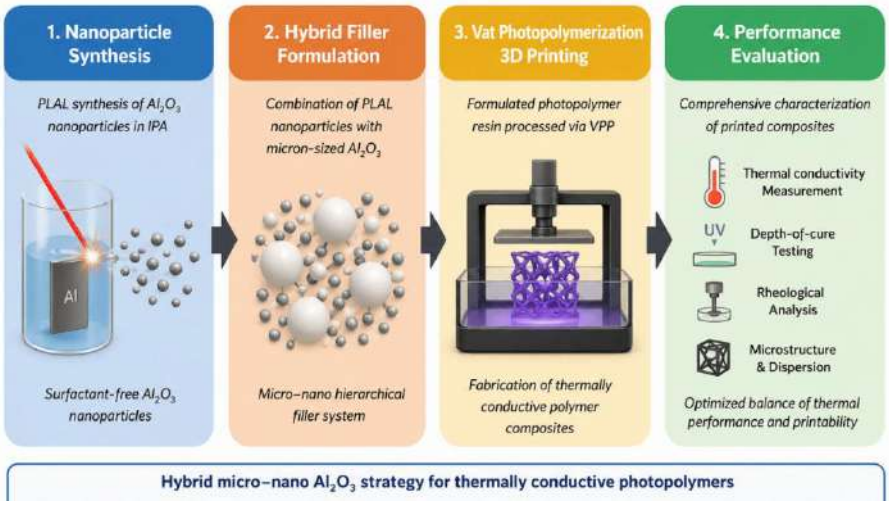
[*b] *GFM UJI - Multiphase Fluids Group, Universitat Jaume I, Spain*

The development of thermally conductive yet electrically insulating polymer systems remains a key challenge for applications in electronics cooling and advanced manufacturing. While ceramic fillers such as alumina are widely used to enhance thermal transport in polymers, achieving high performance without compromising processability is still limited by particle dispersion, viscosity increase, and interfacial thermal resistance.

In this work, a hybrid micro–nano filler approach is explored to improve thermal conductivity in photopolymer systems designed for additive manufacturing. Alumina nanoparticles are synthesized via pulsed laser ablation in liquids (PLAL) in isopropanol, enabling the production of surfactant-free nanoparticles with clean and highly reactive surfaces. These nanoparticles are combined with commercially available micron-sized alumina to form hierarchical filler systems.

The hybrid formulations are incorporated into photopolymer resins and evaluated as model systems for vat photopolymerization (VPP). The study focuses on understanding how the addition of PLAL-derived nanoparticles influences particle packing, dispersion, and interfacial interactions within the composite. Particular attention is given to rheological behaviour, as viscosity plays a critical role in printability and layer formation. Thermal conductivity is measured in printed samples to assess the effectiveness of the hybrid filler strategy, while curing behaviour is investigated through depth-of-cure tests to evaluate the impact of fillers on light penetration and polymerization. The relationship between filler composition, processability, and thermal performance is analysed to identify optimal formulations.

This approach aims to bridge nanoscale interface engineering with practical processing constraints in additive manufacturing, providing insights into the design of thermally conductive photopolymers with balanced printability and functional performance.



Acknowledgments:

The authors would like to thank the Agencia Estatal de Investigación (AEI) for supporting this research under project number PID2023-153196OB-I00, as part of the MINIATURES project.

Generation of Polyethylene Terephthalate (PET) Nanoplastics via Pulsed Laser Ablation in Liquids and their Toxicological Effects on Chironomus riparius

Ignacio Velasco [*a], Ana Mártir-Bueno [*b*c], Mikel Sanz [* b*c], Oscar Galvez [* b*c], Mónica Morales [*a], Raquel Martín-Folgar [*a], Mónica Torres-Ruiz [*d], Esther Rebollar [* e]

[*a] Universidad Nacional de Educación a Distancia (UNED), Dpto. Física Matemática y de Fluidos, Spain.

[*b] Universidad Nacional de Educación a Distancia (UNED), Dpto. Física Interdisciplinar, Spain.

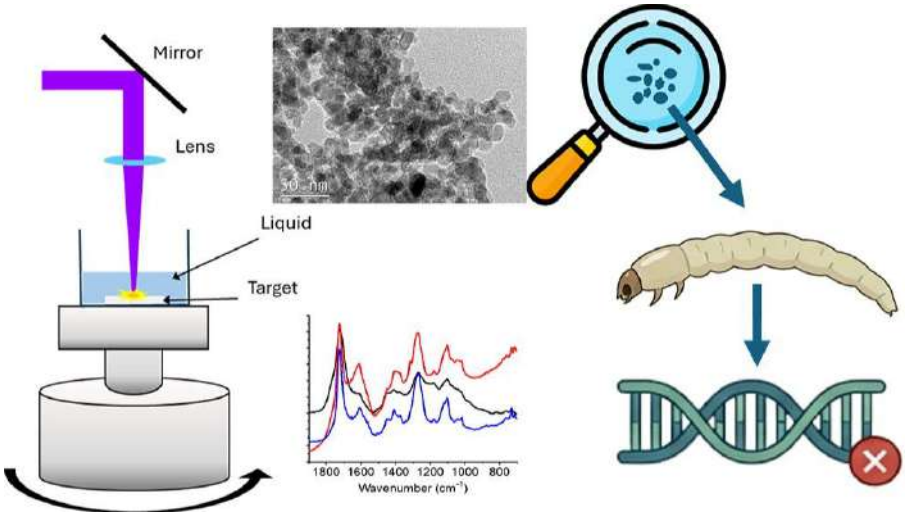
[*c] Spain. 3 NANOesMAT, UNED, Spain.

[*d] Environmental Toxicology Unit, Centro Nacional de Sanidad Ambiental (CNSA), Instituto de Salud Carlos III (ISCIII), Spain.

[*e] Instituto de Química Física Blas Cabrera, IQF-CSIC, Spain.

Aquatic environments are significantly contaminated by nanoplastics. Nanoplastics represent a substantial environmental concern, primarily because of their diminutive size, which renders them accessible to a broad spectrum of organisms, potentially inducing physical and toxicological effects. It is imperative to produce reliable analogs of PET nanoplastics to facilitate research aimed at evaluating their potential impact on various organisms [1]. In this study, we generated polyethylene terephthalate (PET) nanoparticles using pulsed laser ablation in liquids (PLAL). We tested different irradiation conditions (fluence, liquid, time, etc.) at 266 nm wavelength. The generated PET nanoplastics were thoroughly characterized to determine their size distribution, morphology, chemical composition and light absorption. Typically, we achieved a concentration of 60-70 mg/L with a log-normal size distribution centered at 12 nm. Infrared analysis indicated that the nanoplastics retained the original chemical nature of the material. Our findings are consistent with those of previous studies [2].

To assess their biological relevance, we examined the molecular effects of PET nanoplastics on the larvae of the aquatic primary consumer Chironomus riparius, focusing on transcriptional responses related to cellular stress, oxidative stress, endocrine regulation, and larval development. In summary, this study provides a reproducible mechanical approach for generating PET nanoplastics and demonstrates their potential toxicity to aquatic organisms at environmentally relevant concentrations.



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This work was supported by a grant from the Spanish Ministry of Science, Innovation, and Universities PID2023-148109OB-I00 & IMIENS-2023-002-PIC and by the Regional Government of Madrid through the project TEC MATRIX-CM (TEC-2024/TEC-85).

Plasmonic nanoparticle-assisted enhancement of laser-induced coloration on Ti–Al–V surfaces

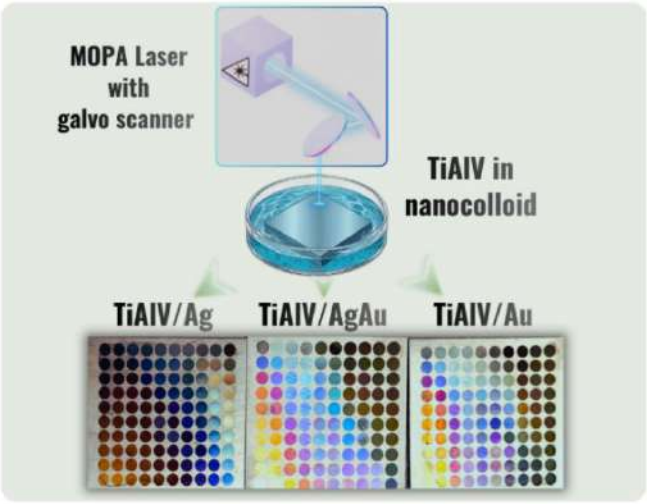
Jithin Kundalam Kadavath[*a], Carlos Doñate-Buendía [*b], Shaji Sadasivan [*a], Gladys Mínguez-Vega [*b]

[*a] Facultad de Ingeniería Mecánica y Eléctrica, Universidad Autónoma de Nuevo León, México.

[*b] Group of Optics-UJI (GROC-UJI), Institute of New Imaging Technologies (INIT), Universitat Jaume I (UJI), Spain

This work demonstrates the plasmonic nanoparticle-assisted enhancement of laser-induced coloration on Ti–Al–V surfaces. Laser-induced coloration on Ti–Al–V surfaces was investigated through the in-situ incorporation of Ag, Au, and Ag–Au bimetallic nanoparticles and compared with a reference surface processed in air. The resulting color distributions were analyzed using the CIE 1931/1976 chromaticity diagram to understand the underlying optical mechanisms. The nanoparticle-coated surfaces exhibited a significantly broadened chromaticity distribution with enhanced color spread and tunability across the diagram, extending beyond the locus formed that of air.

This expanded gamut arises from the localized surface plasmon resonance (LSPR) of Ag and Au nanoparticles and their alloyed configurations, where composition-dependent plasmonic responses enable multiple color states and control over spectral output. The synergistic plasmonic coupling in bimetallic nanoparticles enabled enhanced spectral tunability and smoother color transitions due to broadband absorption and scattering. In contrast, the reference surface displayed more discrete chromatic regions governed by thin oxide layer interference formed during laser processing in air. The comparison reveals a fundamental transition from interference-dominated coloration to plasmonic-dominated behavior, where nanoparticle composition, alloying, and surface morphology collectively control the optical response. This study highlights the potential of laser-assisted nanoparticle integration for designing tunable, stable, and application-specific structural colors on metallic substrates.



Commercial Aqueous Nanofluids: Comparison of Thermal Properties

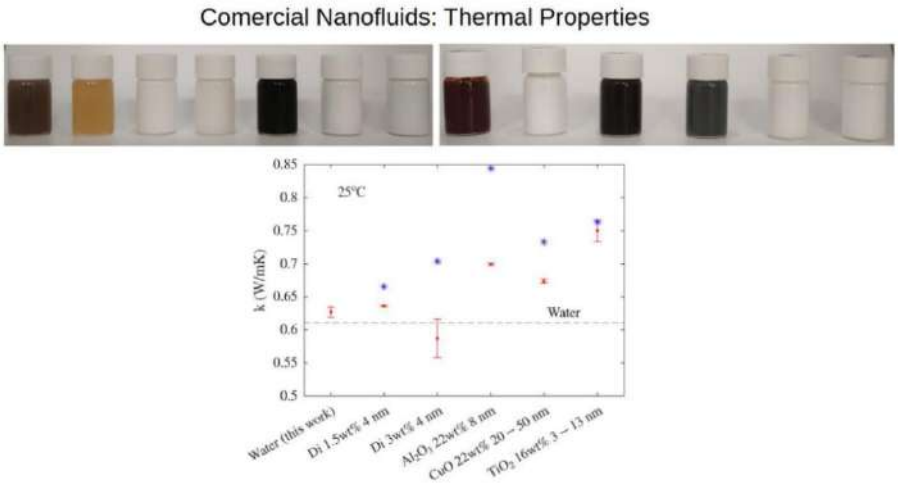
Pablo Ángel Prieto-Díaz [*a*b], Carlos Doñate-Buendía [*b], Jesús Lancis Sáez [*b], Luis Martínez León [*b], Gladys Mínguez-Vega [*b], Leonor Hernández [*a]

[*a] Department of Mechanical Engineering and Construction, University Jaume I, Spain

[*b] GROC-UJI, Institute of New Imaging Technologies (INIT), University Jaume I, Spain

Nanofluids highlight as a potential candidate for liquid heat exchange in different applications, such as electronics or engine cooling. This topic has been extensively addressed in the literature, mainly remaining at concentrations of nanoparticles <5%vol., so the nanofluid remains stable and it has relatively low viscosity. However, companies offer high-concentrated nanofluids that are claimed to be stable. Therefore, this work investigates commercial water-based nanofluids, focusing on the stability, morphology and size of particles and macro-properties such as density, thermal conductivity and viscosity. This study compares commercial nanofluids made from laser-ablation and chemical methods.

Results show that some nanofluids are completely unstable, while others show the deposition of particles over several days. Most nanofluids have larger particles than specified in the datasheets and show very different appearance and stability even for same materials, concentration and suppliers. Regarding the thermal conductivity, most of them show increases between 10 and 25% with respect to water. The incorporation of nanoparticles and possible surfactants in the base fluid produces a higher viscosity for most fluids, but some of them remain in relatively lower values. This produces an overall improvement in using these nanofluids over water, although it is limited. This research calls for a further investigation of high-concentrated nanofluids, production by laser-ablation, and their possible use in thermal applications.



Acknowledgments:

This work has been funded by Ministerio de Ciencia e Innovación with the project PID2022-142907OB-I00 funded by MCIN/AEI/10.13039/501100011033, and by "ERDF: A Way of Making Europe" and research project PID2023-1531960B-I00 funded by MCIN/AEI/10.13039/501100011033, by FEDER and UE. Funding from the Generalitat Valenciana CIPROM/2023/44, CIDEIG/2023/8 is also acknowledged.

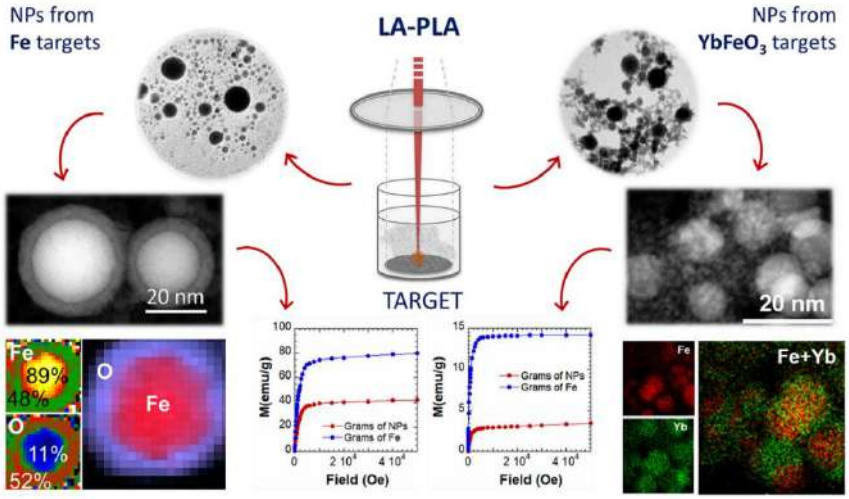
Magnetic Behaviour of Nanoparticles Obtained by Pulsed Laser Ablation in Liquids from Different Targets and Ablation Media.

Eva Natividad[*a], Ruth Lahoz[*a], José Manuel Mánuel[*b], Rocío Litrán[*b], Óscar Bomati-Miguel[*b]

[*a] *Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, EINA, Spain*

[*b] *Departamento de Física de la Materia Condensada and Institute of Research on Electron Microscopy and Materials (IMEYMAT), Universidad de Cádiz, Spain*

Liquid-Assisted Pulsed Laser Ablation (LA-PLA) is an established top-down method to produce colloidal dispersions of nanoparticles (NPs) in an eco-friendly manner. Metallic iron targets [1] are good candidates to obtain magnetic NPs. However, the ablation media governs the final iron phases formed within the NPs and, usually, NPs display a lower saturation magnetization (M_S) than that of the target. Conversely, ceramic targets are a good choice to obtain NPs that combine iron with other heavy elements as ytterbium [2], for example, for biomedical applications. These targets are usually paramagnetic at room temperature. Nonetheless, the nanoparticles produced from these targets may display a ferromagnetic contribution, whose M_S depends on the nature of the target, but also on the ablation media. In this contribution, we will show some examples [1-3] of these magnetic behaviours, determined by SQUID magnetometry, and discussed on the basis of the iron compounds found by X-ray powder diffraction and high-resolution transmission electron microscopy.



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Design, Construction, and Validation of an Open-Source Gold Nanoparticle (GNP) Concentration Tracking Device

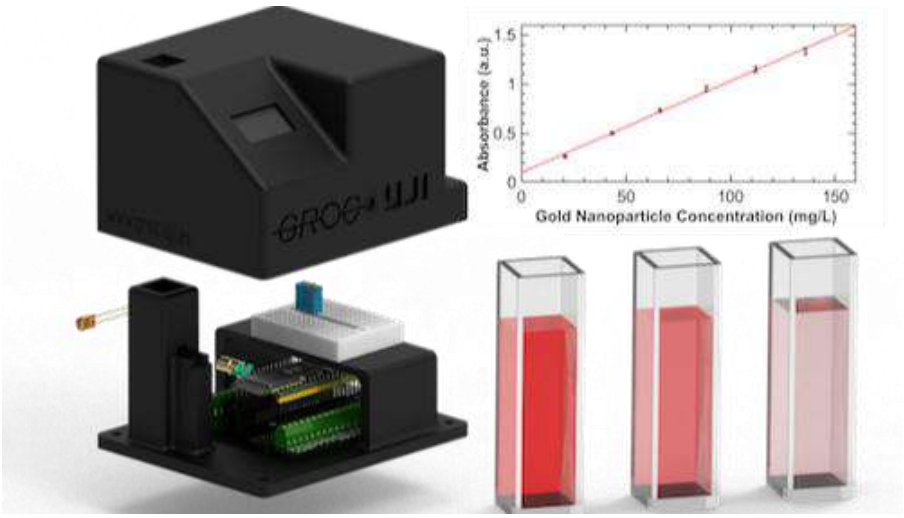
Sergio Molina-Prados [*a], Vicent Sorribes-Paulo [*a], Lucía Arrufat-Sorli [*a], Heberley Tobón-Maya [*a], Francis Rey Cortes [*a], Carlos Doñate-Buendía [*a], Gladys Mínguez-Vega [*a]

[*a] *Group of Optics-UJI (GROC-UJI), Institute of New Imaging Technologies (INIT), Universitat Jaume I (UJI), Spain.*

Gold nanoparticles (GNPs) exhibit unique optical properties governed by localized surface plasmon resonance, enabling applications in biomedicine, sensing, catalysis, and photonics. Among the various GNPs fabrication routes, pulsed laser ablation in liquids (PLAL) has gained recognition as a sustainable route for the synthesis of ligand-free, high-purity GNPs without chemical by-products [1]. Despite its advantages, real-time in situ monitoring of GNP concentration remains a relatively underexplored challenge in PLAL method.

Accurate concentration tracking during fabrication is crucial for controlling GNP stability and functionality [2]. Although UV-VIS spectrophotometers are commonly employed for GNP concentration measurement, most are costly, bulky, and difficult to integrate into fabrication workflows. In this work, we present the design, construction, and validation of a compact, open-source alternative for real-time nanoparticle tracking. The device combines a 405 nm laser, a photodiode, and an ESP32-S3 microcontroller for data acquisition and processing.

All design files, firmware, and 3D-printed casing are openly released. Validation experiments show strong agreement with conventional UV-VIS absorption, demonstrating that the proposed device can replace commercial spectrophotometers. By providing a concentration sensor that can be easily integrated in a production chain, this approach reduces the physical footprint and cost of GNPs fabrication facilities, while maintaining reliable monitoring. With a cost below 40€ and modular architecture, the system enables reproducible, accessible, and sustainable monitoring for PLAL and other nanomaterial synthesis processes.



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Optimisation of Colloidal Zero-valent Iron Nanoparticle Synthesis by Scanning LA-PLA: Effects of Surface Modification and Incubation on Productivity and Particle Properties

Ruth Lahoz[*a], Eva Natividad[*a], Aida Naghilou[*b], Wolfgang Kautek[*c], Oscar Bomatí-Miguel[*d]

[*a] *Instituto de Nanociencia y Materiales de Aragón (CSIC-Universidad de Zaragoza), Spain.*

[*b] *Department of Physical Chemistry, Universität Wien, Austria.*

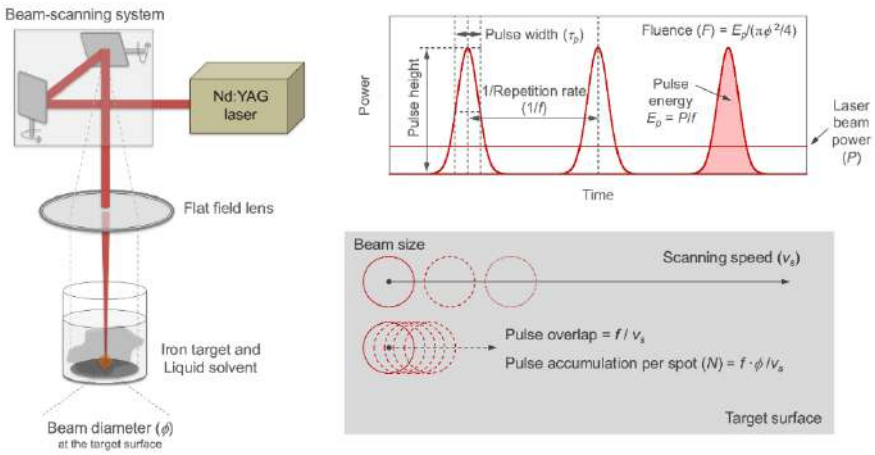
[*c] *Institut für Physikalische Chemie, Universität Wien, Austria.*

[*d] *Departamento de Física de la Materia Condensada and Institute of Research on Electron Microscopy and Materials (IMEYMAT), Universidad de Cádiz, Spain.*

This work presents a systematic study of how surface physicochemical alterations during the laser ablation of submerged massive iron disks in different solvents influence the generation of colloidal iron nanoparticles [1]. For that purpose, laser ablation thresholds and incubation coefficients across various pulse numbers per site and pulse energies in distilled water (DW) and ethanol (EtOH) were measured. Physicochemical characterisation showed higher threshold fluences for ablation in EtOH than in DW, with thresholds decreasing as pulse overlap diminished, a trend far more pronounced in EtOH. The incubation coefficient indicated a weaker incubation effect in DW.

The properties of the synthesized nanoparticles depended on the solvent and pulse overlap: laser ablation in DW produced iron oxide nanoparticles, whereas EtOH yielded core–shell iron nanoparticles. Higher pulse overlap values caused chemical alterations, leading to reduced composition homogeneity and markedly increased nanoparticle polydispersity.

Furthermore, this study aims to optimise the production of nanoscale zero-valent iron (nZVI) particles suitable for biomedical or environmental applications, using nanosecond LA-PLA on iron targets and evaluating various ablation media, laser configurations, and target scanning parameters [2].



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Correlation of Plasma and Cavitation Bubble Dynamics with Bismuth Nanostructures Produced by Pulsed Laser Ablation in Water

Cory Trout [*a], Julianne Griepenburg [*a*b], Sean O'Malley [*a*b]

[*a] *Department of Physics, Rutgers University - Camden, USA*

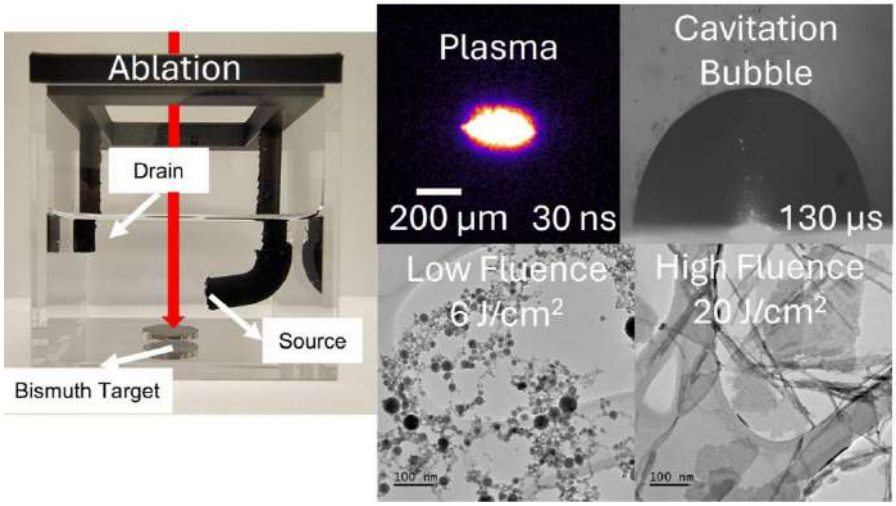
[*b] *Center for Integrative and Computational Biology, Rutgers University, USA*

Understanding the impact of chemical reactivity on nanostructures (NSs) produced by pulsed laser ablation in liquids (PLAL) is crucial for gaining control over NS composition and morphology. Previous work focused on the ablation of bismuth in water with different dissolved gas contents demonstrated that tuning the environmental conditions (i.e., degassed, ambient, or CO_2-saturated), in combination with laser fluence and aging of the colloid, allowed for the selection of a variety of NS compositions and morphologies.

For instance, low fluences (6 J/cm^2) in a degassed environment formed bismuth core/bismuth-oxide shell nanoparticles that remained relatively stable over a 24-hour period, while larger fluences (20 J/cm^2) in ambient conditions transitioned from core/shell nanoparticles to a mixture of bismuth oxide nanowires and bismuth subcarbonate nanosheets, and ultimately to a relatively homogeneous solution of bismuth oxide nanowires after 24 hours.[1] Interestingly, this drastic transition is not observed in low-fluence ablation conducted under ambient conditions, indicating the existence of a threshold fluence above which this transition takes place. While the transition from nanoparticles to higher-order structures such as wires and sheets occurs on minute-to-hour timescales, the primordial nanoparticles resulting from the initial ablation dictate which transition pathway they undergo.

The work presented here builds upon previous studies by comparing early-timescale ablation dynamics (i.e., plasma and cavitation bubble behavior) across a range of fluences (6 to 20 J/cm^2) to elucidate the origin of the transition threshold. The evolution of the plasma was imaged over the initial 100 ns of the plasma lifetime using two bandpass filters (515 nm and 650 nm ±5 nm) to gather information on the volume, morphology, and temperature of the plasma. The temperature was calculated by assuming the plasma emission follows a Planck-like distribution, whereby the temperature can be extracted from the slope of the linearized form of Planck's distribution.

Additionally, the cavitation bubble was monitored over the course of several hundred microseconds using a shadowgraphy technique to compare characteristics such as maximum volume, symmetry, and number of rebounds across the range of fluences. Correlating the plasma and cavitation bubble dynamics with the resulting nanostructure composition and morphology provides insight into the connection between fluence and chemical reactivity.



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Recycled-Waste-Derived Molybdenum Carbide Nanoparticles obtained by Pulsed Laser Ablation in Liquids for Hydrogen Evolution Reaction

Valentina Iacono [*a*b], Helena Rabelo [*c], Maria Chiara Spadaro [*a *b*c], Jordi Arbiol [*c* d], Francesco Priolo [*a* b], Francesco Ruffino [*a*b*e], Salvo Mirabella [*a*b]

[*a] *Dipartimento di Fisica e Astronomia "Ettore Majorana", Università di Catania, Italy.*

[*b] *CNR -IMM, Catania Università, Italy*

[*c] *Catalan Institute of Nanoscience and Nanotechnology - ICN2 (CSIC and BIST), Spain*

[*d] *ICREA, Spain*

[*e] *Research Unit of the University of Catania, National Interuniversity Consortium of Materials Science and Technology (INSTM-UdR of Catania), Italy*

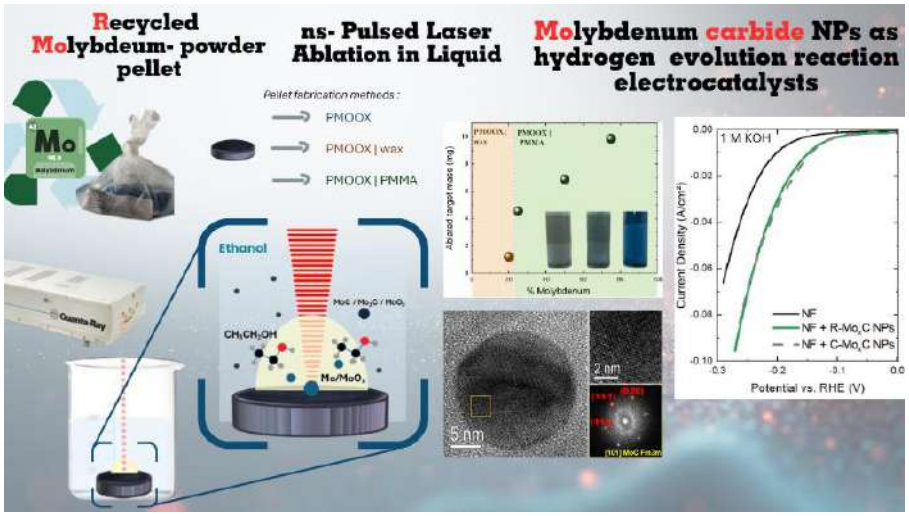
Pulsed laser synthesis is a powerful technique for nanoparticles' production that can valuable contribute toward the development of sustainable materials for green energy applications. Transition metal carbides (TMCs) have shown promising catalytic properties toward green hydrogen (H_2) production through electrochemical water splitting, competitive to those expensive and rare Pt-group metals [1,2,3].The traditional synthesis routes of molybdenum carbide materials usually involve primary raw material use, high energy consumption, use of toxic gases production, and by-products generation [4].In here, nanosecond Pulsed Laser Ablation in Liquid (PLAL) technique is shown as versatile technique for the production of nano-electrocatalysts starting from secondary raw material-based target.

In fact, Recycled Molybdenum-based powder (PMOOX) was obtained from industrial waste from an Italian company (SPIRIT SRL) and used to realise homemade pellet used as target in PLAL process. The robustness of the pellet was studied as a function of different fabrication routes, mostly focusing on the mixing of the Mo- powder with different ratios of a solid acrylic resin, PMMA (C-rich). The pellets were ablated in 8 mL of Ethanol for 5 minutes using a Nd: YAG (Quanta-ray PRO-Series, 12 ns) laser using the 1064 nm wavelength (repetition rate 10 Hz, mean power 5 W, laser fluence 8 J/cm^2). The ablation yield ranged from 4 to 10 mg depending on the ratio between Mo-powder and PMMA.

These values showed an improved productivity compared to the ablation of a commercial molybdenum target (using the same conditions) [5]. Spherical nanoparticles (NPs) (23 nm mean diameter) of hexagonal Mo_2C, cubic MoC and MoO_2 were obtained (named R-Mo_xC). The laser induces decomposition of organic molecules of the liquid medium (containing reductive gas such as CH_4 or CO) and makes carbon atoms available for carbonization of the ablated material [5]. Given the interest on Molybdenum carbide, the laser-obtained R-Mo_xC NPs were tested as electrocatalyst for alkaline hydrogen evolution reaction (HER).

The NPs loaded on nickel foam (catalyst mass 0.2 mg) exhibited significant HER activity in an aqueous 1 M KOH electrolyte, with a potential of 144 mV vs. RHE at 10 mA cm^{-2}, improving the activity toward the bare substrate. The comparison of HER performance was also done toward the C- Mo_xC NPs obtained by the ablation of a Molybdenum commercial metallic target explored in previous authors work, in which the carbide quality is higher due to the absence of oxide traces [5].

Finally, the electrocatalyst performances were compared with the existing recycled-based electrocatalyst reported in literature, highlighting one of the lower overpotential achieved in alkaline electrolyte. The results obtained aim to highlight the versatility of PLAL for recycled based - efficient electrocatalyst production, without waste generation and harmful synthesis conditions.



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Acknowledgments

European Union (Next Generation, EU) has found this work, through the MUR-PNRR project PRIN IMAGE (No. P2022KACL7). ICN2 is supported by the Severo Ochoa program from Spanish MCIN / AEI (Grant No.: CEX2021-001214-S) and is funded by the CERCA Programme / Generalitat de Catalunya. ICN2 acknowledges funding from Generalitat de Catalunya 2021SGR00457. The authors thank support from the project AMaDE (PID2023-149158OB-C43), funded by MCIN/ AEI/10.13039/501100011033/ and by "ERDF A way of making Europe", by the "European Union". Part of the present work has been performed in the framework of Universitat Autònoma de Barcelona Materials Science PhD program. ICN2 is founding member of e-DREAM.

Effects of laser irradiation on semiconductors: a theoretical-experimental study

Rafael Aparecido Ciola Amoresi [*a], Luis Antonio Cabral[*b], Juan Andrés[*a]

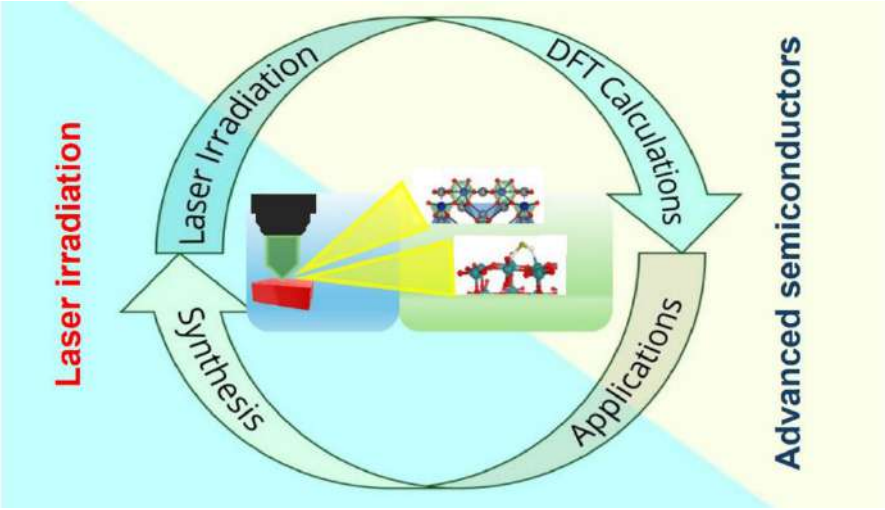
[*a] *Universitat Jaume I, Spain.*

[*b] *UNESP, São Paulo State University, Brasil.*

Light/particle interactions in the form of electromagnetic waves, especially at atomically precise scales, belong to the latest technological advances in materials processing. In particular, laser irradiation (LI) processing is a technique based on the photothermal effect induced by a focused laser, which generates a heat field confined to a desired position with high controllability [1]. This method has become a powerful and innovative tool for modifying materials at the nanoscale, inspiring fundamental research focused on potential technological applications across several areas, such as photocatalytic materials, solar cells, and sensors, among others [2].

Our joint experimental and theoretical investigation consists of the synthesis, post-synthesis under LI, advanced characterizations, DFT, and MD simulations to unveil changes in structural and electronic properties, as well as the underlying mechanisms induced by IL in generating metallic nanoparticles. A wide range of inorganic semiconductors, from binary oxides, such as ZnO, WO_3, and NiO, and complex metal oxide polymorphs, like Ag_2WO_4 and AgX polymorphs (X = Cl, Br, and I) has been selected [3,4].

Our results reveal the diffusion processes of metal cations, the amorphization of irradiated lattices, and a direct interpretation of the temporal evolution for the formation of metal nanoparticles on the surfaces of these materials. Thus, our findings provide detailed insight into structural and electronic features of metal/inorganic semiconductors, as well as viable guidance for developing new materials for multifunctional applications, such as photocatalysts, environmental remediation, and sensing.



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Acknowledgments:

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Novel closed-cycle reaction mode for totally green production of Cu1.8Se nanoparticles based on laser generated Se colloidal solution

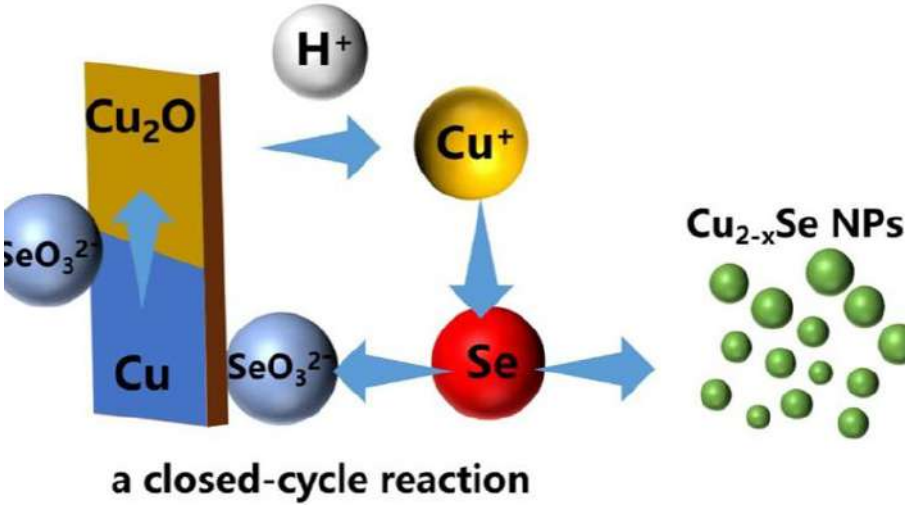
Yixing Ye [*a]

[*a] *Key Laboratory of Materials Physics and Anhui Key Laboratory of Nanomaterials and Nanotechnology, Institute of Solid State Physics, Hefei Institutes of Physical Science, Chinese Academy of Sciences, China*

Non-stoichiometric copper selenide (Cu2-xSe, x=0.18~0.25) nanomaterials have attracted extensive attentions due to their excellent thermoelectric, optoelectronic and photocatalytic performances. However, efficient production of $Cu_{2-x}Se$ nanoparticles (NPs) through a green and convenient way is still hindered by the inevitable non-environmentally friendly operations in common chemical synthesis.

Herein, we initially reveal the coexistence of seleninic acid content and elemental selenium (Se) NPs in pulsed laser generated Se colloidal solution. Consequently, we put forward firstly a closed-cycle reaction mode for totally green production of $Cu_{1.8}Se$ NPs to exclude traditional requirements of high temperature and toxic precursors by using Se colloidal solution. In such closed-cycle reaction, seleninic acid works as the initiator to oxidize copper sheet to release cuprous ions which can catalyze the disproportion of Se NPs to form SeO_3^{2-} and Se^{2-} ions and further produce $Cu_{2-x}Se$ NPs, and the by-product SeO_3^{2-} ions promote subsequent formation of cuprous from the excessive Cu sheet. In experiments, the adequate copper (Cu) sheet was simply dipped into such Se colloidal solution at 70 ℃, and then the stream of $Cu_{1.8}Se$ NPs could be produced until the exhaustion of selenium source.

The conversion rate of Se element reaches to more than 75% when the size of Se NPs in weakly acidic colloidal solution is limited between 1 and 50 nm. The laser irradiation duration shows negative correlation with the size of Se NPs and unobvious impact to the pH of the solution which both are essential to the high yield of $Cu_{1.8}Se$ NPs. Before Cu sheet is exhausted, Se colloidal solution can be successively added without influences on the product quality and the Se conversion rate. Such green methodology positively showcases a brand-new and potential strategy for mass production of $Cu_{2-x}Se$ nanomaterials.



Double Cylindrical focal lens spot size optimization for Femtosecond PLAL upscale

Sergio Molina-Prados[*a], Adrián Aupart-Acosta [a], Jesús Lancis [a], Carlos Doñate-Buendía [a], Gladys Mínguez-Vega [*a]

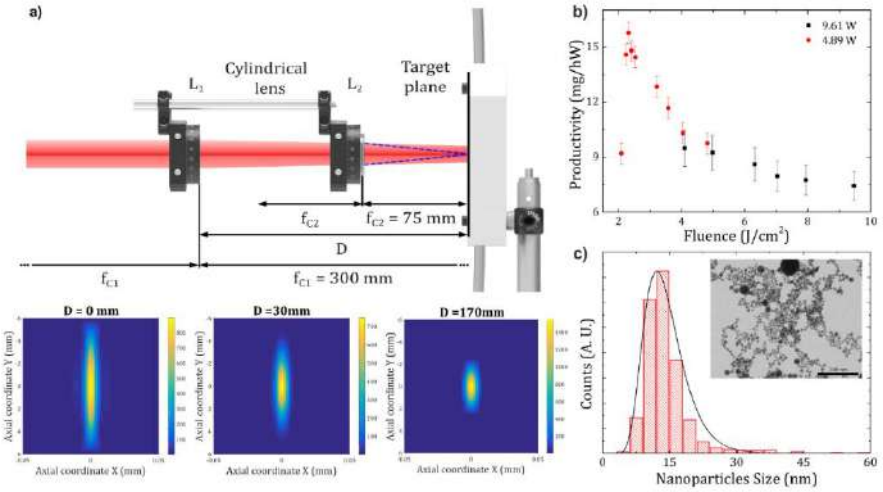
[*a] *GROC-UJI, Institut de Noves Tecnologies de la Imatge (INIT), Universitat Jaume I, Spain*

Femtosecond laser ablation in liquids enables advanced control over nanoparticle (NP) structure, but efficient energy delivery remains a key challenge that can be addressed through beam-shaping strategies [1]. While conventional PLAL setups rely on spherical focusing optics, advanced spatial beam engineering offers new degrees of freedom to control energy distribution and ablation dynamics. In this work, we explore a beam-shaping strategy based on an optical system composed of two cylindrical lenses, enabling independent control of the beam propagation along orthogonal transverse directions. Unlike single cylindrical lens configurations [2], the double cylindrical lens system allows tailored focal conditions and extended flexibility in defining the irradiation geometry at the target surface. Moreover, additive manufacturing by fused deposition modeling (FDM) was employed to fabricate custom-designed ablation chambers with precisely controlled liquid-layer geometries. This approach results in a controlled elliptical or quasi-line focus, increasing the effective ablation area and influencing NP generation mechanisms, shown in Figure 1a).

Experimentally, NPs were synthesised by PLAL using a Ti-Sapphire laser with 800 nm central wavelength, 35 fs and 5 kHz repetition rate. By adjusting the relative position between the two cylindrical lenses, the focal shape and fluence at the target were tuned without modifying the optical path length, enabling controlled energy deposition at the ablation plane. NP productivity was found to strongly depend on the delivered fluence, with maximum yields obtained at intermediate fluence values, indicating an optimal energy density regime. The highest productivity reached 77.1 ± 2.8 mg/h at 4.89 W, corresponding to a maximum efficiency of 15.8 ± 0.6 mg/hW, while total production of 88.9 ± 2.7 mg/h was achieved at 9.61 W, shown in Figure 1b). At lower fluence, ablation was inefficient, whereas excessive fluence promoted nonlinear effects in the liquid, reducing effective energy delivery.

Structural and optical characterization revealed spherical Au NPs with narrow size distribution (10–20 nm), depicted in Figure 1c), showing that the dual cylindrical lens configuration is an effective and flexible approach for optimizing laser ablation synthesis in liquids.

Figure 1: a) Optical setup composed of two cylindrical lenses used to generate an elliptical focus on the target surface. b) NP production rate as a function of laser fluence, which varies by adjusting D. c) Characterization of Au NPs synthesized using the dual cylindrical lens configuration.



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Laser-Driven Reshaping of Au@CeO2 Core–Shell Nanoparticles into Pure CeO2 Nanostructures

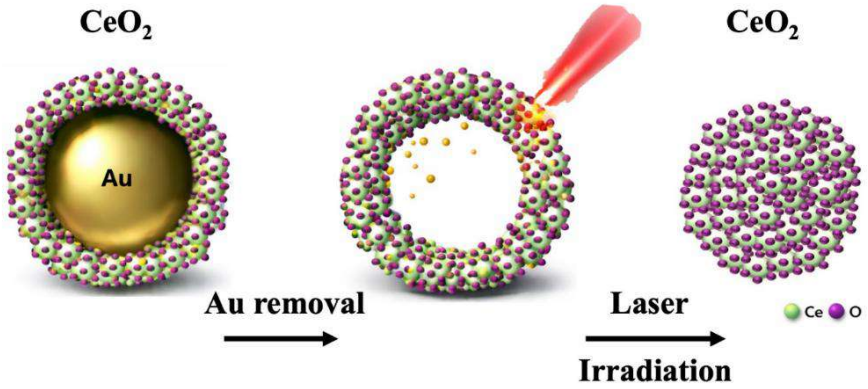
Marina T Candela[*a], Sergio Triviño-Sánchez [*a], Guillermo González-Rubio [*a]

[*a] *Departamento de Química Física, Universidad Complutense de Madrid, Spain*

Metal nanocrystals (NCs) stand out for their localized surface plasmons, which confer unique optical properties that are attractive for applications ranging from cancer therapy to high-resolution displays and optical nanosensing [1]. Core–shell metal–oxide NCs have emerged as versatile platforms for tuning light–matter interactions, where the combination of a metal core and an oxide shell enable enhanced electromagnetic fields and adjustable optical responses. These architectures provide opportunities to design nanomaterials with tailored functionalities and can also serve as templates for subsequent structural and morphological transformations.

Core-shell materials can be prepared through bottom-up colloidal synthesis routes, which allow the composition, morphology, and thickness of the shell to be modified. When subjected to pulsed laser irradiation, colloidally synthesized NCs can experience highly localized lattice heating, leading to changes in morphology, atomic distribution, structure, and optical properties. This behavior has been demonstrated, for example, for colloidal metallic Au–Ag core–shell nanorods irradiated with femtosecond pulses, where variations in laser fluence and irradiation time lead to distinct nanocrystal morphologies and degrees of alloying [2], highlighting the potential of pulsed laser–assisted approaches as a means to access colloidal nanocrystals with compositions and architectures that may be challenging to obtain through conventional synthesis routes.

In this work, we synthesize Au–CeO_2 core–shell nanostructures (e.g.: rods, spheres) in aqueous media and selectively remove the gold cores using chemical etching. The remaining ceria shells are then subjected to nanosecond pulsed laser irradiation to investigate their structural transformation and the formation of CeO_2 NCs. Changes in morphology, composition, and atomic distribution before and after laser treatment are analyzed using high-resolution transmission electron microscopy, energy-dispersive X-ray spectroscopy, and elemental mapping. Structural and optical properties are further characterized by X-ray diffraction and UV–Vis spectroscopy, respectively. These results highlight how gold-templated ceria can be reshaped by laser irradiation and demonstrate the potential of laser-assisted approaches for tuning the structure and properties of functional metal-oxide nanoparticles.



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This work has been supported by the ERC Starting Grant Time4Nano (101164205).

Laser-Induced Interfacial Alloying Enables Tunable Magnetic Heating in Zn-Doped Ferrite Core–Shell Nanoparticles

Fernando Martín [*a], Helena Gavilán [*a], Guillermo González [*a]

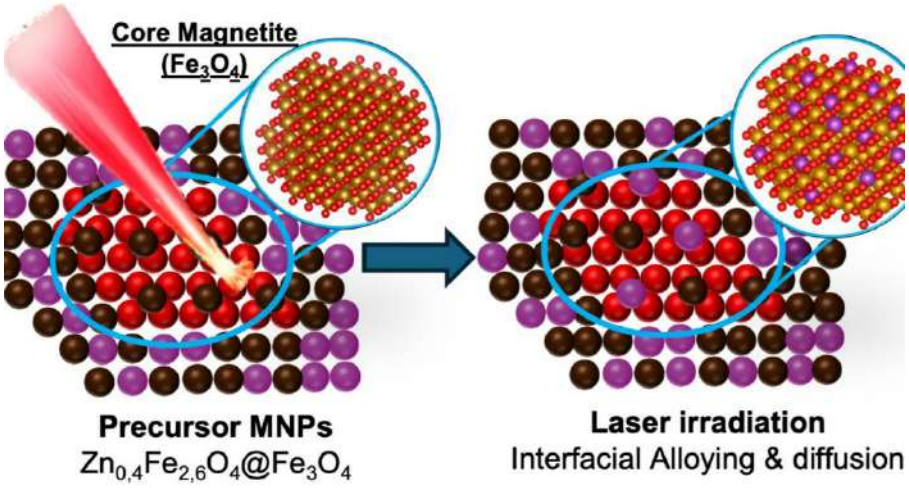
[a*] *Department of Physical Chemistry I, Complutense University of Madrid, Faculty of Chemical Sciences, Spain*

Magnetic nanoparticles (MNPs) are versatile nanomaterials whose properties strongly depend on size, morphology, composition, and interfacial structure. While colloidal synthesis enables precise control over core–shell architectures, post-synthetic strategies offer additional opportunities to tailor magnetic behavior. In this context, laser irradiation emerges as a powerful, non-contact approach to modify nanomaterials by promoting localized energy deposition and thermally driven atomic redistribution.[1]

Here, we investigate the impact of laser processing on the structural and magnetic evolution of $Zn_{0.4}Fe_{2.6}O_4$@Fe_3O_4 core–shell nanoparticles. These heterostructures, synthesized via seed-mediated thermal decomposition, serve as a well-defined platform to study how interfacial composition evolves under external energy input. Controlled laser irradiation is employed as a post-synthetic treatment to induce interfacial cation diffusion and partial alloying between the Zn-doped ferrite core and the iron oxide shell.[2] This nanoscale reorganization modifies the cation distribution and magnetic exchange interactions, leading to changes in the collective magnetic response.[3]

Structural, colloidal, and magnetic properties before and after irradiation were systematically investigated by transmission electron microscopy (TEM), dynamic light scattering (DLS), and AC hysteresis measurements under alternating magnetic fields. Particular attention was devoted to variations in magnetic heating efficiency, quantified by the specific absorption rate (SAR). Changes in SAR upon laser treatment demonstrate that laser-induced interfacial mixing and composition homogenization provide an effective route to tune magnetic energy dissipation mechanisms.[4]

Overall, these results highlight laser irradiation as a versatile post-synthetic tool to engineer magnetic properties through controlled nanoscale alloying, opening new pathways for the design of functional magnetic nanomaterials in applications requiring dynamic and tunable magnetic performance, including biomedicine, sensing, and energy-related technologies.



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This work has been supported by the ERC Starting Grant Time4Nano (101164205).

Additively Manufactured Hybrid Chamber for Laser Ablation in Air with Controlled Liquid Trapping of Nanoparticles

Garvit Sharma [*a], Ahmed Fayez [*a], Sergio Fernández Molina-Prados [*b], Jan Lino Kricke [*a], Gladys Mínguez-Vega [*b], Carlos Doñate-Buendia [*b], Bilal Gökce [*a], Silja-Katharina Rittinghaus [*a]

[*a] *Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering University of Wuppertal Gaußstr, Germany*

[*b] *GROC-UJI, Institut de Noves Tecnologies de la Imatge (INIT), Universitat Jaume I, Spain*

Pulsed laser ablation in liquids (PLAL) is a well-established technique for the synthesis of colloidal nanoparticles, offering a precursor-free route to high-purity materials [1]. In contrast, pulsed laser ablation in air (PLAA) has been reported as a highly efficient approach for nanoparticles (NPs) production, with several studies demonstrating significantly higher material removal and particle generation rates compared to PLAL [1,2]. This behavior is commonly attributed to liquid-induced effects such as cavitation bubble shielding, optical attenuation, and energy losses arising from the interactions between the laser pulse, the target material, and the surrounding liquid medium [2].

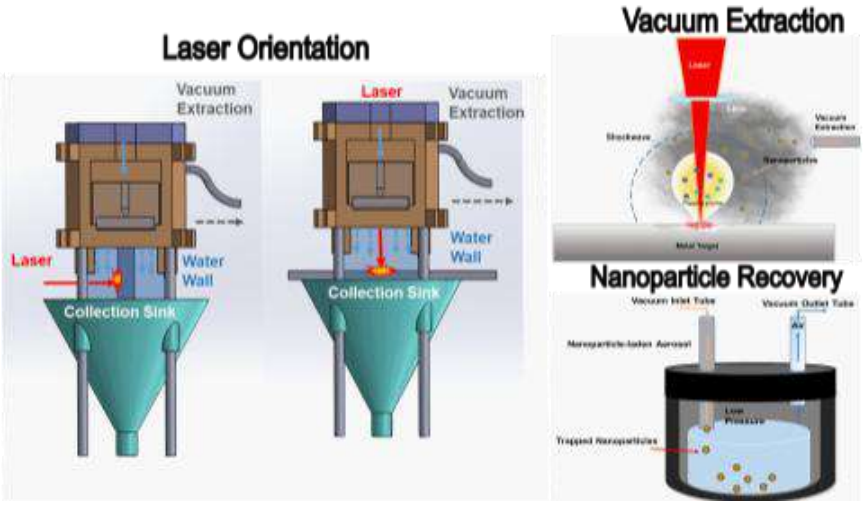
Not only does PLAA enable the direct formation of NPs from solid targets without solvent-derived species or stabilizing agents, it also allows higher production rates by bypassing these liquid-related limitations. This provides direct access to and control over gas-phase plume dynamics, effectively regulating particle formation mechanisms [3,4]. At the same time, PLAL offers clear advantages over PLAA, including improved thermal management, efficient nanoparticle trapping and transport, and inherently confined processing conditions [5].

In this study, we manufactured an ablation chamber prototype using additive manufacturing techniques to enable a regulated and reproducible Liquid-assisted PLAA workflow, combining air ablation with liquid-based capture and handling. The chamber was designed with a vacuum-assisted evacuation system as a main approach to remove laser-generated aerosol and transport NP-laden aerosol out of the ablation zone towards a liquid trapping stage, thereby limiting uncontrolled aerosol dispersion, which is a common limitation of this ablation technique [4,5].

A continuous water wall was retained as a secondary capture and safety feature, which can also provide local cooling for the system and supports direct transfer of airborne NPs into the liquid phase. Key configurations were tested using this design, including a vertical beam path (top entry) through a sealed coated glass window without any interaction with the water and another configuration set up where the beam passes through the water wall, representing a direct water-interaction mode relevant to liquid-assisted laser processing. This evaluation compared beam delivery with and without laser interaction with the water wall, while keeping the target in air, to assess effects on ablation stability and particle recovery.

Further, experiments were performed on various metal target materials including Cu, and a FeNi-based alloy. Target geometry was varied between cylindrical and planar shapes to evaluate the effect on NP yield, productivity and resulting properties.

The generated metal NPs were analyzed using UV-Vis spectroscopy, SEM, DLS and zeta potential measurements in order to correlate the processing conditions with the particle yield and resulting physicochemical characteristics. This design enables reproducible PLAA operation with improved aerosol handling and liquid-phase nanoparticle capture.



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The authors would like to thank the German Federal Ministry of Research, Technology, and Space (BMFTR) for its support within the framework of the NanoMatFutur program (FKZ 03XP0629).

Laser Ultrafast Confined Alloying of Sub-5 nm RuM (M = Cu, Rh, and Pd) Particles on Carbon Nanotubes for Hydrogen Evolution Reaction

Pengfei Li[*a], Taiping Hu[*a*b], Dongshi Zhang[*a], Ningning He[*a*b], Shuxian Wei[*a*b], Xingyu Kang[*a*b], Wei Zhang[*d], Yunyu Cai[*a], Yinxing Ye[*a], Changhao Liang[*a*b*e]

[*a] *Key Laboratory of Materials Physics and Anhui Key Laboratory of Nanomaterials and Nanotechnology, Institute of Solid-State Physics, Chinese Academy of Sciences, China.*

[*b] *Department of Materials Science and Engineering, University of Science and Technology of China, China.*

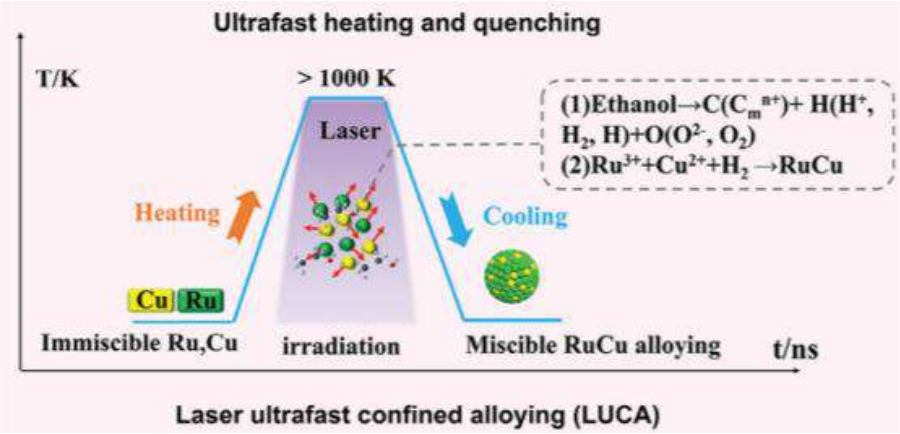
[*c] *Shanghai Key Laboratory of Materials Laser Processing and Modification, School of Materials Science and Engineering, Shanghai Jiao Tong University, China.*

[*d] *Institute for Energy Research, Jiangsu University, China.*

[*e] *Lu'an Branch, Anhui Institute of Innovation for Industrial Technology, China.*

Thermodynamic immiscibility is a challenge for intermetallic alloying of sub-5 nm Ru-based alloys, which are excellent electrochemical catalysts for water splitting. In this study, nanosecond laser ultrafast confined alloying (LUCA) is proposed to break the immiscible-to-miscible transition limit in the synthesis of carbon nanotubes (CNTs) supported sub-5 nm bimetallic RuM (M = Cu, Rh, and Pd) alloy nanoparticles (NPs). The alloying of non-noble metal Cu with varying atomic ratios of RuCu alloys is appealing owing to the low price of Cu and cost-effective synthesis for large-scale practical applications.

Benefiting from the synergistic alloying effect and resultant H/OH binding energy alteration, the $Ru_{95}Cu_5$/CNTs catalysts display excellent electrocatalytic alkaline hydrogen evolution reaction (HER) activity with an overpotential of 17 mV and Tafel slope of 28.4 mV dec^{-1} at 10 mA cm^{-2}, and high robustness over long-term 5000 cyclic voltammetry cycles. The performance is much better than LUCA-synthesized CNTs-supported $Ru_{86}Rh_{14}$, $Ru_{89}Pd_{11}$, Ru, and Cu NPs catalysts, commercial benchmark 20% Pt/C, and other mainstream Ru-based catalysts including wet chemistry-synthesized RuRh particles (overpotential of 25 mV, Tafel slope of 47.5 mVdec^{-1}) and RuCu/CNTs (overpotential of 39 mV) synthesized using the flash Joule heating method, indicating the great potential of LUCA for screening new classes of HER catalysts.



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Laser-generated Au nanoparticles enabling PEGylation in dense brush conformation persisted high stability under elevated temperature

Yunyu Cai [*a]

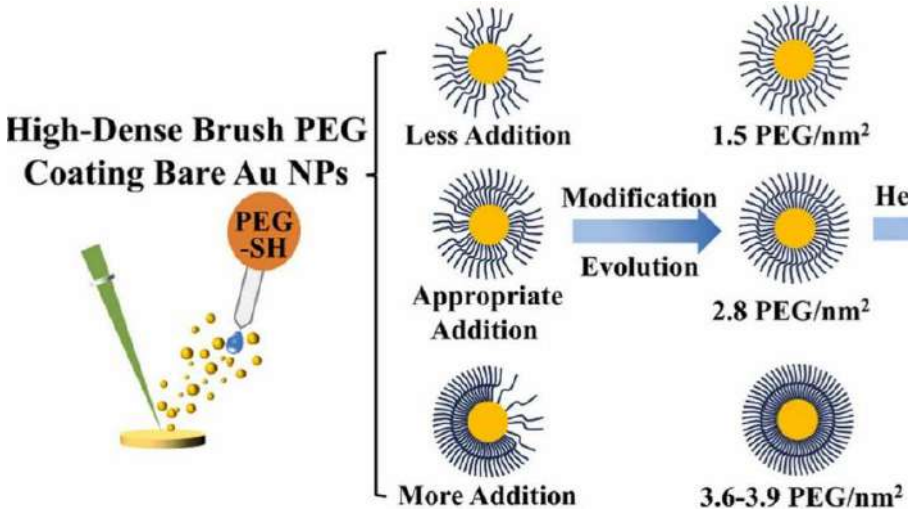
[*] [a] *Hefei Institutes of Physical Science, Chinese Academy of Sciences, China*

PEGylation from Polyethylene glycol thiol (PEG-SH) can give gold nanoparticles (Au NPs) excellent chemical stability and biosafety, however, the stability of PEGylated AuNPs in applications at elevated temperature (50 °C~100 °C) has been limited by the cleavage of Au-S bond to form disulfide bond (-S-S-). Such thermal disturbance can be effectively resisted by increasing the density of PEG-SH molecules on the surface of Au NPs to form dense brush conformation.

However, because the binding sites on the surface of Au NPs are largely occupied by chemical agents during chemical synthesis, this conformation reported in most literatures has not reached the maximum loading capacity for Au NPs. How to improve the modification density and thermal disturbance resistance is still a key point. Here, we report that Au NPs with naked surface generated by laser treatment in liquids, which can successfully achieve a high grafting density up to 3.9 PEG/nm^2 for CH_3O-PEG_{5000}-SH.

The dynamic evolution of PEG chains over time on Au NPs with varying grafting density was systematically investigated, along with their thermal stability and surface state changes at varied temperatures of 50, 75, and 100 °C. Under appropriate added amounts, PEG chains suffer from atom-binding on particle surface and rearrangement into a relatively uniform state within the first 6 h of coating.

Whereas excessive addition leads to PEG chains entanglement, uneven initial coating distribution, and complex coating process. We demonstrated that, a grafting density of 2.8 PEG/nm^2 on Au NPs not only facilitates the rapid and uniform arrangement of PEG chains but also effectively withstands heating treatment up to 100 °C without irreversible shrinkage. Our efforts provide a significant foundation for advancing the development of PEG-SH-modified Au NPs for broader biomedical applications under elevated temperature.

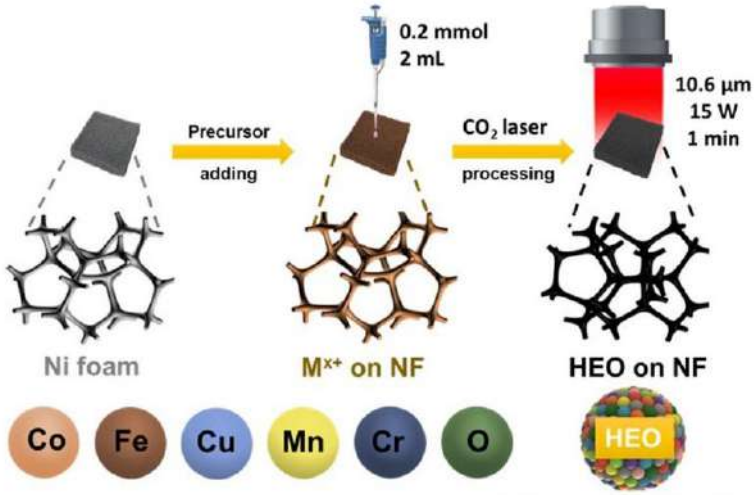


Low-Voltage Glucose Oxidation Enabled by a Laser-Synthesized High-Entropy Oxide Electrode

Gyeong-Ah Kim [*a], Theerthagiri Jayaraman [*a], Myong Yong Choi [*a]
[*a] *Gyeongsang National University, South Korean Republic*

A binder-free high-entropy oxide (HEO) electrode was directly fabricated on nickel foam via a rapid CO_2 laser process and applied to low-voltage glucose oxidation coupled with water electrolysis. The laser-assisted synthesis enables fast, scalable formation of a thin and uniform HEO layer without polymer binders, providing a large electrochemically active surface area. By tuning the electronic structure through a work-function engineering strategy, the HEO@NF electrode exhibits enhanced interfacial charge transfer and catalytic activity. As a result, a low glucose oxidation potential of 1.22 V at 10 mA cm^{-2} is achieved, along with excellent operational stability over 100 h.

Formate and glycolate are identified as the primary oxidation products, demonstrating effective biomass valorization. When integrated into a two-electrode electrolyzer, the HEO@NF||Pt/C configuration delivers hydrogen at a low cell voltage of 1.37 V, significantly reducing overall energy consumption. Combined spectroscopic characterization and density functional theory calculations reveal that Cu sites are mainly responsible for glucose oxidation, while Co sites dominate the oxygen evolution reaction. This work presents an effective and energy-efficient electrode design strategy for simultaneous biomass upgrading and hydrogen production.



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This research was supported by the Korea Basic Science Institute (National research Facilities and Equipment Center) Grant funded by the Ministry of Education (RS-2024-00434932, RS-2025-12872968, and 2019R1A6C1010042) and by the Korea government (MSIT) (PG2025039-02). The authors acknowledge financial support from the National Research Foundation of Korea (NRF) (2022R1A2C2010686, RS-2024-00443792, and RS-2025-02634080).

Femtosecond laser preparation of photothermal materials for spectral control

Zichao Jiang[*a], Dongshi Zhang[*a]

[*a] *Shanghai Jiao Tong University, China*

Spectral regulation is the decisive factor for the efficiency of photothermal conversion. An ideal absorber should achieve high absorption in the solar band (0.3–2.5 μm) to capture energy and maintain low emission in the long-wave infrared window (8–13 μm) to suppress radiative heat loss. By inducing localized surface plasmon resonance through defect engineering, the local surface plasmon resonance can compensate for radiative loss while maintaining the structural advantage of light capture, overcoming the spectral limitations of ultra-wideband absorbing materials and thus breaking through the efficiency bottleneck of traditional photothermal conversion.

This study combines femtosecond laser micro-nano processing and femtosecond laser synthesis. Through the light trapping effect of the interface micro-nano structure and by utilizing the deposition of TiO2-x with abundant oxygen vacancies to achieve the local surface plasmon resonance (LSPR) effect, selective control of the visible light to mid-infrared spectra was achieved. This research demonstrates the spectral controllability of the metal photothermal materials fabricated by femtosecond laser in the context of structural-component co-regulation, providing a new strategy for the development of high-stability and high-performance devices.

Role of Interfacial Liquid Layer for Pulsed Laser Melting in Liquid (PLML) to Reactively Fabricate Submicrometer Spherical Particles

Naoto Koshizaki [*a], Yuji Yamauchi [*a], Yoshie Ishikawa [*b]

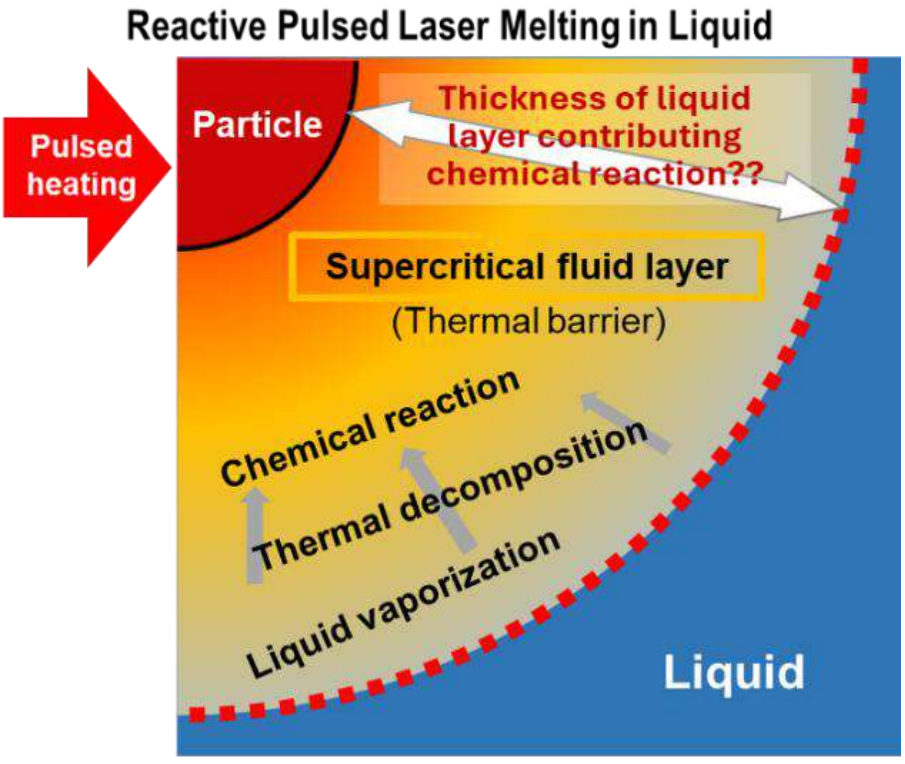
[*a] Graduate School of Engineering, Hokkaido University, Sapporo, Japan.

[*b] National Institute of Advanced Industrial Science and Technology (AIST), Japan.

Pulsed laser melting in liquid (PLML) is a method to fabricate spherical submicrometer particles (SMPs) by irradiating laser light at relatively weak fluence to the raw particles dispersed in liquid [1]. If raw particles have sufficient optical absorption, the temperature is elevated over the melting point during pulsed laser irradiation to form molten droplets and subsequently quenched to form spherical particles.

Reactive PLML processes between raw particles and surrounding liquid have also been reported for FeO/Fe SMPs from Fe_3O_4 [2] and B_4C SMPs from B [3] in organic solvents. The composition of the reduced phase gradually increased with the laser fluence. This reduction is caused by the decomposed carboneous components from ethanol facing to the high-temperature raw particles during laser irradiation.

Temperature dependence of the estimated equilibrium composition by thermodynamic calculation starting from mixture of solid Fe_3O_4 and liquid ethanol suggested that Fe would be generated more. Thus, the actual reaction will not proceed as expected probably due to the very limited amount of liquid at the interface are involved in the reaction even though the raw particles are surrounded by the fairly large amount of liquid. The thickness of interfacial liquid layer contributing to the reaction can be estimated from these results and will be compared with the calculated temperature profile at the liquid-side interface.



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Laser-Assisted Fabrication of CoNiCuPdPt High-Entropy Alloy Catalysts by Pulsed Laser Irradiation in Liquid for Nitrate Reduction

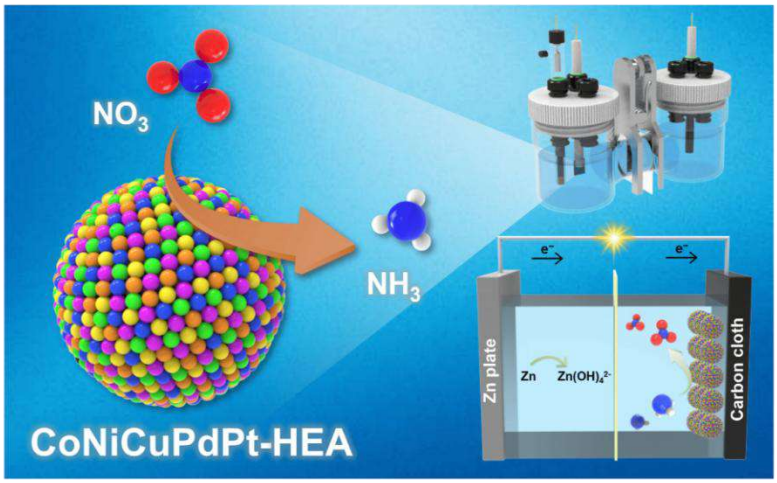
Wonji Go [*a], Myong yong Choi [* a]

[*a] *Gyeongsang National University, Republic of South Korean*

The discharge of nitrate (NO_3^-) from industrial and agricultural activities poses serious environmental and health risks due to its high toxicity, persistence, and accumulation in aquatic systems. Excessive nitrate contamination not only deteriorates water quality but also threatens ecosystems and human health. Electrochemical nitrate reduction (NO3RR) has therefore emerged as a promising and sustainable strategy for nitrate remediation, offering the additional advantage of converting nitrate into value-added ammonia (NH_3) under ambient conditions. In this study, a CoNiCuPdPt high-entropy alloy (HEA) catalyst was synthesized via a pulsed laser irradiation in liquid (PLIL) process.

This laser-based approach enables rapid, one-step, and environmentally benign catalyst fabrication without the need for high-temperature treatment, long processing times, or hazardous chemical reducing agents. The PLIL method also facilitates the formation of clean catalyst surfaces and homogeneous multi-element distributions, which are highly desirable for electrocatalytic applications. The multi-element composition of the CoNiCuPdPt HEA induces synergistic electronic modulation among constituent metals and provides a wide variety of catalytically active sites.

These features collectively enhance charge transfer efficiency and accelerate reaction kinetics during the NO3RR process. As a result, the PLIL-fabricated CoNiCuPdPt HEA exhibits excellent electrochemical stability under operating conditions and achieves efficient nitrate conversion with a high NH_3 yield. Overall, this work highlights the effectiveness of PLIL as a versatile laser-based synthesis strategy for designing advanced HEA catalysts. The results demonstrate the strong potential of PLIL-engineered HEA catalysts as a sustainable platform for nitrate remediation and value-added ammonia production, providing new opportunities for integrating laser processing techniques with electrochemical environmental applications.



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Study and characterization of the gold nanoparticle's formation mechanism by re-irradiation of linear bromide induced gold nanoparticle chains

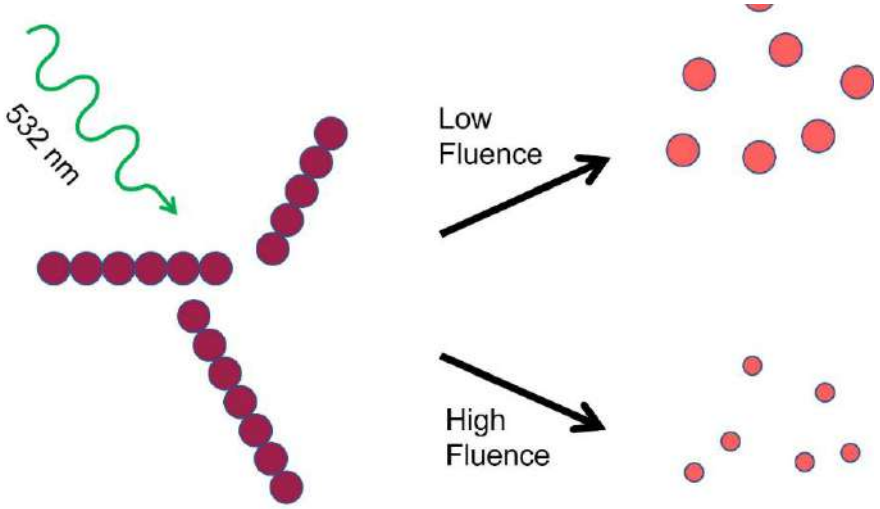
Vittorio Scardaci [*a]

[*a] University of Catania, Italy

One of the main characteristics of metal noble nanoparticles is the Localized Surface Plasmon Resonance (L.S.P.R) which is strictly dependent on the morphology and environmental factors such as refractive index of the medium or the presence of halide ion that can lead to the formation of aggregates that can disrupt the plasmon resonance properties. In this work we present the study and characterization of gold nanoparticle's formation mechanism implied in the re-irradiation of bromide induced gold nanoparticles chain.

We have studied this mechanism starting by aggregating colloidal gold nanosphere with bromide anion followed by re-irradiation at different irradiating fluencies. Through UV-Vis absorption spectra we can show, by setting laser parameters, the formation of gold nanospheres by breaking-up the aggregates without fragmenting them, because the spectral position of gold nanoparticles synthetized in this way are red-shifted than initial colloidal nanosphere but blue shifted from the halide induced aggregates. To confirm that we are not fragmentating our aggregates we have TEM images that can clearly show the morphology evolution during the whole process starting from small gold nanoparticles in colloids pre-aggregation, aggregation and after re-irradiation step and it can be seen that gold nanoparticles synthesized with this mechanism are bigger than the pre-aggregated ones.

To support our hypothesis, we have carried out some surface enhanced Raman spectra (SERS) that confirms the presence of covalent bond of bromide with gold atoms, inside the crystalline matrix, that can explain the bigger diameter of gold nanoparticles synthetized with breaking up mechanisms. So, with this study we can build up the basis to a better comprehension of the disruption and fragmentation mechanisms using as a proof the formation of gold nanoparticles by re-irradiating a bromide induced gold nanoparticles chain.



Acknowledgments:

European Union (NextGeneration EU), through the MUR-PNRR project SAMOTHRACE (ECS00000022)

Laser-synthesized Ti3C2 MXene nanoparticles for near-infrared photothermal therapy

Gleb Tikhonowski [*a], Gleb Tselikov [*a], Ivan Kazantsev [*a], Aleksey Arsenin[*a], Valentyn Volkov [*a]

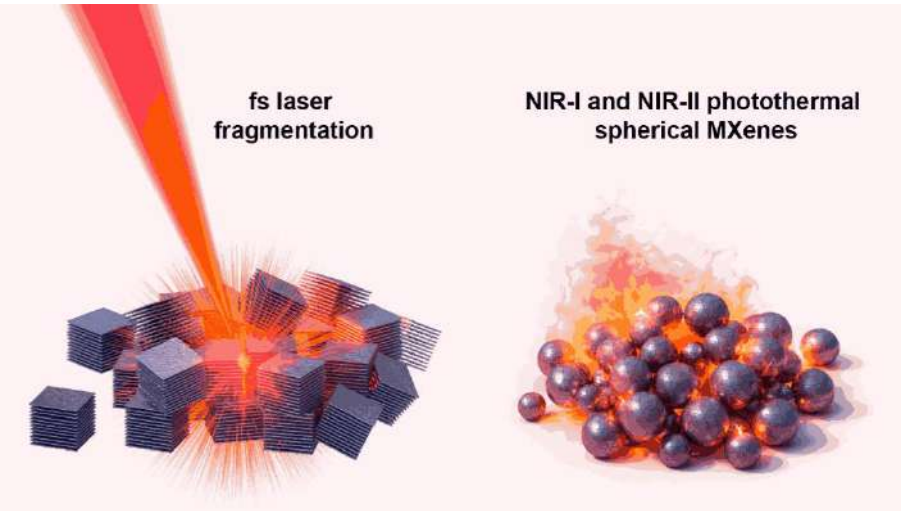
[*a] Emerging Technologies Research Center, XPANCEO, Dubai Investment Park First, United Arab Emirates

MXenes are widely known for their remarkable electronic conductivity, high mechanical strength, and tunable optical properties. These materials are highly versatile, allowing for the development of novel materials with tailored properties for a range of applications, from energy storage to environmental remediation and biomedicine.

Nanomaterials based on MXene Ti3C2 have emerged as promising candidates for biomedical applications due to their broadband absorption, biocompatibility, and ease of surface modification. However, while Ti3C2 exhibit exceptional promise for various applications, the use of these materials in form of nanoparticles (NPs) has remained a significant challenge. Until now, there has been not widely adopted, reproducible, and cost-effective method to fabricate stable colloidal solutions of MXene NPs. This limitation has hindered the full realization of MXenes' potential in modern application modalities, especially in biomedical fields where nanoparticle size, surface chemistry, and colloidal stability are crucial.

Here we present a novel approach to produce stable colloidal solutions of MXene Ti3C2 NPs via femtosecond laser fragmentation in liquid. This nearly universal method is capable of producing stable solutions of naturally charged NPs, with tunable physico-chemical properties. The femtosecond laser fragmentation in liquid provides a simple, reproducible, and scalable method for the controlled synthesis of MXene NPs, addressing a critical gap in the field.

In the context of biomedicine, laser-synthesized Ti3C2 NPs demonstrate significant potential for photothermal and photodynamic therapies. Their tunable optical properties allow for efficient absorption of near-infrared light, enabling photothermal therapy for cancer treatment. In addition, Ti3C2-based NPs exhibit catalytic activity, making them highly effective for photodynamic therapy by generating reactive oxygen species upon light activation. Furthermore, the low toxicity and high biocompatibility of Ti3C2 NPs enhance their applicability for in vivo use. These promising characteristics open up new horizons for the development of advanced therapeutic modalities in cancer treatment, as well as other biomedical fields.


fs laser
fragmentation
NIR-I and NIR-II photothermal
spherical MXenes

Effect of Laser Pulse Duration and Wavelength on MnO and SiO Nanoparticles Prepared by Laser Ablation in Ethanol

Markéta Veselá [*a], Gladys Mínguez-Vega [*b], Carlos Doñate-Buendía [*b], Tomáš Křenek [*a *c]

[*a] *Department of Materials and Engineering Metallurgy, University of West Bohemia, Czech Republic*

[*b] *Group of Optics-UJI (GROC-UJI), Institute of New Imaging Technologies (INIT), Universitat Jaume I (UJI), Spain*

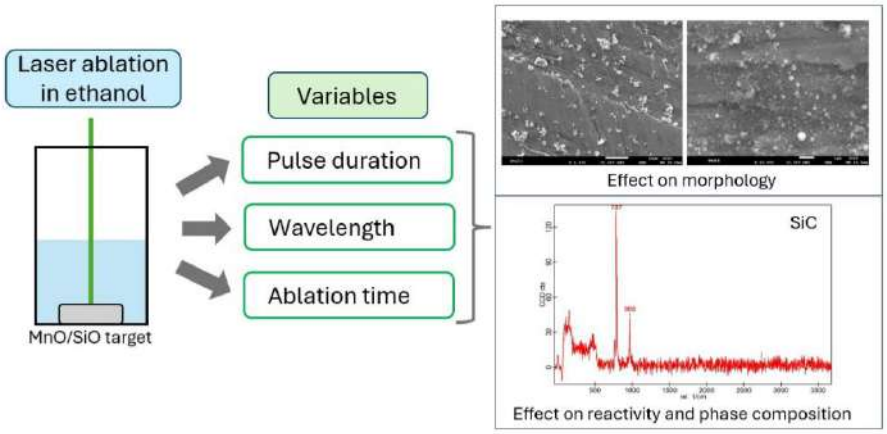
[*c] *New Technologies-Research Center, University of West Bohemia, Czech Republic*

Laser ablation in liquid (LAL) is a versatile and environmentally friendly technique for the synthesis of surfactant-free colloidal nanoparticles, whose properties can be tailored by adjusting laser parameters. Laser parameters such as pulse duration and wavelength significantly influence the ablation mechanism, plasma dynamics, and laser–matter interaction, and consequently affect particle properties such as size, morphology, and zeta potential. However, due to the complex interactions between material and the surrounding liquid, no universal trends can be established, and each material–solvent system must be studied individually.

In this work, the influence of laser pulse duration, wavelength, and ablation time on the formation of manganese monoxide (MnO) and silicon monoxide (SiO) colloids produced in ethanol was systematically investigated. Laser ablation was performed using pulse durations of 291 fs, 1 ps, and 10 ps at wavelengths of 518 nm and 1035 nm, with ablation times of 10, 30, and 60 minutes.

The synthesized colloids were characterized using dynamic and electrophoretic light scattering (DLS, ELS), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and Raman spectroscopy. The results show that both pulse duration and wavelength strongly affect the properties of the produced nanoparticles. Longer pulse duration (10 ps) led to the formation of larger particles, while MnO colloids exhibited the highest zeta potential under these conditions. Ablation at 1 ps resulted in a predominance of spherical particles for both MnO- and SiO-derived colloids, whereas ablation at 518 nm favored spherical morphologies particularly in MnO.

Raman spectroscopy further revealed laser-induced chemical reactions in the liquid environment, including the formation of silicon carbide in SiO colloids and manganese carbonate in MnO colloids. Despite these observations, no single trend was valid across all systems, highlighting the complexity of laser-driven nanoparticle formation in liquids.


Laser ablation in ethanol
MnO/SiO target
Variables
Pulse duration
Wavelength
Ablation time
Effect on morphology
SiC
Effect on reactivity and phase composition

LAL-Induced Formation of CuS and ZnS Nanoparticles for Antibacterial Applications: Impact of the Liquid Environment on Reactive Interactions

Martin Holzman [*a], Tomáš Křenek [*a], Věra Jandová [*c], Veronika Vavruňková [*b]

[*a] *Department of Materials and Engineering Metallurgy, University of West Bohemia, Czech Republic*

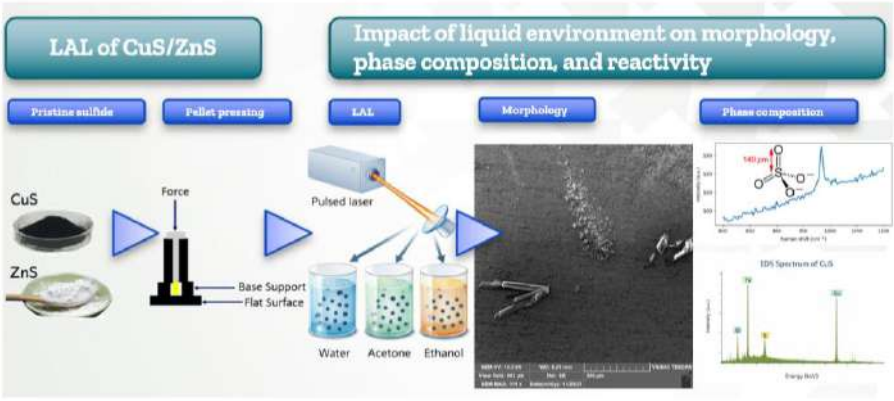
[*b] *New Technologies-Research Center, University of West Bohemia, Czech Republic*

[*c] *Institute of Chemical Process Fundamentals, Czech Academy of Sciences, Czech Republic*

The growing presence of antibiotic-resistant bacteria poses a significant global health threat, creating an urgent need for new antibacterial substances based on materials with chemical stability, low toxicity, sufficient efficacy, and high cost-effectiveness. In this context, the study explores an alternative approach in the fight against bacteria. Motivated by current scientific knowledge, the topic of this study is the origin, formation, and properties of nanostructures based on sulfides of commonly occurring transition metals, specifically CuS and ZnS. Solid targets of CuS, ZnS, and their mixed pellets were used for nanoparticle synthesis.

Nanostructures were prepared by pulsed laser ablation in liquids (LAL), allowing direct comparison between individual sulfide systems and their mixed compositions. In addition to mixed solid targets, colloidal solutions of CuS and ZnS nanoparticles were also prepared separately and subsequently combined, enabling the study of interactions between independently synthesized nanostructures. The LAL process was carried out in three different liquid environments: deionized water, acetone, and ethanol, allowing the investigation of the influence of the surrounding medium on nanoparticle formation and surface chemistry. The comprehensive characterization was performed using SEM/EDX and Raman spectroscopy.

Particular attention is paid to Raman spectroscopy, which reveals different behaviour depending on the selected sulfide and liquid environment. For CuS, LAL in deionized water leads to the formation of sulfate (SO_4^{2-}) vibrational modes, whereas LAL in ethanol does not induce significant spectral changes compared to the pristine CuS powder and Cu–acetylacetonate species are observed in acetone, suggesting interactions between the ablated material and the organic solvent. In contrast, LAL of ZnS in both ethanol and deionized water leads to the formation of partially oxidized ZnS nanoparticles. Mixed CuS-ZnS systems in various liquids, as well as reactive interactions between pre-prepared CuS and ZnS species, were examined. These findings provide insight into the influence of synthesis conditions and material composition on the structural and chemical properties of transition-metal sulfide nanoparticles and their mixtures.


LAL of CuS/ZnS
Impact of liquid environment on morphology, phase composition, and reactivity
Pristine sulfide
Pellet pressing
LAL
Morphology
Phase composition
CuS
ZnS
Force
Base Support
Flat Surface
Pulsed laser
Water
Acetone
Ethanol

Formation of different FeS phase via laser ablation in liquids for solar-light photocatalytic wastewater cleaning

Lukáš Vála[*a], Tomáš Křenek[*a], Rostislav Medlín[*b], Martin Koštejn[*b], Petr Mikysek[*c], Veronika Vavruňková [*b]

[*a] *University of West Bohemia, Department of Materials and Engineering Metallurgy, Czech Republic*
[*b] *University of West Bohemia, Research Centre New Technologies, Czech Republic*
[*c] *Institute of Geology of the Czech Academy of Sciences, Czech Republic*

The search for sustainable and economically viable technologies for the removal of organic contaminants from wastewater continues to drive the development of novel catalytic materials. Among emerging green synthesis methods, laser ablation in liquids (LAL) has attracted increasing attention due to its chemical-free nature and its ability to generate functional nanomaterials with unique structural features.

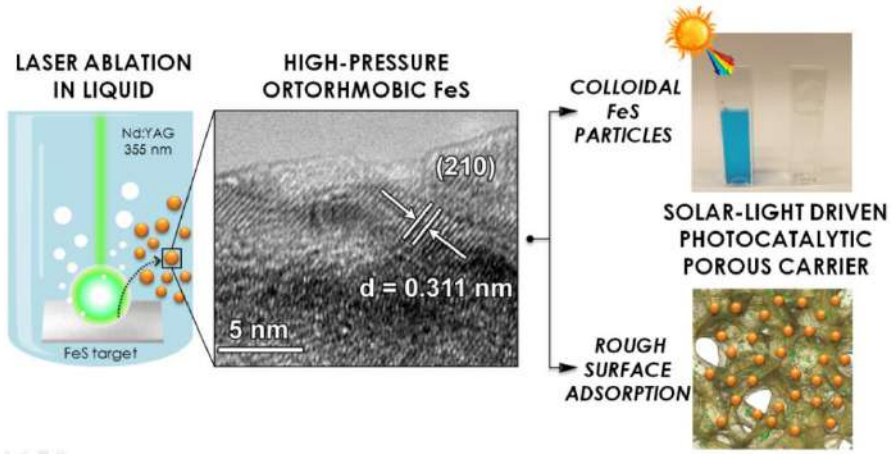
In the present study, pulsed laser ablation of iron sulfide (FeS) in water and ethanol was employed to investigate how the surrounding liquid medium governs nanoparticle formation, phase evolution, and photocatalytic performance. Colloidal particles produced by LAL were first analyzed in situ using Dynamic Light Scattering and zeta potential measurements. Ablation in deionized water yielded FeS-based particles with characteristic sizes around 180 nm, which rapidly formed micron-scale aggregates, consistent with a low electrostatic stabilization (zeta potential ~ +9 mV).

In contrast, ethanol-based ablation resulted in well-dispersed colloids with an average particle size of approximately 215 nm and a highly negative zeta potential (~ −40 mV), indicating markedly improved colloidal stability. Post-ablation characterization after solvent removal revealed pronounced differences in particle morphology and composition. Scanning electron microscopy showed spherical particles spanning from tens of nanometers to several micrometers in both systems, accompanied by distinct secondary morphologies: needle-like structures in water-derived samples and lamellar or sheet-like features in ethanol-derived particles.

Energy-dispersive X-ray spectroscopy confirmed sulfur-deficient compositions, with significantly higher Fe/S atomic ratios for particles formed in water compared to those obtained in ethanol. Structural analyses using Raman spectroscopy, X-ray photoelectron spectroscopy, electron diffraction, and high-resolution transmission electron microscopy demonstrated that LAL induces substantial phase transformations that strongly depend on the liquid environment. Water-assisted ablation led to the formation of orthorhombic high-pressure FeS together with iron oxide phases (magnetite and maghemite), whereas ethanol favored the stabilization of hexagonal FeS with minor magnetite content.

The observation of orthorhombic FeS is particularly noteworthy, as it represents the first report of a high-pressure polymorph of a binary compound generated solely by laser ablation in liquids, without the application of external pressure or electric fields.

The photocatalytic potential of the LAL-synthesized materials was assessed through methylene blue degradation under solar irradiation. Colloids containing high-pressure FeS exhibited significantly enhanced photocatalytic activity compared to those dominated by hexagonal FeS. To overcome aggregation-related limitations inherent to colloidal catalysts, LAL-generated nanoparticles were subsequently immobilized onto porous ceramic substrates via spontaneous adsorption from the colloidal phase. The resulting functionalized carriers demonstrated improved solar-driven photocatalytic efficiency, underscoring laser ablation in liquids as a versatile platform not only for nanoparticle synthesis but also for direct surface functionalization relevant to wastewater treatment applications.



Acknowledgments

SGS-2021-030 - Development of new materials, application of modern methods of their processing, ecological production, welding, and testing.

Laser-Ablative Synthesis of van der Waals Nanoparticles with Tunable Size, Composition and Optical Properties

Gleb Tselikov[*a], Ivan Kazantsev [*a], Gleb Tikhonowski[*a], Georgy Ermolaev [*a], Aleksey Arsenin[*a], Valentyn Volkov [*a]

[*a] Emerging Technologies Research Center, XPANCEO, Dubai, United Arab Emirates

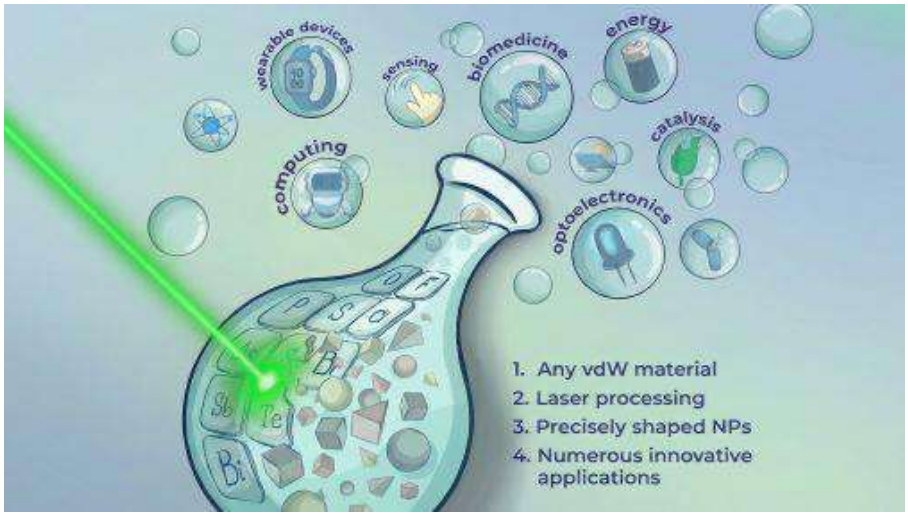
Two-dimensional (2D) van der Waals (vdW) materials, including transition metal dichalcogenides (TMDCs) and MXenes have emerged as a cornerstone for next-generation nanophotonic and optoelectronic devices due to their extraordinary electronic and optical characteristics [1]. However, the wider adoption of these materials is often hindered by the limitations of traditional nanostructuring techniques, which are typically material-specific and involve complex lithographic processes [2].

In this work, we present a universal and high-throughput approach for the fabrication of colloidal vdW nanoparticles (NPs) using femtosecond laser ablation and fragmentation in liquids (PLAL/PLFL) [3]. Our method enables the synthesis of nanostructures from a diverse library of over 50 different vdW precursors while maintaining their crystalline integrity. We demonstrate precise control over the morphology and size of the resulting NPs, ranging from nanospheres and nanocubes to fullerene-like and pyramidal structures.

A key advantage of our laser-based platform is the ability to finely tune the NP dimensions. We report the synthesis of TMDC nanospheres with diameters selectively adjustable from 5 to 250 nm [4]. By combining laser treatment with auxiliary ultrasonic processing, we further extend this control to the quantum-sized regime, producing both 2D and 3D vdW quantum dots with tunable, excitation-dependent photoluminescence [5, 6].

Beyond geometric control, we demonstrate the ability to manipulate the chemical composition and oxidation state of the nanoparticles. Specifically, by adjusting the laser irradiation parameters, we achieved a controlled transformation of MoS_2 into sub-stoichiometric molybdenum oxides MoO_{3-x}, which allows for the continuous tuning of the dielectric response and a significant enhancement of photothermal efficiency [7].

The functional potential of these laser-synthesized vdW NPs is showcased through their application in Surface-Enhanced Raman Scattering (SERS). We show that WSe_2 NPs produced via LFL provide a SERS signal enhancement an order of magnitude higher than that of bulk flakes, offering a promising platform for sensitive, plasmon-free molecular sensing [8]. Our findings establish laser-ablative synthesis as a versatile and powerful tool for engineering functional vdW nanostructures with tailored properties for advanced nanophotonics, sensing, and theranostics.



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Pulsed Laser Processing of Spinel Thin Films in Liquids: Effects on Iron Doping, Surface Cobalt Oxide, and Oxygen Evolution Activity

Dana Schellenburg[*a], Stephan Barcikowski[*a], Shivam Shukla[*b], Alejandro Esteban Perez Mendoza[*b], Lithin Madayan Banatheth[*b], Carl Hendric Scharf[*c], Nils Hartmann[*d], Olaf Magnussen[*c], Ulrich Hagemann[*d], Corina Andronescu[*b], Sven Reichenberger[*a]

[a*] *Technical Chemistry I, Center for Nanointegration Duisburg-Essen (CENIDE), University Duisburg-Essen, Germany*

[*b] *Chemical Technology III, Center for Nanointegration Duisburg-Essen (CENIDE), University Duisburg-Essen, Germany*

[*c] *Institute of Experimental and Applied Physics, Kiel University, Germany*

[d*] *ICAN, University Duisburg-Essen, Germany*

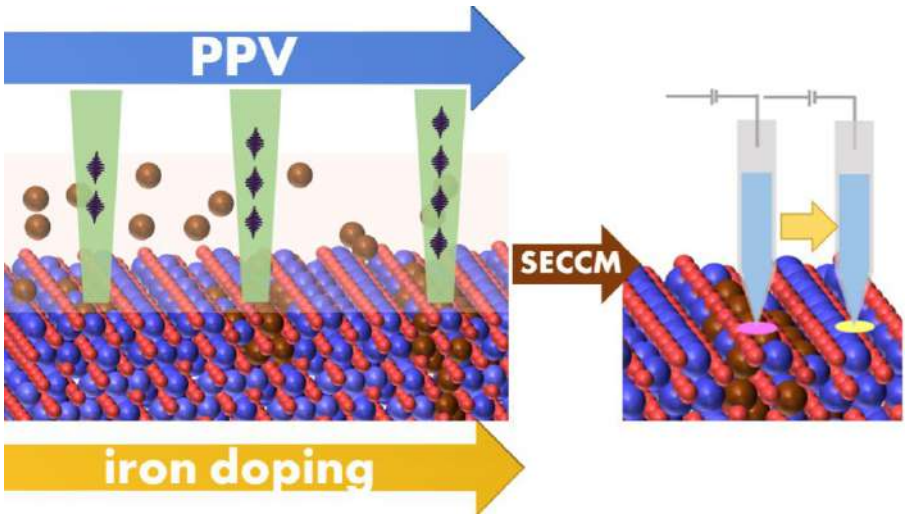
Cobalt oxide spinels such as Co_3O_4 are widely investigated as promising oxygen evolution reaction (OER) electrocatalysts because cobalt is comparatively earth-abundant and exhibits good stability under alkaline conditions. In particular, Co_3O_4 provides a rich landscape of catalytically relevant surface sites.[1]

Thin-film model electrodes based on Co_3O_4 enable well-defined crystallographic orientation, composition, and thickness, which is essential to systematically correlate specific facets or near-surface structures with OER performance. Conventional bulk doping approaches, however, often blur these structure–activity relationships because dopants are distributed throughout the entire particle, owing to different facets, making it difficult to disentangle effects arising from surface versus bulk modifications.[2–7]

Laser-induced iron doping of epitaxial Co_3O_4 thin films is presented as a pulse-controlled strategy for surface-near defect doping for the OER.[8–10] In aqueous $FeCl_3$ solution, the PUDEL (Pulsed Laser Defect Engineering in Liquids) method enables defined incorporation of Fe cations into Co_3O_4 (111) thin films with single-pulse precision.[10,11] Spatially resolved laser pulses yield arrays with 2-4 pulses that are examined via SECCM, TOF-SIMS, and XPS to elucidate the relationship between pulse number, doping profile, and local OER activity.

TOF-SIMS depth profiling shows that Fe penetration depth increases with pulse number, while XPS confirms that laser processing redistributes Fe from the outermost layers into deeper regions of the film. SECCM activity maps at the edges of laser-modified spots reveal a pronounced increase in local OER current density compared to untreated reference regions, with a pronounced activity maximum at intermediate pulse numbers (2-3 pulses), whereas higher pulse numbers lead to decreased activity.

The combined electrochemical and spectroscopic analysis demonstrates that finely tuned, surface-near Fe doping rather than maximum total Fe content is key to optimizing the OER performance of Co_3O_4 thin films. These results establish PUDEL on thin films as a precise, spatially localized platform to probe process–structure–activity relationships in spinel electrocatalysts and to generate model, facet-specific modified catalyst surfaces for future operando studies.



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Acknowledgments

D. S. and S. S. contributed equally to this work. The authors also gratefully acknowledge the Deutsche Forschungsgemeinschaft (DFG) for its financial support under project 388390466 – TRR247 (sub-projects C5, A2 (C.A. and S. S.) and B10). The authors further thank Steffen Franzka (University of Duisburg-Essen, ICAN) for the conducting reflected microscope images andAFM film thickness measurements for the study and to Tobias Bochmann (University of Duisburg-Essen) for SEM measurements.

L.M.B., C.A., and A.P.M. acknowledge financial support from the Bundesministerium für Forschung, Technologie und Raumfahrt (BMBF) in the framework of the PrometH2eusproject (03HY105F). The Interdisciplinary Center for Analytics on the Nanoscale (ICAN) of the University of Duisburg-Essen is gratefully acknowledged (DFG-funded core facility, Resources reference: RI_00313, Project Nos.

233512597 and 324659309). C.A. acknowledges Prof. Patrick Unwin from the University of Warwick for providing the initial SECCM control software (WEC-SPM). Open access funding enabled and organized by Projekt DEAL.

Asymmetric double pulse strategies for optimization of nanoparticle generation by Pulsed Laser Ablation in Liquids

Rémi Bérard[*a], Abdel Rahman Altakroury[*b], Oleksandr Gatsa[*a], Zongwen Fu[*b], Bilal Gökce[*b], Alexander V. Bulgakov[*a]

[*a] *FZU - Institute of Physics of the Czech Academy of Sciences, Czech Republic*

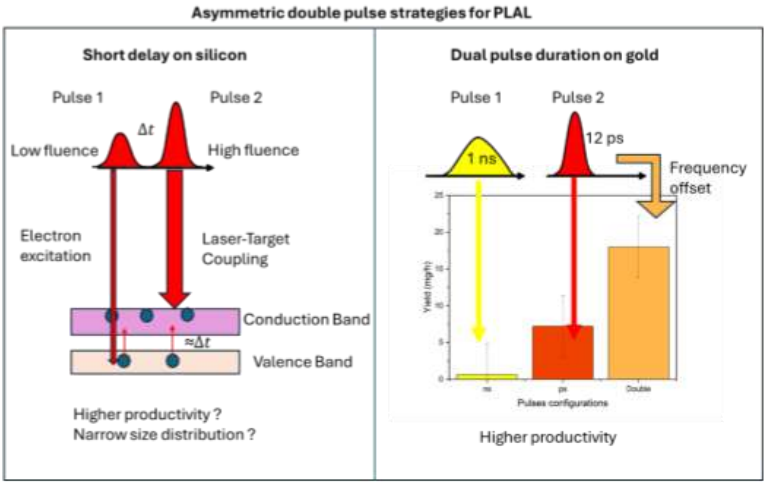
[*b] *Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering, Germany*

Previous studies on double-pulse (DP) laser ablation, surface nanostructuring, or pump-probe analysis have demonstrated that temporally separated pulses provide control over the mechanisms governing the material removal under pulsed laser ablation in liquids (PLAL) and in air. A DP strategy can enhance laser-target coupling, resulting in higher productivity or induce plasma and nanoparticle (NP) (re)processing that refines the size distribution of the NPs. Most investigations of (NP synthesis have been focused on the mid-to-long delay regime when NP reprocessing occurs within the plasma plume or cavitation bubble [1,2].

In this work, we explore the potential of short-delay or asymmetric double-pulse strategies to selectively deposit energy at specific stages of the PLAL process. We present several ongoing experimental approaches emphasizing experimental design choices and their impact on the PLAL process.

First, we investigate DP-PLAL on silicon targets using short delays (3 ps – 100 ps). The objective is to promote valence electrons to the conductive band with the first pulse and thus enhance the coupling with the second pulse. The fluence ratio between pulses is adjusted in such a way that the first pulse is set below the ablation threshold to provide the right amount of energy for electron mobility, while the second pulse is used for ablation. We hypothesize an increase in productivity and a narrowing of the nanoparticle size distribution, which will be discussed.

Second, we present preliminary results on gold nanoparticle synthesis by combining two IR pulses of essentially different durations, nanosecond (1 ns) and picosecond (12 ps) ones. To overcome the absence of precise delay control between the two laser sources, slightly detuned repetition rates (2 MHz and 1.99999 MHz) were employed, enabling statistical sampling over a broad delay range and consequential reproducibility between experiments. The nanosecond pulse fluence was adjusted just below the ablation threshold to preheat the target. Our preliminary results showed an increase in productivity by a factor of 2 to 3 compared to the total ablated material of both individual pulses.



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Acknowledgments

R. Bérard acknowledges support from the Rayleihlab project, Co-funded by the European Union (Physics for Future – Grant Agreement No. 101081515), Institute of Physics of Czech Academy of Sciences, and Czech Academy of Sciences

O. Gatsa and A. V. Bulgakov acknowledge support from the European Regional Development Fund and the State Budget of the Czech Republic (project SENDISO No. CZ.02.01.01/00/22_008/0004596).

Precursor Chemical Incompatibility Mitigation in Laser-Induced Reduction for Expanding the Library of Alloy Nanoparticles

Rikuto Kuroda [*a], Shinichi Fukuda [*a], Takahiro Nakamura [*a]

[*a] *Illuminus Inc, Japan*

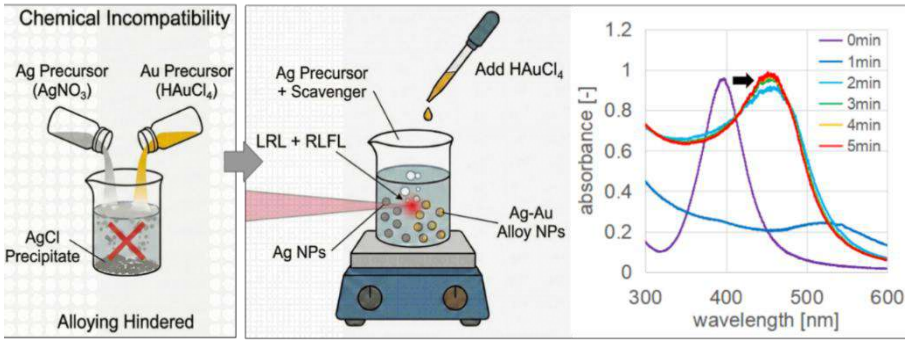
We demonstrate formation of metal and alloy nanoparticles (NPs) by laser-induced reduction (LRL), which is a clean and versatile technique without the need for chemical reducing agents. Active species such as hydrogen radicals, hydroxyl radicals, and solvated electrons are produced by decomposition of solvent molecules by high-intensity laser irradiation in solution. Among them, solvated electrons act as a strong reducing agent for metallic ions, resulting in formation of NPs. A significant advantage of this non-equilibrium reaction environment is the formation of solid-solution alloy NPs from various element combinations that are immiscible under thermal equilibrium, enabling the creation of high-performance nanomaterials through a green process with low environmental impact.

Despite this potential, the practical applicability of LRL is often limited by chemical incompatibility between precursor salts. A representative example is the Ag-Au system. Although the formation of solid-solution alloy NPs by LRL is theoretically possible, the presence of chloride ions in the gold precursor (HAuCl4) leads to the spontaneous precipitation of water-insoluble AgCl when mixed with AgNO3 as the typical silver precursor, hindering the alloy formation process by LRL. Previous studies have reported on the formation of Ag-Au alloy NPs utilized silver perchlorate (AgClO4) or phase-transfer techniques. However, as the demand for alloy NPs expands, a more universal process is required to overcome these chemical constraints for diverse alloy synthesis.

In this study, we selected a fabrication strategy that integrates our established femtosecond (fs) laser-induced LRL technology with reactive laser fragmentation in liquid (RLFL). Our prior work demonstrated that the efficiency of NPs formation could be improved by addition of a scavenger for hydroxyl radicals, which behave as oxidizing agents and inhibit the reduction reaction. By combining this with the RLFL framework—where a NP dispersion was used as the starting target—we aim to provide a universal platform for alloy NP synthesis.

As a proof of concept, Ag-Au NPs were synthesized as a representative system exhibiting chemical incompatibility. First, colloidal Ag NPs were fabricated via fs-LRL. Subsequently, HAuCl4 was added to the dispersion, followed by secondary laser irradiation.

Real-time UV-visible absorption spectra showed an absorption peak at 400 nm originated from localized-surface plasmon resonance (LSPR) for the Ag NPs, which shifted to approximately 460 nm after a few minutes of laser irradiation. This peak position, located between the LSPR peaks of pure Ag (400 nm) and pure Au (520 nm), suggests the formation of solid-solution Ag-Au alloy NPs while maintaining the enhanced fabrication efficiency achieved by radical scavengers. This integrated approach enables the formation of alloy NPs with various compositions and provides a versatile technique capable of meeting the diverse demands for a wider variety of alloy NPs.



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Acknowledgments

This presentation is based on results obtained from a project subsidized by the New Energy and Industrial Technology Development Organization (NEDO), JAPAN.

Combinations of beam splitting and donut-beam shaping for advancing the laser synthesis of nanoparticles in liquids

Rémi Bérard[*a], Abdel Rahman Altakroury[*b], Oleksandr Gatsa [*a], Zongwen Fu [*b], Bilal Gökce [*b], Alexander V. Bulgakov[* a]

[*a] FZU - Institute of Physics of the Czech Academy of Sciences, Czech Republic

[*b] Chair of Materials Science and Additive Manufacturing, School of Mechanical Engineering and Safety Engineering, Germany

Since the development of the pulsed laser ablation in liquids (PLAL) technique for nanoparticle (NP) synthesis, a special emphasis has been put on increasing productivity and on the quality control of the produced NPs (size, shape, composition). Recently, the introduction of diffractive optical elements (DOE) for beam splitting has demonstrated a significant increase in productivity [1,2]. It is also recently shown that shaping a conventional Gaussian laser beam into a donut beam is promising for improving the NP shape and narrowing their size distribution [3].

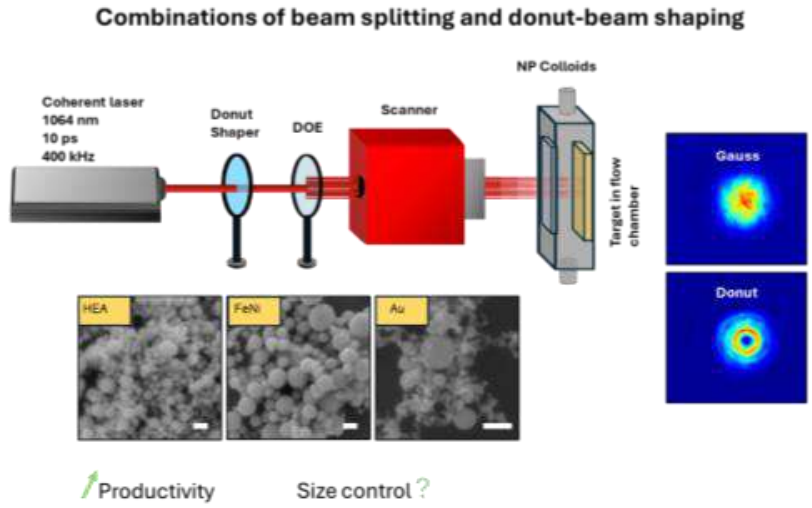
In this work, we explore whether the advantages of these two optical routes can be combined in a single PLAL process. We investigate how the use of DOE-based multi-beam ablation with donut-shaped sub-beams affects the NP yield and size. This combined approach is not a trivial superposition; it allows us to probe the interplay between the multi-beam fluence optimization and size control by donut beams.

Experiments were performed using a 1064 nm Nd: YAG laser (10 ps pulse duration, up to 120 W output power) operating at a fixed repetition rate of 400 kHz with a scanner system. Three target materials were investigated: metal gold, FeNi alloy, and high entropy alloy (HEA). The targets were ablated into a water flow chamber by Gaussian and donut-shaped beams split into either 4 or 11 sub-beams. A wide range of irradiation conditions was explored with the laser fluence in the individual sub-beam ranging from 0.3 to 10 J/cm^2. The Gaussian and donut-shaped beams were compared in terms of both equal fluence and pulse energy in a sub-beam. In addition, the multi-beam PLAL was compared with the conventional single-beam PLAL.

We obtained an extensive dataset correlating the NP yields and size distributions with the beam shape and number of pulses. The results validate that the — single donut-beam PLAL generally reduces the size and narrows the distribution compared to the single Gaussian-beam PLAL, specifically for alloy targets. However, in the case of gold, the results tend to reverse when fluence is optimal for productivity. This indicates that tuning the NP size distribution using donut beams may result in a reduction of productivity, which further motivates the use of a multiple-beam approach.

In addition, it is found that, at high productivities, an additional mechanism of the NP size reduction, laser-induced fragmentation, is likely involved during multi-beam PLAL due to the specific geometry of the DOE-produced spots and flow chamber.

In conclusion, we show that different beam shaping strategies, beam splitting and donut shaping, can be selectively optimized and combined to achieve concomitant nanoparticle size control and higher productivity.



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R. Bérard acknowledges support from the Rayleihlab project, Co-funded by the European Union (Physics for Future – Grant Agreement No. 101081515), Institute of Physics of Czech Academy of Sciences, and Czech Academy of Sciences

O. Gatsa and A. V. Bulgakov acknowledge support from the European Regional Development Fund and the State Budget of the Czech Republic (project SENDISO No. CZ.02.01.01/00/22_008/0004596).

Extinction cross-section of laser-generated plasma during laser fragmentation of gold nanoparticles

Prahlad Kumar Baruah [*a*b], Thaïs Favier [*a], Mehdi Fawaz [*a], Thierry Biben [*a], Samy Merabia [*a], David Amans [*a]

[*a] *Université Claude Bernard Lyon, CNRS, Institut Lumière Matière, France*

[*b] *Department of Physics, Pandit Deendayal Energy University, India*

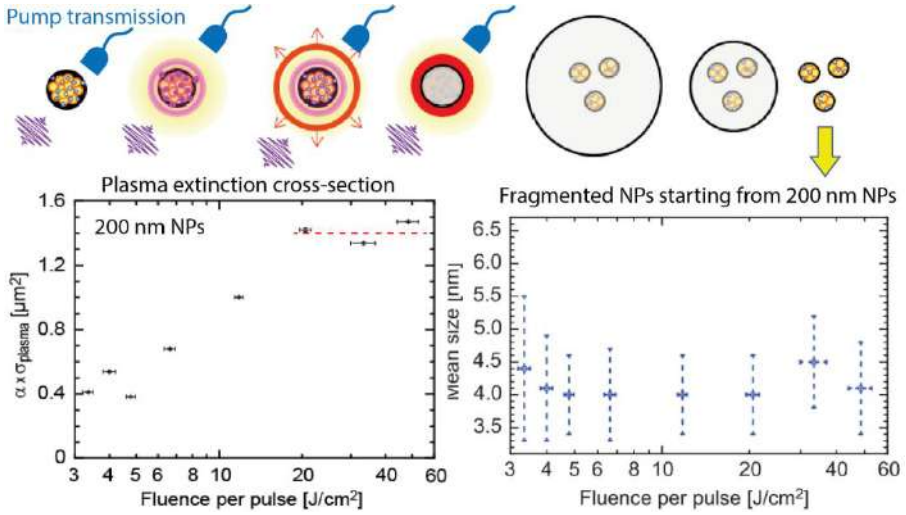
Laser fragmentation in liquids has gained interest in laser synthesis because it enables the production of sharp, monomodal size distributions [1] and is increasingly used as a strategy combined with photochemistry to form alloys, including high-entropy alloys [2]. In laser fragmentation, the laser-generated plasma remains poorly characterized, despite being a potential source of reactive oxygen species (ROS) and solvated electrons, that can trigger chemical reactions.

In this study, we focus on the fragmentation mechanisms induced by nanosecond laser pulses. We aim to characterize the extinction cross-section of the laser-generated plasma formed during the fragmentation of gold nanoparticles. A specific feature of nanosecond-pulse excitation is that the characteristic time for plasma formation is shorter than the pulse duration, leading the nascent plasma to absorb part of the incident laser energy. However, the contribution of this plasma to the overall energy balance remains poorly characterized, despite plasma screening being a well-established issue in laser ablation in liquids.

We developed an experimental setup and a model to evaluate the extinction cross-section of laser-generated plasma following the fragmentation of gold nanoparticles, using pristine particles with diameters of 20, 50, 100, and 200 nm. During fragmentation experiment with the third harmonics of a Nd:YAG source (355nm, 5ns), by measuring the time dependence of the transmitted pulse energy into the colloidal solution, we can follow the time evolution of the fragmentation events. After complete fragmentation of the pristine particles, the size distribution of the resulting particles reveals a monodisperse population, with a mean size of 4 nm (standard deviation < 1 nm), independent of the applied fluence over the range from a few J/cm^2 to 50 J/cm^2, but also of the particle size in the pristine solution.

The monodisperse distribution indicates that the fragmentation process is a single-step event [3]. As the solution is continuously composed of two particle populations, namely pristine particles and fragmented particles, it is therefore possible to deduce, from the temporal evolution of the pump attenuation into the colloid solution during fragmentation, the contribution of the plasma to pump extinction. It appears that the extinction cross-section of the laser-generated plasma is much larger than the absorption cross-section of the particles in the pristine solution, confirming that a significant portion of the pulse energy is absorbed by the plasma when using nanosecond sources for laser ablation or fragmentation in liquids.

From our modeling, we can also characterize a time evolution of the fragmentation probability, i.e., an increase in fragmentation probability (decrease of the fragmentation threshold) as the solution is continuously illuminated. We interpret this as the accumulation of "defects" in the illuminated particles without them undergoing fragmentation.



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Acknowledgments

This work has benefited from financial support from the ANR through the CASTEX project (ANR project # 21-CE30-0027).

Continuous synthesis of nanoparticles using laser ablation in liquids with a target extrusion system

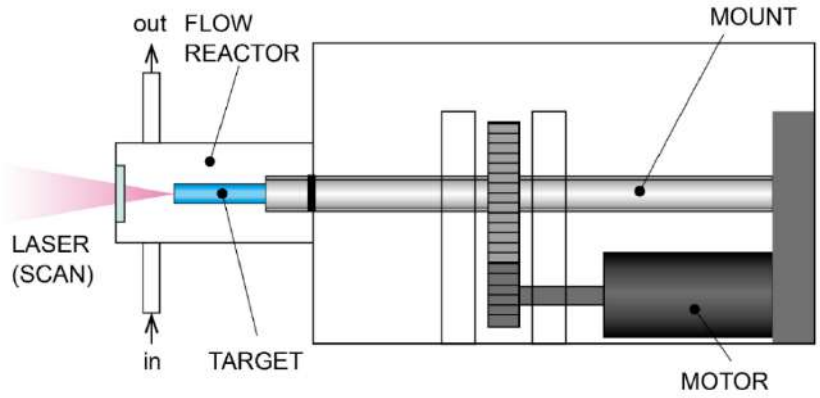
Takahiro Nakamura [*a], Fukuda Shinichi [*a], Rikuto Kuroda[*a]

[*a] *Illuminus Inc, Japan*

Laser Ablation in Liquid (LAL) is known as a simple and clean nanoparticle (NP) synthesis method capable of producing NPs by irradiating a target material placed in solution with pulsed laser light at a certain laser fluence condition. In recent years, numerous studies have reported for mass production with various techniques, such as flow system and high-speed laser scanning on the target surface, aiming for the practical application of NPs synthesized by the method. In this study, aiming to realize efficient and continuous NP synthesis using the LAL, we attempted to develop a focus-controllable NP synthesis system employing a target extrusion system with a rod-shaped target material.

A 10-mm diameter rod-shaped copper was mounted and positioned with its end face within a flow cell and used as a target. A solution was flowed through the flow cell at a certain flow rate while laser light (wavelength 1064 nm, pulse width 100 ns, repetition rate 60 kHz) was irradiated onto the target surface through a focusing lens. The target position was moved using an external gear connected to the mount, altering the position under multiple different conditions relative to the laser focal point. This allowed for changing the laser fluence conditions on the target surface. The laser beam was scanned across the target surface at 1,000 mm/s using a galvanometer scanner.

The relationship between laser fluence and NP synthesis efficiency was clarified by precisely controlling the laser fluence on the target surface using the LAL with a target extrusion system. Furthermore, this system enabled continuous NPs synthesis by maintaining optimal laser fluence conditions for NP synthesis. This was achieved by pushing the target material according to the etching rate on the target surface. Additionally, since a narrow laser scanning range is sufficient, large target materials are not required for mass production enabling system miniaturization. We will discuss in detail the results of the NP synthesis achieved using the developed system in the presentation.



Acknowledgments

This presentation is based on results obtained from a project subsidized by the New Energy and Industrial Technology Development Organization (NEDO), JAPAN.

High Power Ultraviolet Laser Microparticle Fragmentation Enabling Scalable Silver Nanoparticle Synthesis for Advanced Magnetic Materials

Nadine Stratmann[*a], Christoph Reifenrath[*a], Gaurav Kanu[*b], Niklas Brendt [*b], Sabrina Disch [*b], Stephan Barcikowski [*a], Anna Rosa Ziefuss [* a]

[*a] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE) University of Duisburg-Essen, Germany*

[*b] *Faculty of Inorganic Chemistry and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany*

Permanent magnets are essential in electric power generation, electromobility, and robotics, yet their reliance on critical rare-earth elements such as neodymium poses persistent economic and supply chain challenges. Silver nanoparticles have emerged as powerful additives for Nd-Fe-B-based feedstocks in laser powder bed fusion, where their incorporation enhances thermal conductivity in the melt pool and stabilizes grain boundaries, thereby promoting improved densification and refined microstructures during solidification. These microstructural effects translate into increased as-built part density and coercivity, creating opportunities to reduce the overall rare-earth content in high-performance permanent magnets. [1,2]

The scalable supply of such functional nano-additives therefore represents a particularly attractive showcase for high-throughput nanoparticle generation via laser processing in liquids, combining chemically clean synthesis with continuous operation. Within this framework, microparticle laser fragmentation in liquids (MP-LFL) is a key concept, as it employs inexpensive microparticle feedstocks, avoids solid target exchange, and is compatible for scalable nanomanufacturing.

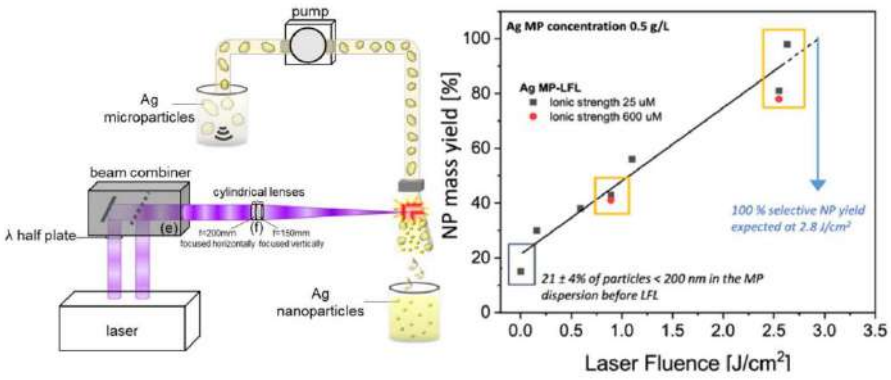
Depending on the laser pulse duration, MP-LFL operates in fundamentally different interaction regimes. In the ultrashort-pulsed regime, i.e., femtosecond and picosecond MP-LFL, stress confinement leads predominantly to photomechanical fragmentation pathways such as spallation, pressure focusing, and shock-induced fracture. Although these mechanisms are well understood, the near-surface energy deposition typically limits single-pulse mass conversion to nanoparticle yields of approximatly 10%. [3]

Here, we contrast this regime with nanosecond MP-LFL, which follows a fundamentally different, photothermally dominated energy coupling pathway. During nanosecond excitation, thermal diffusion extends well beyond the optical penetration depth and can approach the characteristic microparticle dimension. Careful matching of the thermal diffusion length to the particle diameter, therefore, enables the conversion of surface-confined absorption into deep volumetric heating, suppressing photomechanical spallation in favor of heating melting and most likely phase explosion.

Implementing this regime with two synchronized 343 nm, 200 W beams in a flat liquid jet geometry enables steady-state fragmentation of silver microparticles under single-pulse-per-volume conditions into nanoparticles with high mass yield and throughputs of up to 10 g h^{-1}. The resulting particle size distribution is shifted into the sub-10 nm range at elevated fluence, and small-angle X-ray scattering together with analytical disc centrifugation reveal

no intermediate colloidal fragments, consistent with nearly complete (80-98%) volumetric fragmentation.[4]

Collectively, these findings establish ultraviolet nanosecond MP-LFL as a next-generation platform for continuous silver nanoparticle synthesis with record mass conversion and tunable colloids, providing a technologically relevant basis for nanomodified permanent magnet 3D printing feedstocks and other high-performance materials systems.



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Acknowledgments

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One Pot Laser Preparation of Bismuth Oxobromoiodide Solid Solutions for Photocatalysis

Sergei Kulinich [*a], Vyacheslav Korepanov [*b], Valery Svetlichnyi [*b]

[*a] *Tokai University, Japan*

[*b] *Tomsk State University, Rusia*

Laser-based methods offer tremendous potential for synthesizing a wide range of nanostructures suitable for photocatalytic applications [1]. Considerable progress has been achieved in the targeted design of complex oxide nanoparticles (NPs) using various reactive laser-synthesis approaches [2, 3]. Photocatalytic technologies, in turn, play a key role in addressing sustainability challenges, including environmental remediation, processing of bio-renewable feedstocks, CO_2 recycling, and hydrogen fuel production [4].

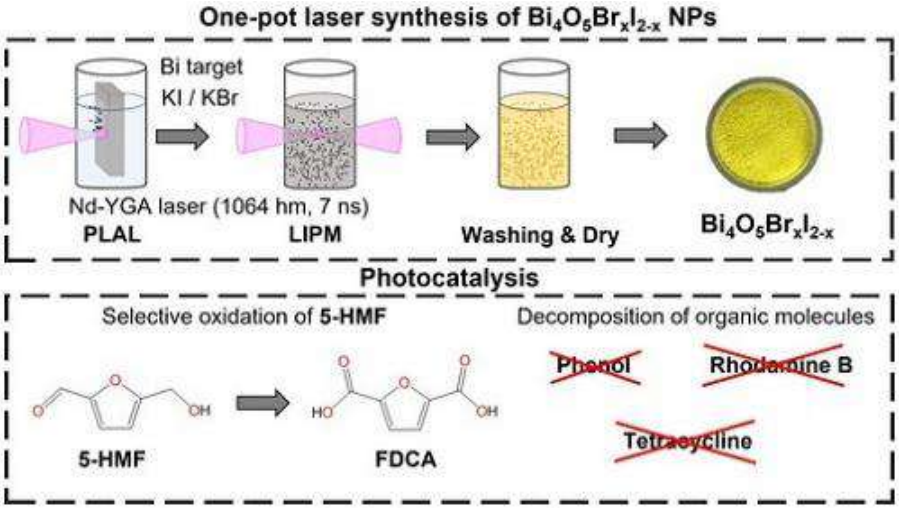
Among other photocatalysts studied, layered bismuth-based materials, particularly bismuth oxohalides with the general formula $Bi_xO_yX_z$ (BiOX), where X = Br or I, have attracted significant attention. BiOX NPs containing multiple halogens (solid solutions), as well as heterostructures derived from them, show strong promise for diverse photocatalytic applications. Traditionally, layered bismuth oxohalides $Bi_4O_5X_2$ with a monoclinic structure are synthesized via solvothermal methods that require bases, organic solvents, and surfactants. In contrast, the one-pot laser synthesis method we recently developed and reported in work [5] enables the formation of $Bi_4O_5X_2$ directly from neutral aqueous solutions of potassium halides, without the need for additional precursors or annealing.

In this work, we used a one-pot laser synthesis approach to produce solid solutions of bismuth oxobromoiodide. The technique involves two stages. First, pulsed laser ablation (PLAL) of a metallic Bi target is carried out using focused Nd:YAG laser radiation (λ = 1064 nm, τ = 7 ns, f = 20 Hz) in aqueous KBr and KI solutions with varying KBr/KI ratios. After ablation, the target is removed from the reactor, and the resulting colloidal solution is irradiated with a tightly focused beam from the same laser in the so-called “plasma mode” (LIPM), in which plasma is generated at the focal point within the solution. This irradiation promotes efficient interaction between Bi NPs and halide ions, OH groups, and dissolved oxygen, leading to the formation of bismuth oxohalide NPs. The obtained NPs were then rinsed with distilled water to remove residual potassium halides and dried in air.

The resulting powders were characterized using XRD, SEM, UV–Vis, and Raman spectroscopy. The NPs were found to form solid-solution bismuth oxobromoiodides $Bi_4O_5Br_xI_{2-x}$ with a monoclinic structure, consistent with the structures of their single-halogen analogs $Bi_4O_5Br_2$ and $Bi_4O_5I_2$. By varying the KI/KBr ratio in the reaction medium during synthesis, we obtained samples with different Br/I compositions. In particular, the solid-solution structures $Bi_4O_5Br_{1.3}I_{0.7}$ and $Bi_4O_5Br_{0.7}I_{1.3}$ were confirmed.

The photocatalytic properties of the prepared nanomaterials were evaluated in the degradation of several organic ecotoxicants, phenol, rhodamine B (RhB), and tetracycline (TC), as well as in the selective oxidation of 5-hydroxymethylfurfural (5-HMF). All synthesized NPs exhibited excellent photocatalytic activity. Compared with the single-halogen $Bi_4O_5Br_2$ and $Bi_4O_5I_2$ NPs, the solid-solution compositions $Bi_4O_5Br_{1.3}I_{0.7}$ and

$Bi_4O_5Br_{0.7}I_{1.3}$ showed higher selectivity in the oxidation of 5-HMF to 2,5-furandicarboxylic acid (FDCA), along with improved efficiency in degrading the tested organic ecotoxicants.



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Acknowledgments

This study was supported by the Tomsk State University Development Programme (Priority-2030).

Laser ablation on custom NiFe powder targets and water splitting application

Cristiano Lo Pò [*a], Stefano Boscarino [*a], Francesco Ruffino [*a]
[*a] *University of Catania, Italy*

Hydrogen (HER) and Oxygen (OER) evolution reactions play a fundamental role in the field of green sustainability, because they are key reactions for water electrolysis. The high-performance materials are platinum for HER, while iridium and ruthenium oxides for OER. These materials are precious and rare, thus in economic terms, earth abundant and non-pollutant electrocatalysts should be employed. A valuable alternative is provided by nickel-iron alloy and compounds since the synergistic effects of these two transition metals is proved and observed in literature.

This work takes place in a framework of circular economy and environmentally friendly perspective since the starting point are iron and nickel commercial powder, with the future purpose of using industrial recycled powder. The novelty of this work consists in uniformly mixing and reduced in size commercial powders with ball milling and then pressed. Pulsed Laser Ablation in Liquid (PLAL) is used to obtain bimetallic oxide nanoparticles in an innovative and easy way, starting from two different powders ablated in water, without relying on a complex chemical procedure.

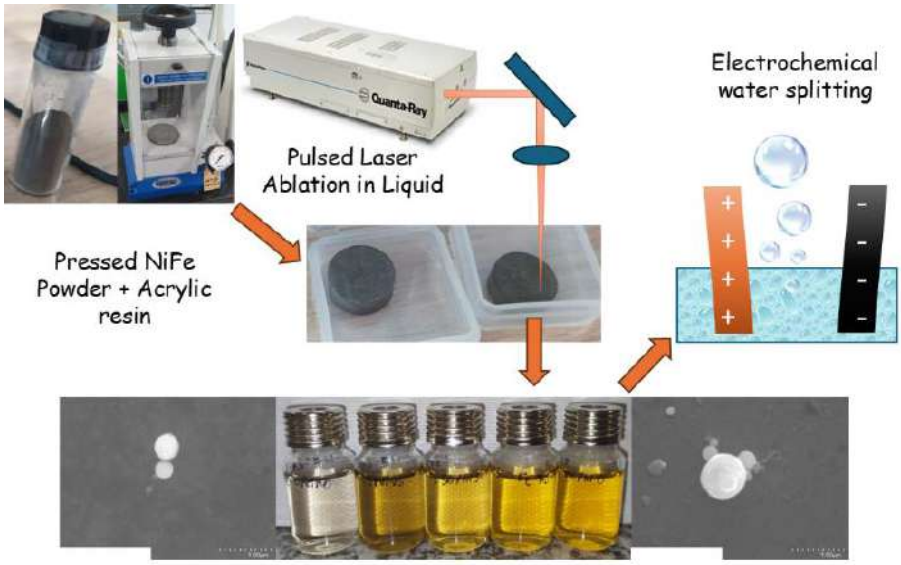
PLAL is performed using a Nd:YAG ns-pulsed laser in water over five produced targets (λ=1064 nm, 10ns, 5W, 10Hz) for 10 minutes.

Every target was obtained by ball milling (to obtain a uniform powder nanomixture) a total amount of a few grams of nickel and iron powders with the following mass ratio (100%:0%, 75%:25%, 50%:50%, 25%:75%, 0%:100%) in order to have also the reference with just iron and nickel. A few milligrams of the obtained powders were mixed with acrylic powder and pressed in order to obtain a disc pellet for laser ablation usable multiple times.

Morphological, structural and compositional characterizations have been performed by Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Raman Spectroscopy, UV-Vis Spectrophotometry, Energy Dispersive X-Ray (EDX).

Electrochemical measurements have been performed in an electrolyte consisting of 1 M KOH. Nanoparticles are dropcasted on an inert carbon substrate (graphene paper) whose only 1 $cm^{2,}$ and is immersed in the electrolyte. A three-electrode setup has been used with platinum wire as the cathode and a saturated calomel electrode (SCE) as the reference electrode. OER activity was investigated using Cyclic Voltammetry (CV), Linear Sweep Voltammetry (LSV) and Electrochemical Impedance Spectroscopy (EIS).

The produced electrodes produced a strong improvement in catalytic activity toward oxygen production at the standard current density of 10mA/cm^2, as expected, in particular by nickel-iron bimetallic oxides.



Acknowledgments

This work was funded by European Union (Next Generation EU), through the MUR-PNRR project SAMOTHRACE (Grant No. ECS00000022).

NiFeCoMo-Based Catalysts Synthesized by Laser Ablation in Liquids for Compositional Investigation of Alkaline Water Electrolysis Performance

Davide Beschi [*a], Stephan Barcikowski [*a*b], Benjamin Mockenhaupt [*a], Moritz Pilaski [*c], Kerstin Witte-Bodnar [*d]

[*a] *Nano Energie Technik Zentrum (NETZ), Germany.*
[*b] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE), Germany.*
[*c] *Zentrum für Brennstoffzellen Technik GmbH (ZBT), Germany.*
[*d] *Fraunhofer Institut für die Mikrostruktur von Materialien und Systemen (IMWS), Germany.*

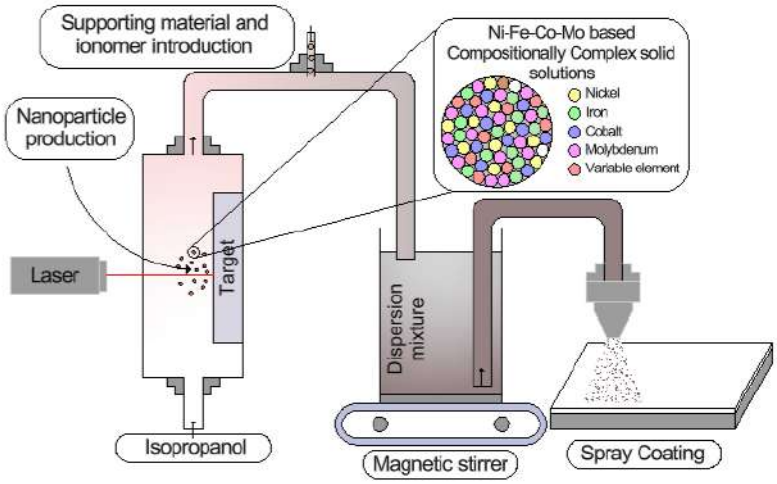
Hydrogen is a promising energy carrier due to its high energy density with water as the only byproduct in fuel cells [1]; however, large-scale hydrogen production via water electrolysis is hindered by the sluggish kinetics of the oxygen evolution reaction (OER), which dominates the overall energy demand [2]. Although noble-metal catalysts exhibit excellent activity, their high cost and limited availability restrict widespread application [3].

Compositionally complex solid solutions (CCSSs) offer a compelling noble-metal-free alternative, as their tuneable multicomponent compositions enable synergistic elemental interactions, enhanced stability, and bifunctional activity toward both the OER and hydrogen evolution reaction (HER) [4][5]. Laser ablation in liquids (LAL) provides a clean and scalable synthesis route for CCSS nanoparticles, yielding high-purity, surfactant-free materials with controlled composition and surface properties suitable for electrocatalytic applications [6][7].

In this study, noble-metal-free CCSS nanoparticles based on Ni, Fe, Co, and Mo are synthesized, with a fifth element systematically varied to tailor the alloy composition and assess its influence on electrocatalytic activity toward both OER and HER in alkaline media. Nanoparticles are produced by LAL in isopropanol under controlled and reproducible conditions and formulated into catalyst inks, which are deposited onto electrodes by spray coating to ensure homogeneous catalyst layers and compatibility with scalable fabrication methods.

Following compositional screening, selected CCSS alloys are investigated under anion exchange membrane water electrolysis (AEM-WE) relevant conditions to assess their performance in electrolyzer-relevant environments. The most promising catalysts will subsequently be co-deposited onto industrial-type electrolyzer membrane, enabling operando activity analysis by magnetic field imaging. This operando method will allow localization of highly active zones on the membrane and thus identification of the most active catalysts for alkaline water electrolysis, supporting a rational catalyst design strategy.

While the primary focus of this work lies in compositional optimization and electrochemical assessment, a longer-term objective is the implementation of a continuous and scalable workflow integrating LAL nanoparticle synthesis and catalyst ink formulation into an automated electrocatalyst preparation process. The results are expected to support the development of cost-effective, stable, and scalable electrocatalysts for sustainable hydrogen production.



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Acknowledgments

The authors thank the Industrielle Gemeinschaftsforschung (IGF) for financial support within the project: IGF_2024_01736

Pulsed Laser Ablation in Liquids as a Suitable Method to Generate Compositionally Complex Solid Solution Nanoparticles for CO_2 Hydrogenation Catalysis

Benjamin Mockenhapt[*a], Varatharaja Nallathambi [*a*b], D. Makhmutov [*c], Rakibul Hasan[*a], Sven Reichenberger [*a], Sebastian Wohlrab[*c], Stephan Barcikowski [*a]

[*a] *Technical Chemistry I, University of Duisburg-Essen and Center for Nanointegration Duisburg-Essen (CENIDE), Germany.*

[*b] *Max Planck Institute for Sustainable Materials, Germany.*

[*c] *Leibniz Institute für Katalyse e.V., heterogeneous catalysis, Germany.*

Introduction

CO_2 is a major greenhouse gas driving global warming, but also an abundant carbon feedstock. [1, 2] Its hydrogenation can yield methane or methanol as promising platform chemicals and energy storage molecules. However, temperature hotspots and the inhibiting effect of water on active sites limit the long-term stability and efficiency of current CO_2 hydrogenation catalysts. [3-5] New materials are therefore required for efficient, durable conversion of CO_2 to C_1 platform chemicals.

Compositionally complex solid solutions (CCSS), sometimes called medium or high entropy alloys (MEA, HEA), are promising candidates, as multicomponent alloys with five or more elements can form stable mixed-solution configurations[6] and exhibit electronic structures distinct from those of the individual elements.[8] While bulk CCSS synthesis is relatively straightforward, preparing homogeneous CCSS nanoparticles remains challenging for conventional wet-chemical methods. Using bulk CCSS targets, pulsed laser ablation in liquids (LAL) offers an alternative route to generate stable, ligand-free CCSS colloidal nanoparticles directly from the solid material. [6,7]

Materials and Methods

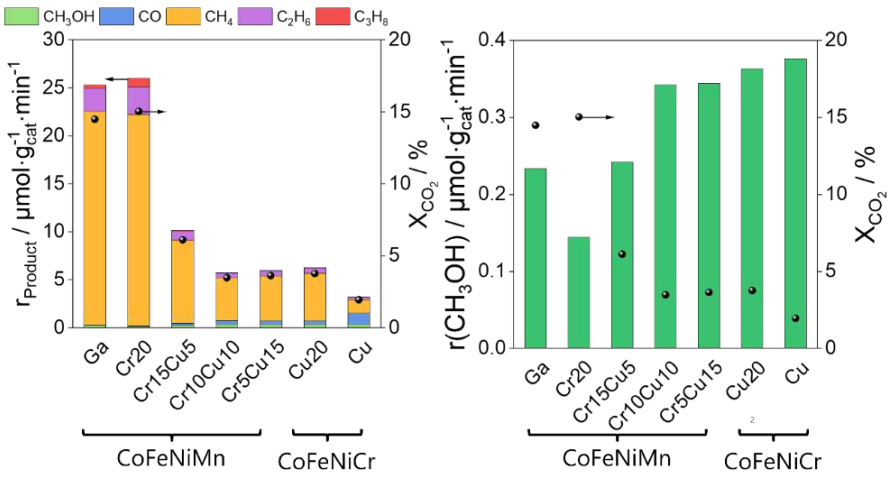
Six CCSS compositions based on CoFeNiMn with Ga, Cr, or CrCu additions, plus one Mn-free CoFeNiCrCu, were prepared by mixing pure metal powders and vacuum arc melting to obtain alloy nuggets. These served as targets for pulsed laser ablation in degassed deionized water using a 532 nm laser at 5 kHz and 50 W to generate nanoparticles.

Results and Discussion

Single-phase fcc alloy targets were prepared via Arc melting. Pulsed laser ablation in liquid produced nanoparticles with an average hydrodynamic diameter around 15 nm. The broadened diffraction reflections confirm the nanoscale nature of the materials and correspond to the fcc crystal structure of the parent alloys. Additional minor reflections indicate the presence of surface oxides, likely caused by segregation processes during LAL in water.

Despite this, the CCSS nanoparticles were active in CO_2 hydrogenation at temperatures below 200 °C and 20 bar total pressure (Fig. 1). The main product was methane, but methanol was also formed, with its selectivity increasing with rising copper content. Chromium promoted the formation and activity of copper species but also contributed catalytically on its own. As expected, Co, Fe and Ni, which are typical Fischer–Tropsch metals, led to the formation of higher hydrocarbons, as evidenced by ethane and propane in the product gas stream.

The highest CO_2 conversion of about 15% was obtained with a Mn- and Cr-containing CoFeNi-based CCSS catalyst, which also yielded the highest overall product formation rate. This study demonstrates that laser-fabricated CCSS are a new and promising catalyst class for CO_2 hydrogenation to C_1-based platform chemicals, contributing to a more sustainable chemical industry.



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Varatharaja is grateful for the financial support from the International Max Planck Research School for Interface Controlled Materials for Energy Conversion (IMPRS-SurMat), now International Max Planck Research School for Sustainable Metallurgy (IMPRS-SusMet), and the Center for Nanointegration Duisburg-Essen (CENIDE).

Simultaneous Dual Synthesis Nature of Nano Pulse Laser-Colloid Interaction; Fused Ferromagnetic Submicron and Fragmented Superparamagnetic Nano-particles

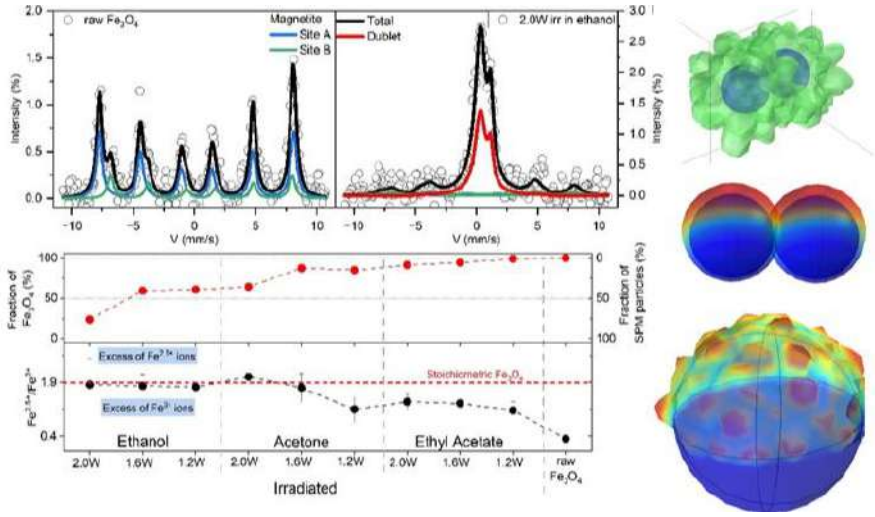
Mohammad Sadegh Shakeri [*a], Zaneta Swiatkowska-Warkocka [*a], Arkadiusz Zarzycki[*a]

[*a] *Institute of Nuclear Physics Polish Academy of Sciences, Poland*

Pulsed laser-colloid interaction (PLCI) represents a powerful, surfactant-free synthesis route for engineering nanomaterials with controlled morphology and phase structure [1]. In this study, we report the simultaneous formation of fused submicron particles and fragmented nanoparticles from colloidal Fe_3O_4 subjected to nanosecond pulsed laser irradiation in various organic solvents. Depending on the solvent and laser power, laser-induced heating and melting of magnetite nanoparticles result in size redistribution through explosive fragmentation and surface fusion, forming polydisperse systems composed of both superparamagnetic and ferromagnetic domains.

Synchrotron-based techniques, including soft and hard X-ray absorption spectroscopy, as well as scanning transmission X-ray microscopy, were used to investigate oxidation state distributions and to map the local structural evolution of the iron oxide phases [2]. The results reveal laser-driven partial oxidation/reduction processes and the emergence of mixed-phase systems, including near-stoichiometric magnetite and highly defective superparamagnetic iron oxide nanoparticles.

Zero-field cooled, field-cooled, and AC susceptibility measurements confirm a thermomagnetic transition anomaly around 50 K, likely related to nanoscale phase separation. Field-cooled hysteresis measurements indicate that this “50 K phase” is crucial for the onset of exchange bias and coercivity enhancement. Mössbauer spectroscopy confirms the transformation of raw defective magnetite into a mixture of stoichiometric magnetite and superparamagnetic phases. This work highlights PLCI as a tunable method to fabricate complex magnetic nanostructures with tailored properties.



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We gratefully acknowledge Poland's high-performance Infrastructure PLGrid, ACC Cyfronet AGH for providing computer facilities and support within computational grant no PLG/2025/018879. We also thank Polish Synchrotron Radiation Facility (SOLARIS), including ASTRA, PIRX, and DEMETER beamlines helping us to analyse the samples using hard and soft X-ray absorption spectroscopy and scanning transmission X-ray microscopy.

Determinants for internal phase structure tuning of ignoble and noble metal high-entropy alloy nanoparticles synthesized via laser ablation and microparticle laser fragmentation in liquid

Christoph Rehbock [*a], Robert Stuckert [*a], Felix Pohl [*b], Natalia Shkodich [*c], Oleg Prymak [*d], Nico Koch [*a], Nikola Apanowicz [*a], Ulrich Schürmann [*b], Michael Farle [*c], Lorenz Kienle [*b], Stephan Barcikowski [*a]

[*a] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany.*

[*b] *Institute for Material Science, Christian-Albrechts University of Kiel, Germany.*

[*c] *Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany.*

[*d] *Inorganic Chemistry and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany.*

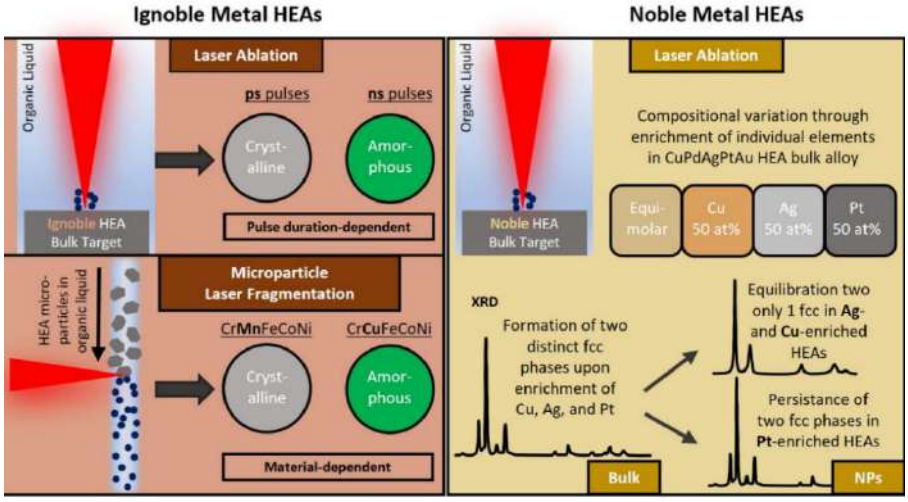
High-entropy alloy (HEA) nanoparticles (NPs) represent a relatively new class of nanomaterials composed of at least five elements at a near-equimolar ratio, offering nearly limitless compositional tunability, e.g., for applications in electrocatalysis. The synthesis of HEA NPs by laser ablation in liquids (LAL) is a well-known, green, and scalable method previously utilized for the generation of colloidal CrMnFeCoNi NPs with homogeneous elemental distributions, though structural differences were observed, and crystalline HEA NPs were found after LAL in ethanol [1], while LAL in acetonitrile yielded amorphous structures [2].

However, to what extent process variables like the solvent, laser pulse duration, or the composition of the bulk target affect the phase structure of HEA NPs remains underexplored. Another emerging laser-based synthesis technique is microparticle laser fragmentation in liquid (MP-LFL), which was shown to be suitable for the synthesis of inorganic nanoparticles and excels due to scalability and a fully continuous operation mode [3]. However, MP-LFL has not been mentioned in the context of high-entropy alloys yet.

In this work, we present a systematic investigation of the key driving factors for the formation of crystalline (fcc) and amorphous structures for both CrMnFeCoNi and CrFeCoNiCu HEA NPs, synthesized via LAL and MP-LFL in organic solvents, utilizing electron microscopy (TEM, EDX, SAED), X-ray diffraction, and calorimetric analysis techniques for particle characterization. In LAL, the use of picosecond- and nanosecond-pulsed lasers led to the formation of HEA NPs of similar sizes (mean diameters of 20-30 nm) and elemental compositions.

Interestingly, polycrystalline structures could be observed after ps-LAL, while metastable amorphous phases were observed during ns-LAL, a phenomenon we attribute to different carbon incorporation kinetics during the formation of the nanoparticle cores in the ablation plume [4]. In contrast, during ns-pulsed MP-LFL, material-specific aspects were dominant and crystalline CrMnFeCoNi NPs formed, while CrFeCoNiCu NPs were amorphous, probably attributed to element-specific carbon incorporation pathways [5].

While we could not validate a similar trend for noble metal CuPdAgPtAu HEA NPs, we found unique phase structure segregation tendencies upon enrichment of individual elements (Cu, Ag, or Pt). We show that upon increasing the molar fraction of Cu and Ag to 0.5, a single kinetically stabilized fcc crystal structure emerged, even though the particles were generated from biphasic bulk alloy targets. Interestingly, this phenomenon could not be observed upon Pt-enrichment, where a unique biphasic structure was found in the nanoparticles. This work advances the understanding of formation mechanisms in pulsed laser-synthesized noble and ignoble metal HEA NPs, facilitating future design strategies for these nanomaterials and enabling prospects for large-scale synthesis.



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Acknowledgments

Financially supported by the German Science Foundation (DFG), BA 3580/18-4 (ID 277627168) and CRC/TRR270 (ID 405553726)

Plasmonic Color Formation via Thermal Laser Processing of Titanium–Gold Thin Films

Vita Petrikaitė [*a], Aušra Selskienė [*b], Evaldas Stankevičius [*a]

[*a] *Department of Laser Technologies, Center for Physical Sciences and Technology, Lithuania*

[*b] *Department of Characterisation of Materials Structure, Center for Physical Sciences and Technology, Lithuania*

Conventional synthetic dyes provide a broad range of colors but frequently release toxic, non-biodegradable substances that pose environmental risks [1]. In contrast, plasmonic nanostructures – especially gold nanoparticles – present a more sustainable alternative because of their size-dependent optical properties. By changing the size, shape, and composition of metal nanoparticles, their light absorption and scattering properties can be adjusted to create specific colors. Unlike conventional structural colors, which depend on the periodicity of nanostructures that determine the visible color, plasmonic colors are the result of localized resonances in individual nanostructures [2].

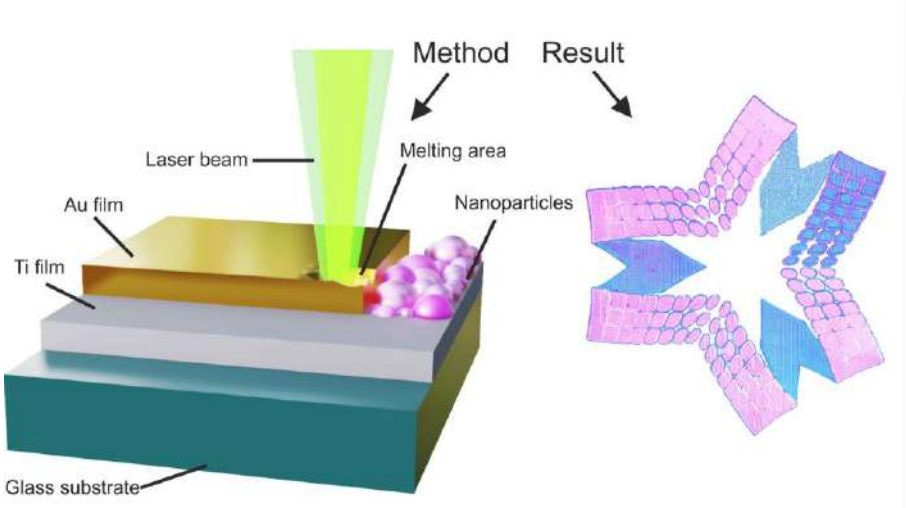
However, gold thin films generally exhibit a limited color range due to morphological constraints [3]. This study aims to overcome the inherent limitations of gold thin films and expand the range of achievable plasmonic colors by introducing a titanium (Ti) adhesion layer beneath the gold film [4], modified by laser-induced thermal heating processing. This method aims to improve both the diversity of plasmonic colors and the adhesion properties of the film.

Gold nanoparticles were generated on glass substrates with Ti underlayers using a nanosecond pulsed laser operating at a 532 nm wavelength. A systematic investigation was carried out by varying the pulse energy (3.5-38.5 μJ), scan speed (1-500 mm/s), repetition rate (0.5-100 kHz), and hatch spacing (25-75 μm) to optimize the laser parameters for plasmonic color formation. It was found that coatings with an adhesive Ti underlayer broadened the achievable color range, including hues beyond the limited palette of gold thin films. Also exhibited more intense localized surface plasmon resonance (LSPR) peaks.

The layer configuration Ti 10 nm + Au 10 nm exhibited the widest color spectrum, with a maximum color difference parameter $\Delta E=36.83$, and high extinction values, even at low pulse energies. It was found that increasing the thickness of the Ti sublayer causes a red shift towards longer wavelengths and reduces the pulse energy required to obtain color. It has been shown that using a single coating, it is possible to create a coherent image of different colors.

Broader characterization using EDS combined with SEM confirmed that surface texturing and nanoparticle distribution directly influence optical properties.

These results highlight the potential of Ti/Au thin films and laser-induced dewetting for producing high-resolution, lithography-free plasmonic color features, suitable for various applications, including high-resolution printing, anti-counterfeiting, decorative finishes, plasmonic sensors, photonic components, and eco-conscious optical printing technologies.



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Acknowledgments:

This project has received financial support from the Research Council of Lithuania (LMTLT).

Functionalized Gold-Iron Nanoparticles Obtained by Laser Ablation in Liquid for In Vitro RNA-Delivery

Catherine Reffatto [*a], Veronica Torresan [*b], Giovanna Brusatin [*b], Vincenzo Amendola [*a]

[*a] *Department of Chemical Sciences, University of Padova, Italy*

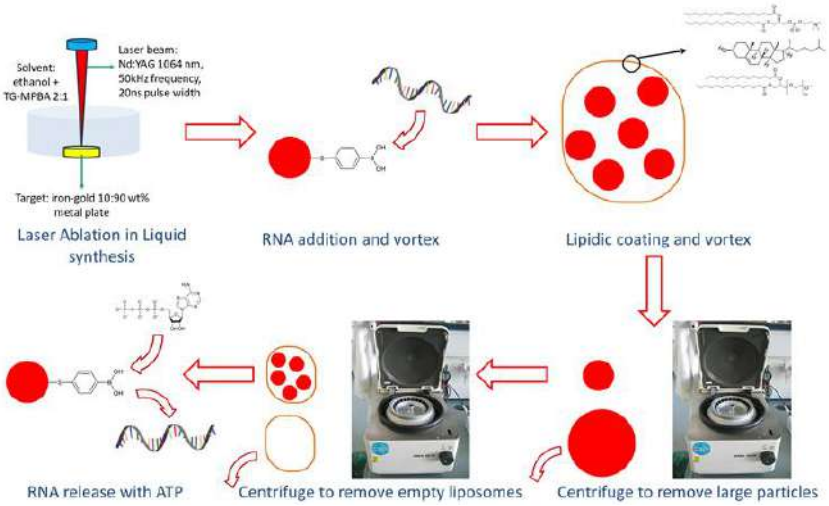
[*b] *Department of Industrial Engineering, University of Padova, Italy*

RNA-delivery with nanoparticles has already been studied as an innovative approach to precision medicine applications, thanks to a targeted delivery of genetic material and the avoidance of toxic molecules. To enhance the theranostic effects of RNA, gold-iron nanoalloys were selected as the cores of these nanovectors, because of their well-known plasmonic and magnetic properties, which are highly useful for radiotherapy and imaging.

Here we show the development of an RNA-delivery vector effective at cellular level, using gold-iron nanoalloys [1] functionalized with Glucose (TG) and PhenylBoronic Acid (MPBA) derivatives. The boronic acid group is known in scientific literature for efficiently linking to the ribose unit present in several biomolecules such as RNA and ATP.[2] The idea is to deliver RNA inside the cell thanks to MPBA-functionalized nanoparticles and then releasing the RNA strands due to the presence of ATP molecules, which are expected to cleave the MPBA-ribose bonding.[3] The synthesis of these NPs is achieved through Laser Ablation in Liquid (LAL). The set up consists of a AuFe 90-10 wt% metallic target in an EtOH solution irradiated by 1064nm, 50kHz nanosecond laser pulses to produce the required particles.[4] In order to functionalize the NPs and reduce their size, the previously mentioned thiols were added to the synthesis solution.

This method ensures a high degree of purity and avoids chemical contaminants typically associated with conventional wet-chemical synthesis techniques. Following the synthesis, the NPs are linked to the RNA chains and coated in a lipidic bilayer to improve their biocompatibility and cellular uptake. The lipidic bilayer results in a stable and biocompatible nanovector as shown in fig.1c.

The physicochemical characterization of the NPs, alongside systematic evaluation of their stability, surface properties, and functional performance are performed. Subsequently, in vitro studies are planned to assess their biocompatibility, cytotoxicity, and potential as contrast agents for multimodal imaging. These nanoconstructs are of interest for their theranostic capabilities in the context of radiosensitization for X-ray radiotherapy, aiming to improve therapeutic outcomes in oncological treatments.



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Acknowledgments

This research is funded by the AIRC – MFAG 2021 project ID. 25681 – P.I. V. Amendola

LAL and LFL of Gold NPs Functionalized with Peptides for Dynamic Cell Interaction

Asya Zerbato [*a], Marta De Zotti[*a], Vincenzo Amendola [*a]
[a*] *Department of Chemical Sciences, University of Padova, Italy*

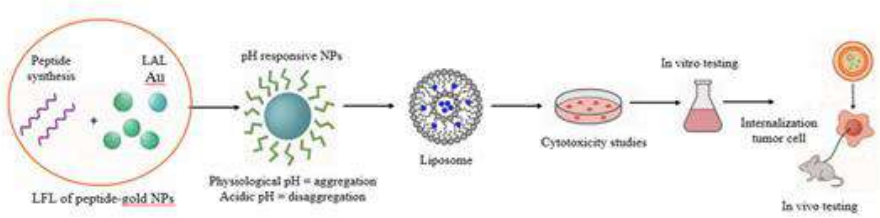
The aim of this project is the development of a dynamic vector at the cellular level, utilizing gold nanoparticles functionalized with a specifically designed peptide engineered to respond to environmental stimuli, such as pH variations.[1]

Gold nanoparticles were synthesized by laser ablation in liquid (LAL) using nanosecond NIR laser pulses (λ = 1064 nm, 20 ns, 50 kHz) focused onto a high-purity metallic gold target immersed in an aqueous NaCl solution (2×10^{-4} M), leading to the generation of colloidal Au nanoparticles. This method represents a green synthesis approach, as it employs only a solid target and a solvent while ensuring a high degree of purity because the technique avoids the use of chemical precursors, reducing contamination risks commonly associated with conventional wet-chemical synthesis methods[2]. An additional advantage of this technique is its ability to enable rapid functionalization and the possibility to change only the surface coating of the NPs by keeping the same metallic cores. In this way, only the effect of the coating can be studied.

In this context, several peptides–PEG mixtures with various molar compositions were investigated to combine their respective properties and identify the most effective formulation. Based on these results, gold nanoparticles were subsequently functionalized with the peptide LipoK, obtained through solid-phase peptide synthesis, and with a short-chain PEG to further enhance biocompatibility [3]. This surface functionalization not only provides colloidal stability but also enables reversible aggregation at physiological pH and disaggregation under acidic conditions, which are characteristic of the extracellular environment of cancer cells. Such behavior enhances intracellular localization, promoting nanoparticles migration toward the perinuclear region and thereby increasing their potential therapeutic efficacy.

After functionalization, a laser-induced fragmentation in liquid (LFL) process is performed. In this step, the colloidal suspension is irradiated with an UV nanosecond-pulsed laser, inducing photofragmentation and allowing precise control over nanoparticles size and reducing polydispersity. Smaller nanoparticles are desirable for the increased *in vivo* biodistribution while simultaneously reducing liver accumulation and long-term persistence in the human body.

The physicochemical characterization of the NPs, alongside systematic evaluation of their stability, surface properties, and cytotoxicity confirm that these nanosystems are appealing tools in the context of radiosensitization for X-ray radiotherapy, aiming to improve therapeutic outcomes in oncological treatments.[4]



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Acknowledgments

This research is funded by the AIRC – MFAG 2021 project ID. 25681 – P.I. V. Amendola

The sensitization effect of laser-generated metal nanoparticles in proton therapy

Lars Krenz[*a], Sandra Zwiehoff[*a], Carina Behrends[*b*c*d*e], Feline Heinzelmann[*b*c*d*e], Johannes Esser[*b*c*d*e], Christian Bäumer[*b*c*d*e], Beate Timmermann[*b*c*d*f], Christoph Rehbock[*a], Stephan Barcikowski[*a]

[*a] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany*

[*b] *West German Proton Therapy Centre Essen (WPE), Germany*

[*c] *West German Cancer Center (WTZ), Germany*

[*d] *Department of Physics, TU Dortmund University, Germany*

[*e] *German Cancer Consortium (DKTK), Germany*

[*f] *Department of Particle Therapy, University Hospital Essen, Germany*

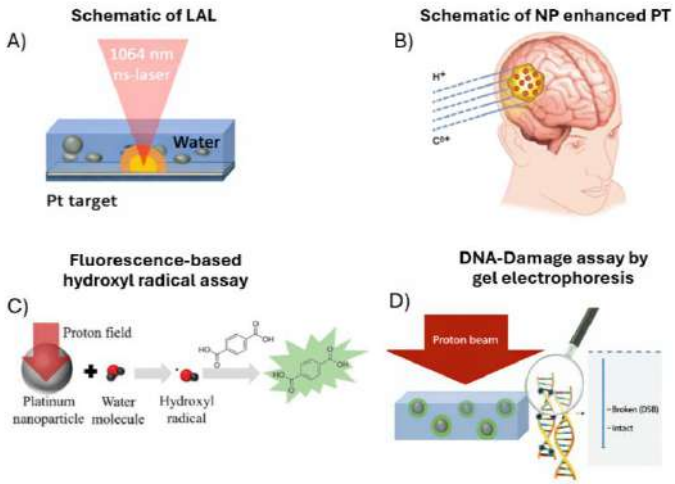
Proton therapy (PT) enables highly localized dose deposition within tumor tissue and is therefore an effective cancer treatment method, particularly for tumors located in radiosensitive tissue of children. Metal nanoparticles (NPs) have been shown to work as radioenhancers in PT [1] through increased generation of reactive oxygen species (ROS) [2], but the interplay between material composition, catalytic surface chemistry, and spatial selectivity under clinically relevant proton doses is still insufficiently understood. Hence, further improvement of tumor-selective radio-sensitization by tuning of the particle properties remains a central challenge.

In this work, we investigate surfactant-free Pt and Au NPs synthesized by laser ablation in liquids (LAL) as model sensitizers for PT by irradiation of water phantoms at clinically relevant doses (2-5 Gy). ROS generation was quantified using fluorescence-based hydroxyl radical assays and complemented by DNA double-strand break (DSB) analysis via gel electrophoresis. Here, initially ligand-free NPs from laser synthesis served as particularly suitable model systems [3] to elucidate fundamental mechanisms and to enable the rational tuning of NP properties for maximum efficiency in PT, especially since commonly used stabilizers in chemical NP synthesis, such as sodium citrate, have been shown to adversely affect ROS formation [4].

We observed a linear dependence of ROS generation on both irradiation dose and particle surface concentration [5]. However, we also found a higher efficiency for the smaller 5 nm Au NPs compared to their 30 nm counterparts, even at an identical total surface area. This indicates that the presence of additional effects is governed by surface chemistry, such as the density of structural defects [4]. This interpretation is further supported by the significantly higher activity of Pt NPs relative to Au NPs, which we attribute to the intrinsically higher catalytic activity of Pt surfaces toward ROS generation [5]. Finally, we observe that clinically approved ligands like Bovine serum albumin, Tween, and polyethylene glycol on the NP surface work as DSB enhancers. Furthermore, synergetic effects occur between ligands and NPs, exceeding the sum of individual ligand and particle effects, even at low and clinically relevant particle concentrations and irradiation doses. [6]

Finally, we utilized a PMMA step phantom, emulating the proton depth-dose curve, to assess whether sensitization is localized in the maximum of the depth-dose curve and to evaluate potential side effects in the entrance volume upstream of the tumor.

Overall, our results highlight ligand-free, LAL-generated metal nanoparticles as a relevant model platform that combines medical-approval-oriented synthesis with tunable defect density [4] and, in perspective, systematic element and alloy screening for optimized proton therapy sensitization.



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Acknowledgments:

We thank the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – GRK3043 – 527826293 for funding this work.

Continuous laser melting in liquids: overcoming the challenges of high-power/high-frequency lasers to scale up from batch to flow processes

Nico G. Koch[*a], Christoph Rehbock[*a], Naoto Koshizaki[*b], Stephan Barcikowski[*a]

[*a] *Technical Chemistry I and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Germany*

[*b] *Graduate School of Engineering, Hokkaido University, Japan*

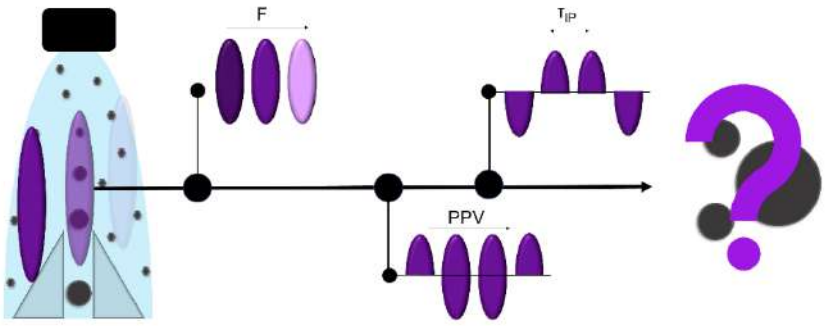
Laser-based synthesis in liquids is a versatile and environmentally friendly approach to generating functional nanomaterials with controlled size, morphology, and composition. However, producing monodisperse, spherical submicrometer particles remains a significant challenge in the context of high-performance materials due to the simultaneous requirement for surface smoothness, structural integrity, and synthetic scalability. Pulsed Laser Melting in Liquids (LML) offers a promising solution to this problem by enabling the rapid melting and resolidification of nanoparticles in a liquid environment.

While LML is well established as a batch process and has been widely employed, its scalability remains inherently limited by low volumetric throughput and the difficulty of maintaining process homogeneity across larger reaction volumes [1]. Continuous-flow LML [2] has therefore emerged as a logical next step to overcome these constraints, and may offer improved energy efficiency, reproducibility, and process control. A central question arising from this transition concerns the transferability of process parameters from batch systems operated at low repetition rates to continuous configurations employing high repetition rate lasers, where distinct thermal and hydrodynamic conditions prevail.

In this study, we present the adaptation of a flat jet flow-through reactor [3] to the LML process. Here, boron carbide (B_4C) nanoparticles suspended in ethanol are irradiated by a high-power, high-repetition-rate nanosecond UV laser in a precisely controlled hydrodynamic environment, allowing the investigation of fluence- and pulse-dependent particle formation pathways. Transmission electron microscopy and dynamic light scattering reveal a bimodal size distribution with mean diameters of approximately 50 nm and 100 nm. Under batch conditions approaching thermal equilibrium, such systems would be expected to evolve toward a unimodal distribution dominated by the energetically favored larger particles (>300 nm).

The persistence of a distinct, small particle fraction is therefore remarkable, as it points to a non-equilibrium state in which thermal equilibrium driving forces for coarsening are effectively counteracted or kinetically constrained. This bimodal size distribution arises from distinct isochoric reshaping and aggregation–melting–fusion mechanisms, respectively. The smaller particle fraction forms under quasi-equilibrium conditions, while the larger size mode develops via kinetically controlled, multi-step aggregation. By systematically varying the number of laser pulses interacting with the colloidal volume, we identify a critical regime that maximizes particle growth before kinetic constraints dominate. Beyond a distinct fluence threshold, the process transitions to laser fragmentation, defining the upper boundary of the laser melting and growth window.

These findings establish that LML, which is controlled by particle growth kinetics and not thermal equilibrium conditions, can be used to synthesize spherical boron carbide nanoparticles in a scalable way in flat jet reactors. B_4C is an ultra-hard material that is traditionally resistant to spheroidization, and it opens new possibilities for the continuous, high-throughput production of advanced ceramic nanomaterials.



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Acknowledgments

We gratefully acknowledge financial support from GF-GG under project No.: 491146928 (DFG-GEPRIS). We also gratefully acknowledge the DFG Deutsche Forschungsgemeinschaft for its financial support under 555656461 (DFG-GEPRIS).

CO2 laser-irradiation mediated NiMo Dual-Atom Dimer on Pd Nanosheets for PET Plastic Upcycling

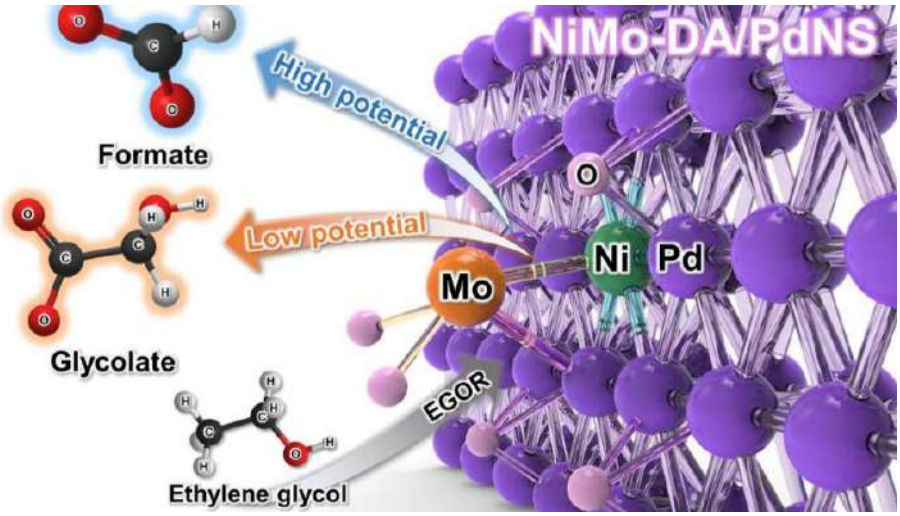
Seongbo Lee [*a], Juhyeon Park [*a], Myong Yong Choi [*a]

[*a] *Department of Chemistry (BK21 FOUR), Research Institute of Advanced Chemistry, Gyeongsang National University, Republic of Korea*

Electro-reforming of polyethylene terephthalate (PET) via selective C–H and C–C bond cleavage of its monomer, ethylene glycol (EG), offers a promising strategy for plastic upcycling into high-value C_2 and C_1 products. However, achieving sustainable catalytic control over product selectivity remains a critical challenge. Herein, we report the CO gas–mediated synthesis of palladium nanosheets (PdNSs) as the first palladene substrate for atomically dispersed dimer catalysts. We further present the first report of NiMo dual-atom dimer immobilization on PdNSs (NiMo-DA/PdNS) using rapid CO_2 laser irradiation (wavelength ≈ 10.6 μm; power ≈ 7 W) within 10 min.

Localized heating from CO_2 laser irradiation drives Ni^{2+} and Mo^{6+} reduction, Ni anchoring on Pd sites and subsequent migration of Mo species toward these anchored Ni atoms, where they couple to form stable heteronuclear Ni–Mo dimers via strong *d*-orbital hybridization and thermodynamic preference, thereby overcoming the limitations of conventional atomic-level catalyst syntheses, such as high energy demand, long reaction times, and uncontrolled metal agglomeration. Dual-atom catalysts (DACs) overcome this by introducing synergistic metal sites, improving intermediate adsorption, and preventing surface poisoning.

Reported systems, such as Pd–N4/Cu–N4 and Ni–Fe DACs, show improved GA selectivity but rely on costly, complex synthesis. Here, we report a NiMo dual-atom dimer on Pd nanosheets (NiMo-DA/PdNS) that achieves potential-dependent control of EGOR selectivity toward both FA and GA an insight not previously reported. The catalyst is fabricated via a rapid, low-cost CO_2 laser irradiation method (~10.6 μm, 7 W, 10 min), ensuring precise atomic dispersion, strong metal–support interactions, and prevention of sintering. Pd nanosheets provide a flat, conductive platform with intrinsic EGOR activity and balanced C_1/C_2 selectivity, offering a scalable approach for efficient plastic upcycling.



Acknowledgments

This research was supported by Korea Basic Science Institute (National research Facilities and Equipment Center) grant funded by the Ministry of Education (No. 2019R1A6C1010042, RS-2024-00434932, and RS-2025-12872968) and by the Korea government (MSIT) (PG2025039-02), National Science and Technology Council, Taiwan (NSTC 112-2923-M-011-003-MY2 and 112-2635-M-194-001), and the Sustainable Electrochemical Energy Development Center (SEED Center), funded by the Ministry of Education (MOE), Taiwan.

The authors acknowledge financial support from the National Research Foundation of Korea (NRF) (2022R1A2C2010686 and RS-2024-00405324) and Core-Facility Center for Photochemistry & Nanomaterials, Gyeongsang National University, In-situ Cryo X-ray Absorption Spectrometer, IC-XAS (NFEC-2025-07-307201). WL acknowledges the NSRF via the Program Management Unit for Human Resources & Institute Development, Research & Innovation (B49G680115). Ultrahigh Resolution Double Cs Corrected Scanning Transmission Electron Microscopy (Z-202508282901) was used at Korea Institute of Energy Technology facility.

Laser-Driven In-Situ Synthesis of ZnSnO3-Decorated Surface-Modified Multiwalled Carbon Nanotube Heterostructures for Enhanced Triboelectric Energy Harvesting Applications

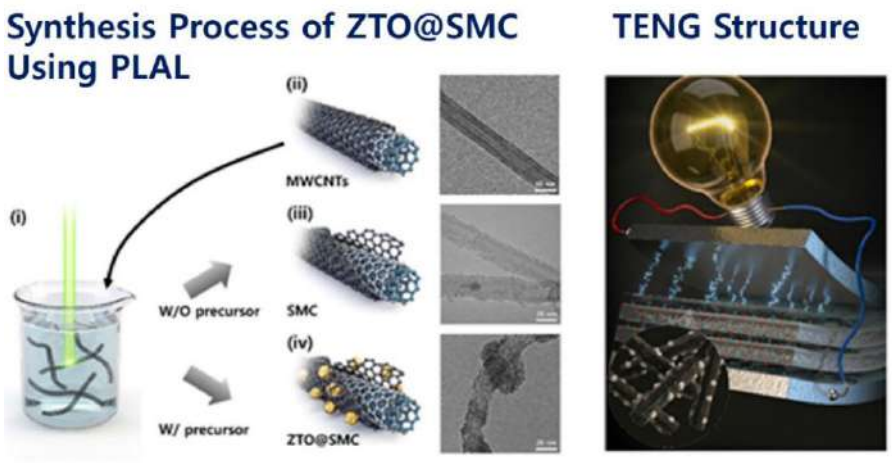
Eel-Ho Yun [*a], Geon Woo Heo [*a], Jeong-Won Kang [*a], Il-Song Kim [*a], Donggun Lim [*a], Manbok Park [*a], Tae-Whan Hong [*a], Jong-Tae Son [*a], Jeong Ho Ryu [*a]

[*a] *Korea National University of Transportation, Republic of South Korea*

The rational design of heterogeneous nanostructures with tailored interfaces is pivotal for advancing energy harvesting technologies [1]. In this work, we present a facile and effective strategy to fabricate $ZnSnO_3$ decorated on surface-modified multiwalled carbon nanotubes (ZTO@SMC) utilizing Pulsed Laser Ablation in Liquid (PLAL**)**. While conventional synthesis often requires complex steps to ensure interface quality, PLAL offers a unique non-equilibrium pathway to achieve both surface functionalization and in-situ heterostructure formation sequentially.

Pristine MWCNTs dispersed in ethanol were first irradiated with a 355 nm pulsed laser to induce surface defects and introduce hydroxyl and carboxyl functional groups, converting them into surface-modified CNTs (SMCs) with high reactivity. Subsequently, zinc and tin precursors were introduced to the SMC suspension and subjected to laser irradiation. The localized high-temperature plasma plume generated by the laser facilitated the crystallization and direct anchoring of hemisphere-like $ZnSnO_3$ (ZTO) nanoparticles onto the functionalized CNT surfaces.

TEM and XPS analyses confirmed the successful formation of ZTO@SMC heterostructures with robust interfacial bonding. This laser-engineered architecture effectively bridged the conductive network of CNTs with the high-permittivity ZTO, significantly boosting the interfacial polarization within the polymer matrix. Consequently, when integrated into a polydimethylsiloxane (PDMS)-based triboelectric nanogenerator (TENG), the device demonstrated a remarkable output voltage of 797 V and current of 65 μA. These findings highlight PLAL as a powerful processing technique for creating advanced fillers that maximize the performance of triboelectric energy harvesters.



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Acknowledgments

This research was supported by the Ministry of Trade, Industry and Energy (MOTIE) and the Korea Institute for Advancement of Technology (KIAT) through the "Support for Middle Market Enterprises and Regional innovation Alliances (R&D, RS-2025-02633071)" program.

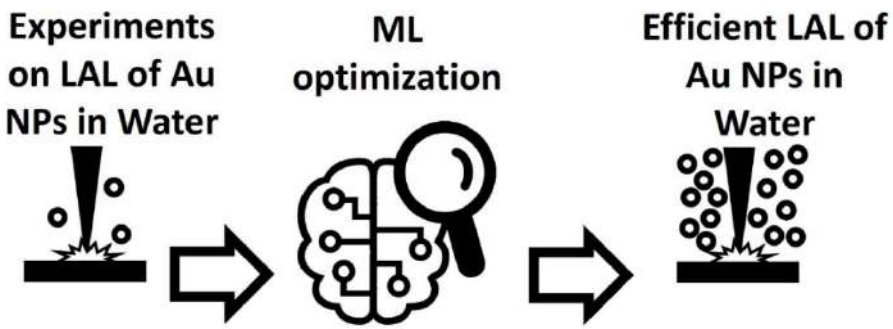
Optimization of LAL synthesis of Au NPs in water through Machine Learning

Vincenzo Amendola[*a], Miao Runpeng[*a], Catherine Reffatto[*a], Rafael Omar Torres Mendieta[*a]

[*a] *Department of Chemical Sciences, University of Padova, Italy*

Gold nanoparticles are extensively used across modern technologies, yet their large-scale production remains limited by cost, sustainability, and purity constraints. These issues are particularly critical in applications such as biomedicine and catalysis, where surface contamination can strongly affect performance. Laser ablation in liquids has emerged as a promising alternative for the synthesis of chemically clean gold nanoparticles, as it avoids the use of molecular precursors and stabilizers.

However, the scalability of this approach was so far much lower than that of conventional wet-chemical routes. In this work, the batch synthesis of gold nanoparticles by laser ablation in liquids was optimized through a machine-learning strategy, leading to a substantial improvement in productivity and economic efficiency. The resulting nanoparticles exhibited interesting properties for several applications in optics, catalysis, analytical science and biomedicine. Overall, this study strengthens our previous demonstration [1] of the strong potential of machine-learning-optimized laser ablation in liquids as a viable route toward low-cost, sustainable production of metal nanoparticles with properties that are difficult to achieve through traditional chemical synthesis.



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Acknowledgments

This research is funded by the AIRC – MFAG 2021 project ID. 25681 – P.I. V. Amendola

Electrospun Amorphous FePO4 Nanofiber Cathodes for Laser Power Modules: Low-Temperature Processing and SEM/XRD/XPS-Based Structural and Interfacial Characterization

Geon-Woo Heo[*a], Eel-Ho Yun[*a], Soon-Man Jang[*a], Seung-Min Jung[*a], Jong-Hwi Park[*a], Hae-Won Lee[*a], Jong-Tae Son[*a], Il-Song Kim[*a], Donggun Lim[*a], Manbok Park[*a], Tae-Whan Hong[*a], Jeong-Won Kang[*a], Jeong Ho Ryu[*a]

[*a] *Korea National University of Transportation, Republic of South Korea*

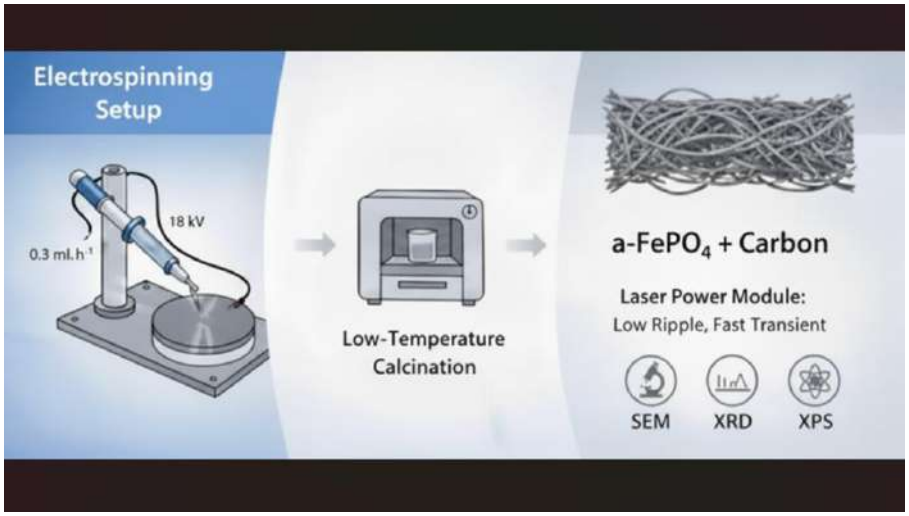
Power supplies for laser systems require low-ripple, low-noise rails and fast current transients, and meeting these demands hinges on transport-pathway engineering and interfacial stability at the battery electrode level [1]. Polyanionic phosphate cathodes, such as $FePO_4$, are attractive for safety and thermal robustness, yet their intrinsic electronic/ionic transport limitations necessitate architecture-level solutions for high-rate operation with minimal voltage excursion [2,3].

Here, we report a simple and effective route to fabricate amorphous $FePO_4$ (a-$FePO_4$) nanofiber cathodes via electrospinning followed by low-temperature treatment that preserves amorphicity while integrating conductive carbon. Unlike traditional powder-based electrodes, this electrospun fiber network creates a seamless 3D pathway for electrons and ions. This open, interconnected structure removes bottlenecks in charge transport, providing the rapid power response and steady voltage necessary for high-performance laser drivers.

The a-$FePO_4$ nanofibers were synthesized by electrospinning a precursor solution of iron sulfate, phosphoric acid, and PVP at 18 kV (0.3 mL h^{-1}). Subsequent low-temperature calcination produced carbon-integrated amorphous nanofibers, successfully stabilizing the Fe-O-P network while ensuring high conductivity.

Processing parameters were optimized to suppress crystallization and microcracking: polymer-assisted electrospinning to produce uniform fibers, a stabilization step, and carbon introduction below the crystallization temperature to form conductive domains within or around the fibers. Structural and interfacial integrity were verified by XRD, which showed a broad amorphous halo without crystalline peaks; SEM, which revealed a uniform fiber-diameter distribution and crack-free, interconnected fiber films on the current collector; and XPS, where Fe 2p indicated stable Fe chemical states in a phosphate environment, P 2p showed PO_4^{3-} bonding, and C 1s exhibited sp^2/sp^3 and oxygenated functionalities, evidencing carbon integration and stable interfacial chemistry at the fiber surface.

This laser-oriented electrode architecture achieves materials robustness and transport readiness at the electrode level and, when coupled with appropriate cell design and power-conditioning electronics, provides a practical pathway to support high-rate, low-excursion operation.



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Acknowledgments

This research was supported by Korea National University of Transportation in 2026.

How Laser and Material Parameters Direct Laser-induced Surface Doping of Ni-Based Nanoparticle Catalysts

Philipp Lemm[*a], Kristian Maier[*a], Oleg Prymak[*b], Robert Stuckert[*a], Benjamin Mockenhaupt[*a], Stephan Barcikowski[*a]

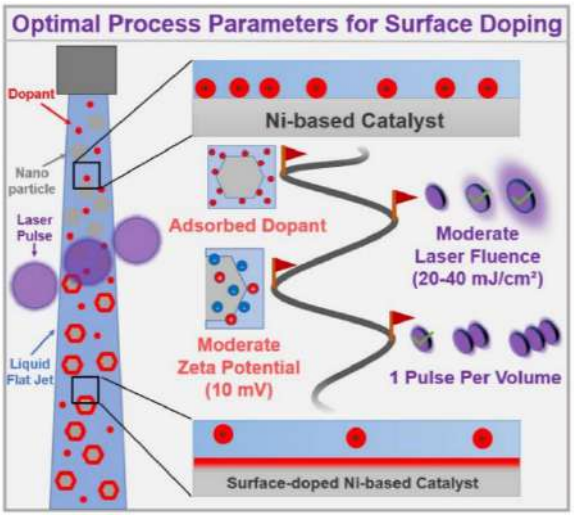
[*a] *Universität Duisburg-Essen, Technische Chemie I, Germany*

[*b] *Universität Duisburg-Essen, Anorganische Chemie, Germany*

Pulsed Laser Diffusion Enhancement in Liquids (PUDEL) has emerged as a promising low-energy laser-processing strategy for surface-selective cation doping of nanoparticle catalysts, offering a complementary approach to conventional bulk-doping methods. PUDEL not only allows for defined defect engineering in oxide [1,2] and metal nanoparticles [3,4], but also doping of solutes into the dispersed nanoparticles. [5] However, for technologically relevant systems such as Ni-based electrocatalysts used in anion exchange membrane water electrolysis (AEM-WE), the parameters determining PUDEL-induced surface doping remain insufficiently understood.

In this study, UV-PUDEL is systematically evaluated using NiO, $NiFe_2O_4$, and NiFe nanoparticles doped with Li^+, Fe^{3+}, and Ce^{3+} ions across a broad parameter matrix including laser fluence, pulses per volume, laser wavelength, counter anions, and zeta potential, with the oxygen evolution reaction (OER) serving as the functional readout. Adsorption experiments and extensive analytical characterization (XPS, XRF, XRD, TEM-EDX) were performed to elucidate mechanistic pathways of laser-induced surface doping and accompanying surface and structural changes.

Clear parameter-activity relationships were identified: moderate fluences (20-40 mJ/cm^2), a single pulse per volume regime, and intermediate zeta potentials (~10 mV) reproducibly yield the most favorable OER responses, while the counter anion exerts no significant influence after PUDEL treatment. Mechanistically, a cation adsorption-controlled process is evidenced in which dopant ions must pre-accumulate at the nanoparticle surface before laser-induced diffusion into the host nanoparticle surface can occur. Combining the material matrix (3 cations x 3 catalysts) with a matrix of PUDEL parameters (fluence, pulse number, photon energy) allows to extract the effector strength of key determinants during laser-based catatyst doping.



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Acknowledgments

This work has been supported by the Deutsche Bundesstiftung Umwelt. The authors also gratefully acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) for funding the UV ns-laser system used in this study (Project 491146928) and for the financial support under Project 388390466 – TRR 247 and the support by the Interdisciplinary Center for Analytics on the Nanoscale (ICAN) of the University of Duisburg-Essen (DFG-RIsources reference: RI_00313), a DFG-registered core facility (Project Nos. 233512597 and 324659309).

Coeditores:
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ISBN: 978-84-09-86423-2 | MAY 2026