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# Status and demand of research to bring laser generation of nanoparticles in liquids to maturity

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ABSTRACT

Nanoparticles are already implemented as functional elements on surfaces and into volume, but also in hybrid nanostructures. Each application requires specific features regarding size, morphology, surface chemistry, purity, colloidal stability, defects, or doping. However, integration of the "nano-function" into products is still limited due to drawbacks of gas phase and chemical synthesis methods regarding particle aggregation and contamination by adsorbates causing deactivation of their surfaces. In addition, thermodynamically-controlled synthesis methods naturally face limited access to alloy nanoparticle systems with miscibility gaps. The development of new synthesis methods which can be reliably scaled up to industrial levels of production is mandatory to overcome these limitations and then widen the application prospectives of nanomaterials. Since the nineties, Laser Ablation in Liquids (LAL) has proven its reliability and its versatility to synthesize colloidal nanoparticles. More generally, laser/matter interaction in liquids offers several synthesis routes for nanoparticle generation. In addition to LAL, Laser Melting in Liquids (LML), Laser Fragmentation in Liquids (LFL), as well as pulsed Laser Photoreduction/oxidation in Liquids (LPL), offer different routes to obtain colloids with controled nanoparticle sizes. We will present a digest of the breakthroughs achieved in the last years not only on the synthesis control, but also on the understanding of the basics. These achievements suggest that laser generation of nanoparticles in liquids is mature enough for industrial outlets of colloid production, with series products likely to approach the real world in the near future.

## 1. History

Since the nineties, laser ablation in liquids has proven its reliability and its versatility to synthesize nanoparticles, and reviews are available (see Fig. 1) [1,2,3,4,5,6,7,8,9,10]. The method appears with a set of works published in the early nineties. Fig. 1c shows a digest of the key findings in laser synthesis of colloids. In 1991, Lida et al. [17] were looking for a solid sampling technique to prepare samples for inductively coupled plasma atomic emission spectroscopy (ICP-AES). They described the production of "*a suspension consisting of fine particles of around 1 μm or less*" which can be directly introduced into an ICP. A brass sheet was ablated with Nd:YAG laser, and the Cu:Zn ratio in the colloidal suspension appeared to be identical to the one of the target. The method was called LALM (Laser ablation in a Liquid Medium). However, the word *nanoparticle* was still not used. Between 1992 and 1993, several teams have reported the synthesis of carbon based materials [18,19,20,21], but the synthesis processes were not understood at that time [10]. Fojtik and Henglein [19] performed laser ablation of graphite microparticles suspended in toluene with a ruby laser and managed to produce carbon clusters, including C60 and C70. Ogale et al. [18] produced micro diamonds, from 5 μm to 20 μm, by laser irradiation of a graphite target immersed in benzene, using a pulsed ruby laser. In 1993, Neddersen et al. [16] were looking for surface-enhanced Raman spectroscopy active colloids. Stable colloids of Ag, Au, Pt, Pd and Cu nanoparticles were prepared by ablation of metal targets in water and organic solvents using an Nd:YAG laser. A mean size of 20 nm was reported for the Ag nanoparticles. The main advantages of the laser ablation in liquids were then explicitly described: "*A new and highly promising method for preparing metal colloids is described that eliminates some of the problems associated with the chemical procedures* […] *Advantages of this method include the simplicity of the procedure, its versatility with respect to metals or solvents, and the absence of chemical reagents or ions in the final preparation.*" The experimental conditions described in this pioneering work are still the most widely used, including the laser source, its focusing, the use of a batch chamber, and the target motion.

With the increasing number of works, it appears that laser ablation in liquids supports complex mechanisms which has to be controlled or avoided, such as the post-irradiation of the produced colloids. In 1997, Prochazka et al. [22] would like to synthesize size-controlled silver nanoparticles dedicated to SERS. In their contribution, they addressed three topics: the achievement of nanoparticle size-reduction by laser fragmentation of large particles, the aggregation and the sedimentation occurring with time in laser-generated colloids, and the influence of the anions content on the size distribution of laser-generated colloids. To control the particle sizes, they achieved a two-step process, first nanoparticles are produced by laser ablation of a solid target, then the solution is irradiated to induce the fragmentation of the larger particles (> 40 nm). The fragmentation process is now specifically developed to produce well defined nanoparticles from larger ones, including metals [23,24,25,26,27,28,29,30,31], oxides [32,33,34,35,36], semiconductors [37,38,39], and copper hexadecafluorophthalocyanine [40]. In the Prochazka's pioneering work, the effect of the anions content on the size distribution is also shown, however without a positive effect on the colloidal stability. The reason is that the anions concentration used was too high. Indeed, it has been shown later that

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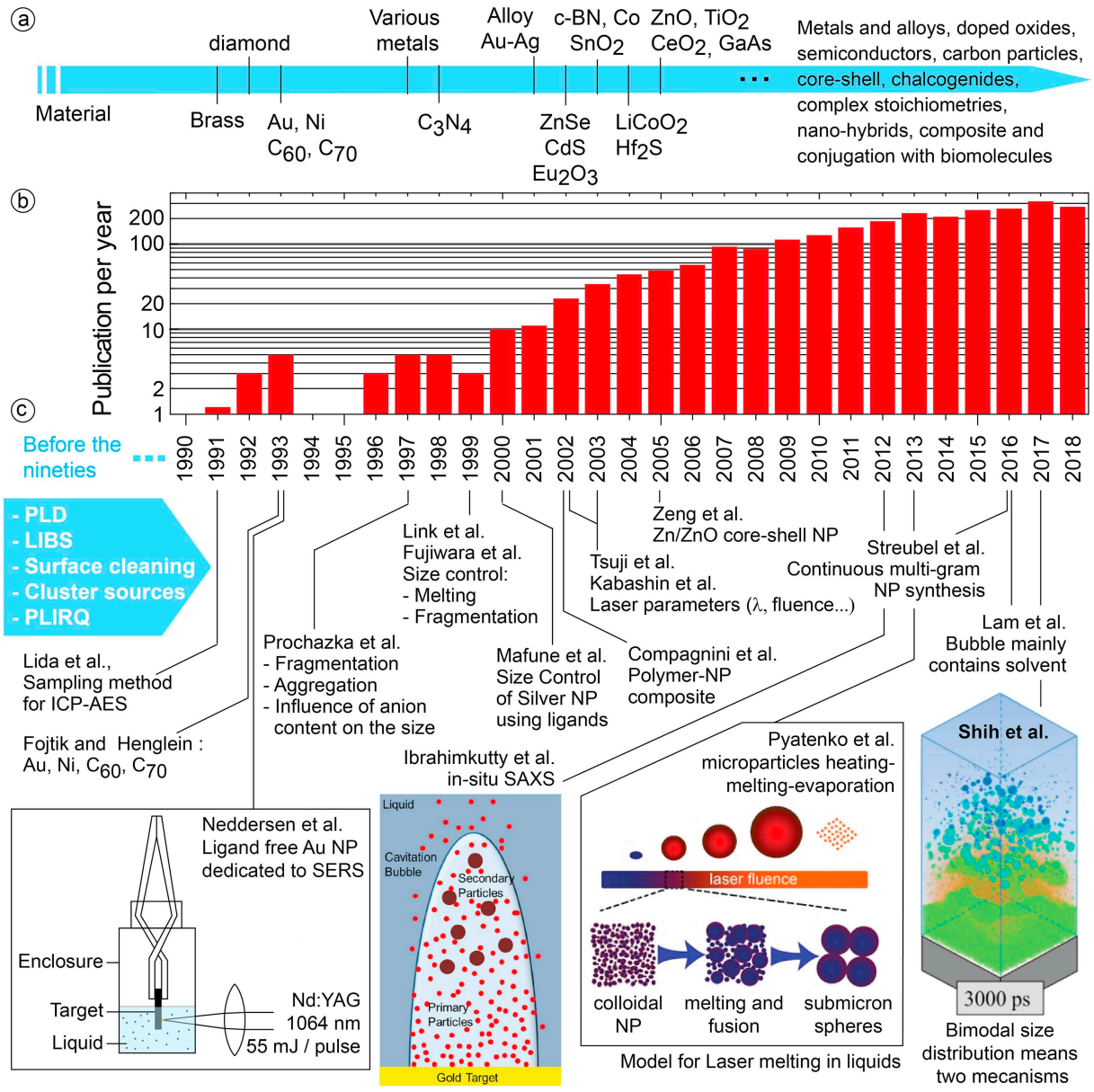


**Fig. 1.** Key findings in laser synthesis of colloids: (a) materials produced using laser ablation in liquids. Comprehensive reviews are available [1,2,3,4,5,6,7,8,9,10]. (b) Publication count from Web of Science™ (Thomson Reuters). (c) A digest of significant milestones (see plain text for details). Regarding the earlier experimental setups dealing with laser matter interaction, PLD, LIBS and PLIRQ stand respectively for pulsed laser deposition, laser-induced breakdown spectroscopy, and pulsed-laser-induced reactive quenching [11,12]. ICP-AES stands for coupled plasma atomic emission spectroscopy. The illustration come from Ibrahimkutty et al. [13], Pyatenko et al. [14], and Shih et al. [15]. The scheme of the original experimental setup from Neddersen et al. [16] has been redrawn.

the colloidal stability of metallic particles can be enhanced when the concentration of chaotropic anions in the solution is between a few tens and a few hundreds of μmol [41,42]. This method yields monodisperse particles, where the anion's action takes place already within the cavitation bubble on microsecond time scale [43].

In 1998, Wang et al. performed the laser ablation of a carbon target in ammonia, and reported the synthesis of Carbon Nitride $C_3N_4$ [44,45]. It then appeared that atoms from the solvent can significantly contribute to the stoichiometry of the produced nanoparticles. Wang et al. named the method Pulsed Laser Induced Liquid-solid Interfacial Reaction (PLIIR) in accordance with the physico-chemical mechanisms they assumed [45]: "(*1*) *The interaction of the laser beam with the bulk target* […] *results in the formation of a high-temperature, high-pressure, and high-density plasma of evaporated materials*. (*2*) *The interaction of the plasma with the liquid at the interface. The high-temperature of the plasma can lead to the production and emission of a high level of positive ions and electrons from the liquid interface*. (*3*) *Most of the positive ions from the solid target and liquid, respectively, react with each other at the interface between the plasma and liquid to form the nuclei of the nanocrystals* […] *Therefore, with the plasma rapidly quenching in the liquid, the metastable-phase nuclei grow large. As the growth times of the nuclei are very short, all metastable phases formed in the reactive process may co-exist, after plasma quenching.*" Even if physico-chemical mechanisms are still under debate, some recent evidence from experiments appears consistent with some assumptions made in this pioneering work. Professor Sakka's group showed that in the early stage, the nascent plasma and the liquid partially merge [46]. They also showed the transfer of $Li^+$ and $Na^+$ ions dissolved in the liquid into the plasma using plasma spectroscopy [47]. The fast quenching of the plasma has also been documented. The cooling rate observed in laser ablation in liquids can reach $10^{10}$ K/s at the early 200 ns [10], faster than the cooling observed in other methods [48]. As emphasized by Wang et al., laser ablation in liquids appears particularly

relevant to prepare metastable phase compounds, including diamond [10], cubic-BN [49,50], tetragonal nanophase of Ge [51], monoclinic $Gd_2O_3$ [52,53,54], but also bimetallic nanoparticles frozen in metastable morphologies [55,56]. Following this pioneering work, several works report the contribution of the solvent in final products, even if the growth mechanisms involving solvent remain scarcely described. Indeed, carbon nitrides were observed after carbon ablation in ammonia [57,58]. Numerous oxides were obtained from laser ablation of pure metal targets in water [59,60,61,62,63,64,65]. Boron carbide $B_4C$ particles were obtained after irradiation of boron powder in various organic solvents [66]. TiN and TiC were obtained from laser ablation of titanium target in liquid nitrogen [67] and dichloroethane [68], respectively. Large area $Cu_2S$ nanorod arrays in the high temperature phase (α) are obtained by laser ablation of a copper foil in carbon disulfide [69]. Ablation of metals in organic solvents can also lead to core-shell structure with a shell consisting in carbon layers [70,3,71]. Based on a series of LAL and LFL works in acetonitrile, Choi's group systematically analyzed the carbon shell thickness into detail, and found a thicker shell with increasing nanoparticle diameter [72]. Interestingly, with high relevance for catalysis, these layers are nitrogen-doped graphitic layers on nickel nanoparticles, as the smartly chosen solvent was acting as both the carbon and nitrogen source. Marzun et al. recently identified the role of dissolved molecular oxygen on the oxidation of copper nanoparticles [73]. They also observed a carbon shell around copper nanoparticles when produced in acetone, attributing its formation to the well-known copper-catalysed C—C coupling. These carbon shells seem not to be fully tight, so potentially allowing molecular access to the copper surface (for catalysis), and at the same time providing oxidation protection.

In 1999, laser-induced melting is reported on gold colloids by two groups [23,24]. The laser-induced melting and evaporation of the nanoparticles, initially considered as a problematic side-effects during LAL, has gained a renewed interest in the last decade. Laser melting in liquids (LML) has been extensively studied [26,27,14,74] to reshape colloids [75,76,77] or to produce sub-micrometer spheres of high purity [78,79,80]. Koshizaki's group recently showed that sub-micrometer spheres created by LML bear up to 40% of the ideal tensile fracture strength calculated using density functional theory [81]. Hence, these spherical particles obtained using LML exhibit quite strong and unique mechanical properties, highly relevant for tribology. The same group has also elaborated a low-threshold random laser from a film composed of highly pure sub-micrometer-sized ZnO spherical particles [78,79].

In 2000, Mafune et al. showed that the addition of ligands in the aqueous solution helps to achieve a better control of the colloidal stability, as well as a size control of the produced nanoparticles [82]. Such a positive effect of the ligands has been observed for both LAL and LFL. It also appears that the ligands can help to prevent the formation of metal hydroxyde, as observed for ZnO synthesis [83,84], but can also lead to a control of the shape of the nanoparticles, as observed for $Ag_2O$ [85]. One can find a comprehensive review on the use of ligands in Zhang et al. [6].

In the early days of the millennium, the basics of nanoparticle generation and excitation by lasers in liquids were laid, including Laser Ablation in Liquids (LAL), laser fragmentation in liquids (LFL), and laser melting in liquids (LML). Laser parameters have been addressed [86,87]. Synthesized materials are becoming more and more diversified (see Fig. 1a), and the number of contributions to the field is rising together with the number of contributors (see Fig. 1b).

More recently laser generation of hydrogen peroxide has been demonstrated [88], opening the door to photochemistry [89]. It leads to another strategy, which can be called laser photo-reaction in liquid (LPL), bringing closer laser generation of nanoparticles in liquids to photochemistry. Laser-mediated reduction of metal salts is developed to produce core-shell particles [90] or nanoparticles composed of materials with low miscibility [91]. Fluorine-Doped Carbon Nanoparticles are laser-generated from Hexafluorobenzene [92] and Bare Iron Nanoparticles are laser-generated from Ferrocene Hexane [93].

Pulsed laser ablation in liquids is also used to produce precursor solution, and then a post-treatment is applied to the freshly produced colloid to control the crystal structure or the particle shape. Silver nanoplates are produced by addition of hydrogen peroxide in LAL-generated colloidal silver [94]. $Pt/SnO_2$ nanocomposites are produced after ageing LAL-generated non-stoichiometric $SnO_x$ nanoparticles in a solution of $Na_2PtCl_4$ [95]. Laser ablation of a tungsten target followed by an ageing treatment [95,96] or an hydrothermal treatment [97] leads to various shaped particles of tungsten oxide $WO_3$. Ageing can also lead to phase transition, from LAL-produced amorphous nanoparticles into nanoparticles with well-defined crystal structure. Amorphous selenium nanoparticles evolve into trigonal Se [96]. Amorphous germanium nanoparticles evolve into a metastable tetragonal structure, and then transformed into the stable cubic structure [98].

Laser-based methods of generation of colloids are becoming more and more diversified with the aim to reach a better control of the product (size, morphology, crystal structure), which remains an inherent shortcoming of laser ablation in liquids involving highly transient physico-chemical processes. That is why many efforts are made to achieve a comprehensive description of these processes.

## 2. Understanding of the processes

Along all these years, many teams have sought to understand and describe the physico-chemical processes involved in the laser generation of nanoparticles in liquids. Many efforts have been made to develop *in situ* characterization. Fig. 2 outlines the different characterizations reported in the literature, as well as the provided information, and the reachable time scale for each experimental method. From these measurements some findings are now widely accepted. First of all, *in situ* time-resolved small-angle X-ray scattering [13,118,119,43], as well as light scattering experiments [102,101], not only showed that the nanoparticles are confined inside the vapor bubble, but also showed that nanoparticles are present from the early stage (see insets in Fig. 1c). In particular, light scattering experiments suggest that nanoparticles are present after a few hundreds of nanoseconds. This is consistent with the fast cooling of the plasma reported from plasma spectroscopy [10], keeping in mind that the fast cooling of a laser-generated hot gas or plasma leads to nucleation and growth of particles [131,48,132]. This scenario is also supported by numerical simulations. In particular, a breakthrough in the understanding has recently been achieved thanks to molecular dynamics. The Zhigilei's group has developed an atomistic simulation of the laser ablation of metal targets in liquid environment [15,133,134]. They clearly showed two mechanisms of nanoparticles generation occurring in less than a few nanoseconds for femtosecond and picosecond pulses: (i) a rapid nucleation and growth of sub-10 nm particles in the water-metal mixing region, and (ii) an instability of the superheated metal layer formed at the interface with water leading to particles of a few tens of nanometers. They then succeeded to explain the bi-modal size distribution frequently reported from transmission electron microscopy [135,136], but also from SAXS measurements: a first population of nanoparticles of around 10 nm diameter, and a second population of larger nanoparticles with diameters of a few tens of nanometers.

Nevertheless questions remain. The process leading to the fast vaporization of the solvent [116], to its decomposition, and then to its reactivity [72] is not fully described. The transfer of solvated ions ($Na^+$, $Li^+$) into the plasma has been reported [47], which is unexpected for standard vaporization. It has then been suggested that for nanosecond pulses the water experiences explosive boiling. This echoes the questions on the size quenching induced by anions for metallic particles, or ligands in general. The size quenching induced by the chaotropic anion's action during laser synthesis of metallic particles in a solution of low salinity happens already in the vapor phase of the cavitation bubble [43]. Drastic size quenching observed with ligands [130,111,84] is also

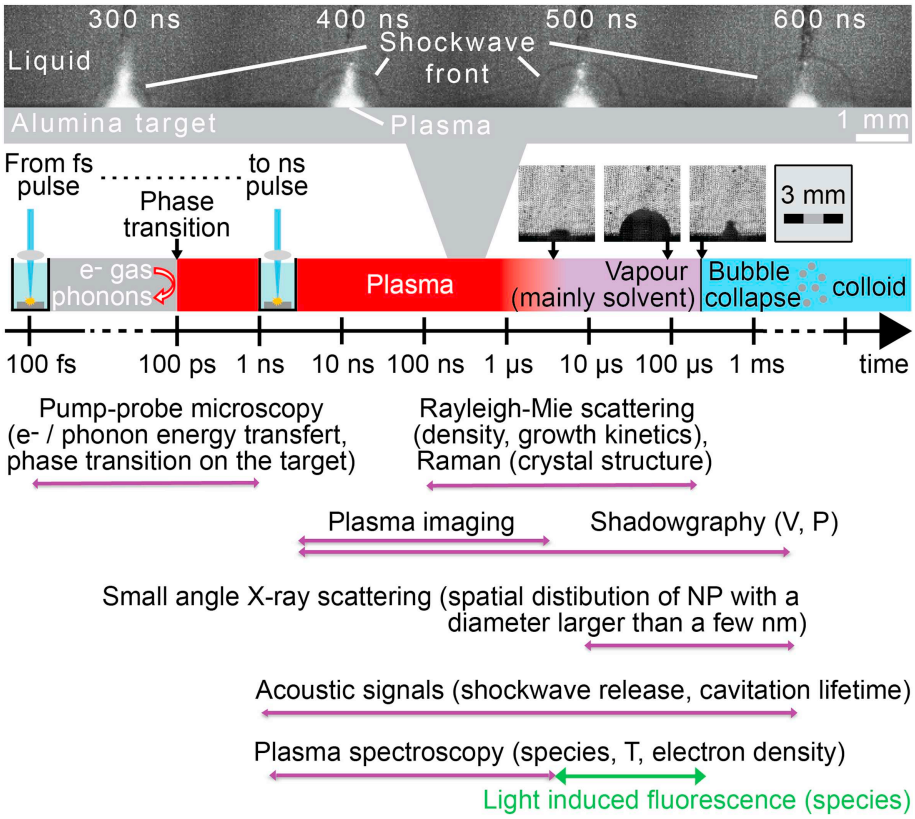


**Fig. 2.** Overlapping time scales of laser synthesis of colloids. At the top, the spatial distribution of the plasma is observed from shadowgraph imaging, as well as the laser induce shockwave [10]. Three pictures from shadowgraph imaging show the cavitation bubble (ablation of a carbon target, 5 ns pulse duration, 45 mJ/pulse, 355 nm) [10]. The time frame gives some insight into the different characteristic times of the main physical process in laser ablation in liquids: energy transfer from the laser excited electron gas to the matrix (a few ps), phase transition of the target (above 100 ps), plasma lifetime (a few µs), and bubble lifetime (a few hundreds of microseconds). *In situ* characterization has been developed to obtain information on the processes involved during laser ablation in liquids: Pump-probe microscopy [99,100] Rayleigh-Mie scattering [101,102,103], Raman scattering [104], plasma imaging [46,105,106,107,108], shadowgraph imaging [103,109,110,111,112,113,114,115,116,117], small angle X-ray scattering [13,43,118,119], acoustic signals [111,120,121], and plasma spectroscopy [10,47,101,107,112,122,123,124,125,126,127,128,129,130]. The arrows display the reachable time scale for each experimental method, taking into account the integration time of the signal. The main information provide by each experimental method are also displayed. Light-induced fluorescence has not been reported yet in the framework of LAL, but it would be the next step to obtain deeper information on the intermediate species.

consistent with an early size quenching during the cooling of the plasma, and then to an early penetration of the ligands into the system. On the other hand, it is difficult to imagine that the ligands were not decomposed when they interact with the plasma, since the decomposition of the solvent can occur [92,93]. As a matter of fact, hydrogen and oxygen emission has been reported during laser ablation in water [137], as well as during laser irradiation of colloids [137,138,139,88].

At last, if one accepts that the nanoparticles appear early in the plasma, the maturation of the particles during whole lifetime of the vapor bubble remains poorly addressed. One can imaging Ostwald ripening, coalescence, or aggregation.

## 3. Economical viability

Nanoparticles are widely implemented with a wide spectrum of applications such as optics, optoelectronics, electronics, biomedicine, pharma and health, catalysis, energy science, automotive industry, or nutrition. These high-end-applications of colloidal nanoparticles require very well defined material properties not being compromised by impurities, and downstream processability of colloids. Both criteria perfectly met by laser-synthesized colloids. In contrast to chemical routes, LAL does not require using surfactants or chemical precursors. Moreover, LAL can be performed in a wide variety of liquids beyond the standard solvents, including ionic liquids [142,143], and liquefied gas [67,144,145,146,147,148]. Hence, as an alternative synthesis route, laser generation of nanoparticles in liquids has proven its capability to generate ligand-free colloidal nanoparticles with high purity for a variety of materials [6]. Ligand-free surfaces are interesting for catalysis as it drastically increases the yield of particle deposition on the solid co-catalyst (that is used, *e.g.* for wash-coats or fuel cell electrode impregnation). This year, the first real fuel cell device has been demonstrated based on laser-generated Pt/C nanoparticles [149].

In materials science, alloy nanoparticles bear great potential [150,151,152]. Alloys illustrate one of the advantages of LAL with respect to usual chemical synthesis. The transferability of the laser synthesis route to a variety of materials further enabled high-throughput screening of molar fraction series, sometimes not accessible to usual chemical synthesis. Alloy nanoparticles series were synthesized (*i.e.* AgAu, NiMo, AuFe, AgNi, FeNi, AlMg) [153,140,154,155,156,157,55,137]. Interestingly, on the one hand, phase diagram seems to play a role in ruling the nanoparticles crystal structure and phase segregation, but at the same time, unusual structures difficult to access by conventional synthesis methods are yielded, indicating kinetic control.

Beyond the above examples, the versatility of the aforementioned synthesis methods involves a high potential for applications, including bioimaging [158,159,160], cancer therapy [161,162], antibacterial coatings [163], heterogeneous catalysis [164,157,95,8,165], photoelectrocatalysis [166], proton exchange membrane fuel cell [149], oxygen evolution reaction [36,167], hydrogen evolution reaction [168], water oxidation catalysts [169], plasmonic [170], Fano resonance [171], random lasers [78,79], photovoltaic [172,173,174], additive manufacturing [175,176], and nanoparticle-polymer composites [7,177,178]. Surface-functionalized nanoparticles can be prepared in a one-step process [158]. Looking at the application in life sciences, the biodistribution issue has been addressed [179,180].

Recently the Gökce's group achieved a crucial breakthrough for industrial outlets, but also for fundamental studies where a large amount of material is needed to conduct experiments and to address reproducibility, specifically for application in life-sciences. Good reproducibility and significant up-scaling of nanoparticle generation were achieved by a continuous flow synthesis using a high-power ultrafast laser system leading to a productivity of up to multi-gram, multi-liter colloidal nanoparticles [181,182]. LAL is then scalable and

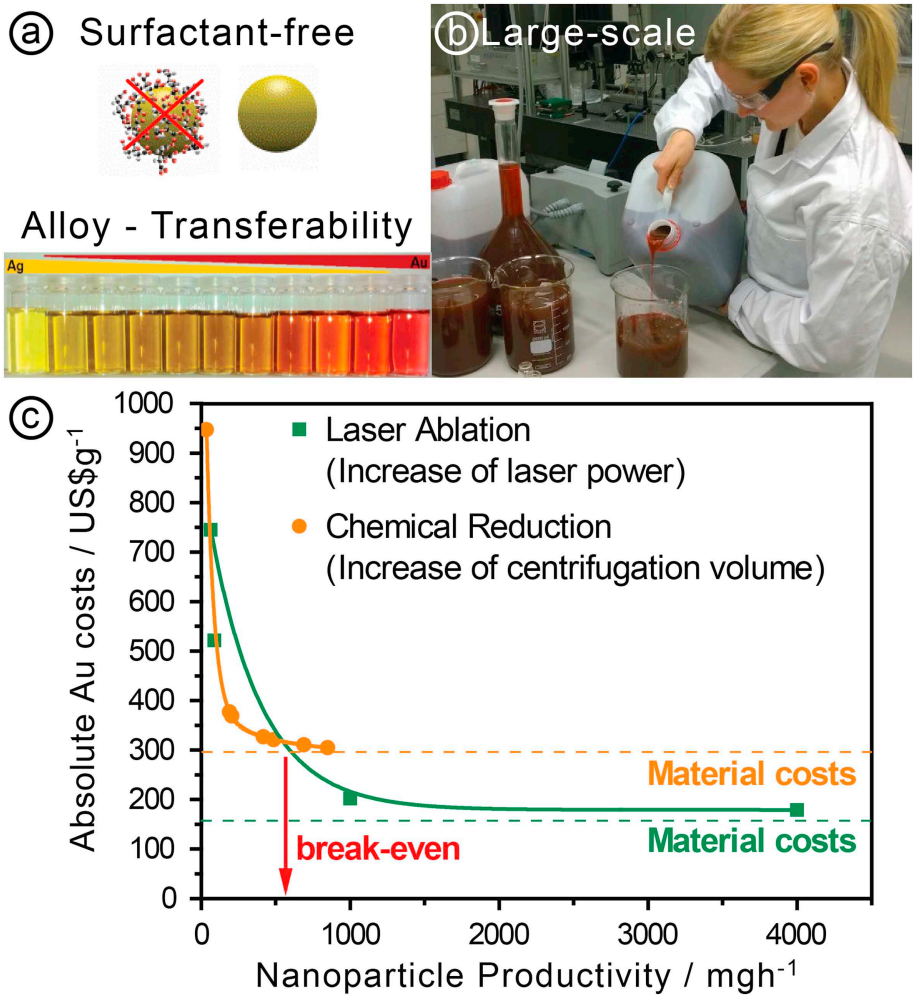


**Fig. 3.** a) Laser ablation in liquids enables the production of surfactant-free alloys [140]. b) Dr. Galina Marzun handling multi-liter of laser-made concentrated colloidal gold (multi-gram). c) Absolute manufacturing- and labor costs for the synthesis of 1 g colloidal gold in dependence of the nanoparticle productivity for pulsed laser ablation of gold in water and chemical reduction.
(Figure from Jendrzej et al. [141].)

economically feasible [141] (Fig. 3).

Thanks to these advantages, companies are doing business since almost a decade with laser-generated nanoparticles, as well as LAL-made heterogeneous catalyst powders: Particular GmbH [183], the distributor Strem Chemicals, Inc. (USA), and the i-Colloid in-house branch of IMRA (USA) [184]. The materials produced support a concentration of at least 100 mg $L^{-1}$. Biocompatible colloids and ligands-free colloids are available.

## 4. Future challenge

The progress in these fields is biannually presented at the international ANGEL meeting [185], and special issues are published concomitantly [186,187,188,189,190,191]. It appears that the question of the nanoparticle formation is still only partially answered. Molecular dynamics as well as experimental developments tend to show that the processes occurring at the early time scales, ranging from several femtoseconds to several microseconds, define the characteristics of the produced nanoparticles [192]. Numerical and experimental developments are then mandatory to catch the early time scales. One of the main challenge for molecular dynamics simulation is to include laser-matter interaction for nanosecond pulses. Indeed numerical simulation assuming femto- and picosecond pulse duration cannot catch the whole complexity of the processes resulting from the plasma-laser interaction which occurs for nanosecond pulse duration. Plasma/liquid interaction has to be addressed to understand the fast vaporization of the solvent, as well as the parameter favouring its decomposition and its reactivity. Light-induced fluorescence would help to obtain deeper information on the intermediate species.

The purity of the product, the selectivity in the crystal structure of the oxide for instance, a fine control of the particle size distribution, and a tight control of the morphology of the particles are shortcomings of the former laser ablation in liquids. As a consequence, the community has developed various strategies to obtain a tight control of the products, leading to various laser-based methods of colloids generation. However, efforts must be maintained to reach the tight control achieved by the chemical routes.

Last but not least, the aforementioned companies sell laser-generated metal and metal alloy colloids in the fine chemicals market. But there is a trend towards coming closer to application, *e.g.* colloids developed for biotechnology (lateral flow assays, IMRA), or so-called supported nanoparticles for heterogeneous catalysis in larger scale (catalyst powders, STREM Chemicals, Particular GmbH). On the one hand, this points out the maturity of the laser-based synthesis of colloids. But on the other hand, end-products based on laser-made colloids did not reach the market, yet. An industrial series product or manufacturing process based on laser-synthesized particles is yet to come.

## References


[1] Z. Yan, D.B. Chrisey, Pulsed laser ablation in liquid for micro-/nanostructure generation, J Photochem Photobiol C: Photochem Rev 13 (3) (2012) 204, https://doi.org/10.1016/j.jphotochemrev.2012.04.004.

[2] H. Zeng, X.-W. Du, S.C. Singh, S.A. Kulinich, S. Yang, J. He, W. Cai, Nanomaterials via laser ablation/irradiation in liquid: a review, Adv. Funct. Mater. 22 (2012) 1333, https://doi.org/10.1002/adfm.201102295.

[3] V. Amendola, M. Meneghetti, What controls the composition and the structure of nanomaterials generated by laser ablation in liquid solution? Phys. Chem. Chem. Phys. 15 (9) (2013) 3027–3046, https://doi.org/10.1039/c2cp42895d.

[4] S. Barcikowski, G. Compagnini, Advanced nanoparticle generation and excitation by lasers in liquids, Phys. Chem. Chem. Phys. 15 (2013) 3022.

[5] J. Xiao, P. Liu, C.X. Wang, G.W. Yang, External field-assisted laser ablation in liquid: an efficient strategy for nanocrystal synthesis and nanostructure assembly, Prog. Mater. Sci. 87 (2017) 140–220, https://doi.org/10.1016/j.pmatsci.2017.02.004.

[6] D. Zhang, B. Goekce, S. Barcikowski, Laser synthesis and processing of colloids: fundamentals and applications, Chem. Rev. 117 (5) (2017) 3990–4103, https://doi.org/10.1021/acs.chemrev.6b00468.

[7] D. Zhang, B. Goekce, Perspective of laser-prototyping nanoparticle-polymer composites, Appl. Surf. Sci. 392 (2017) 991–1003, https://doi.org/10.1016/j.apsusc.2016.09.150.

[8] D. Zhang, J. Liu, P. Li, Z. Tian, C. Liang, Recent advances in surfactant-free, surface-charged, and defect-rich catalysts developed by laser ablation and processing in liquids, ChemNanoMat 3 (8) (2017) 512–533, https://doi.org/10.1002/cnma.201700079.

[9] D. Zhang, J. Liu, C. Liang, Perspective on how laser-ablated particles grow in liquids, Sci. China-Phys. Mech. Astron. 60 (7) (2017) 074201, , https://doi.org/10.1007/s11433-017-9035-8.

[10] D. Amans, M. Diouf, J. Lam, G. Ledoux, C. Dujardin, Origin of the nano-carbon allotropes in pulsed laser ablation in liquids synthesis, J. Colloid Interface Sci. 489 (2017) 114–125, https://doi.org/10.1016/j.jcis.2016.08.017.

[11] S.B. Ogale, P.P. Patil, D.M. Phase, Y.V. Bhandarkar, S.K. Kulkarni, S. Kulkarni, S.V. Ghaisas, S.M. Kanetkar, Synthesis of metastable phases via pulsed-laser-induced reactive quenching at liquid–solid interfaces, Phys. Rev. B 36 (1987) 8237, https://doi.org/10.1103/PhysRevB.36.8237.

[12] P.P. Patil, D.M. Phase, S.A. Kulkarni, S.V. Ghaisas, S.K. Kulkarni, S.M. Kanetkar, S.B. Ogale, V.G. Bhide, Pulsed-laser induced reactive quenching at a liquid-solid interface - aqueous oxidation of iron, Phys. Rev. Lett. 58 (3) (1987) 238–241, https://doi.org/10.1103/PhysRevLett.58.238.

[13] S. Ibrahimkutty, P. Wagener, A. Menzel, A. Plech, S. Barcikowski, Nanoparticle formation in a cavitation bubble after pulsed laser ablation in liquid studied with high time resolution small angle x-ray scattering, Appl. Phys. Lett. 101 (10) (2012) 103104, , https://doi.org/10.1063/1.4750250.

[14] A. Pyatenko, H. Wang, N. Koshizaki, T. Tsuji, Mechanism of pulse laser interaction with colloidal nanoparticles, Laser Photon. Rev. 7 (4) (2013) 596–604, https://doi.org/10.1002/lpor.201300013.

[15] C.-Y. Shih, C. Wu, M.V. Shugaev, L.V. Zhigilei, Atomistic modeling of nanoparticle generation in short pulse laser ablation of thin metal films in water, J. Colloid Interface Sci. 489 (SI) (2017) 3–17, https://doi.org/10.1016/j.jcis.2016.10.029.

[16] J. Neddersen, G. Chumanov, T. Cotton, Laser-ablation of metals - a new method for preparing SERS active colloids, Appl. Spectrosc. 47 (1993) 1959, https://doi.org/10.1366/0003702934066460.

[17] Y. Lida, A. Tsuge, Y. Uwamino, H. Morikawa, T. Ishizuka, Laser ablation in a liquid-medium as a technique for solid sampling, J. Anal. At. Spectrom. 6 (7) (1991) 541–544.

[18] S.B. Ogale, A.P. Malshe, S.M. Kanetkar, S.T. Kshirsagar, Formation of diamond particulates by pulsed ruby-laser irradiation of graphite immersed in benzene, Solid State Commun. 84 (4) (1992) 371–373, https://doi.org/10.1016/0038-1098(92)90479-S.

[19] A. Fojtik, A. Henglein, Laser ablation of films and suspended particles in a solvent - formation of cluster and colloid solutions, Ber. Bunsen-Ges. Phys. Chem. Chem. Phys. 97 (2) (1993) 252–254.

[20] J. Singh, M. Vellaikal, J. Narayan, Laser-enhanced synthesis and processing of diamond films from liquid hydrocarbons, J. Appl. Phys. 73 (9) (1993) 4351–4356, https://doi.org/10.1063/1.352819.

[21] A.K. Sharma, R.D. Vispute, D.S. Joag, S.B. Ogale, S.D. Joag, P. Ayyub, M. Multani, G.K. Dey, S. Banerjee, Diamond nucleation at the organic liquid-metal interface by laser-induced reactive quenching, Mater. Lett. 17 (1–2) (1993) 42–48, https://doi.org/10.1016/0167-577X(93)90145-N.

[22] M. Prochazka, P. Mojzes, J. Stepanek, B. Vlckova, P.Y. Turpin, Probing applications of laser ablated Ag colloids in SERS spectroscopy: improvement of ablation procedure and SERS spectral testing, Anal. Chem. 69 (1997) 5103, https://doi.org/10.1021/ac970683+.

[23] S. Link, C. Burda, M. Mohamed, B. Nikoobakht, M. El-Sayed, Laser photothermal melting and fragmentation of gold nanorods: energy and laser pulse-width dependence, J. Phys. Chem. A 103 (9) (1999) 1165–1170, https://doi.org/10.1021/jp983141k.

[24] H. Fujiwara, S. Yanagida, P. Kamat, Visible laser induced fusion and fragmentation of thionicotinamide-capped gold nanoparticles, J. Phys. Chem. B 103 (14) (1999) 2589–2591, https://doi.org/10.1021/jp984429c.

[25] S. Besner, A.V. Kabashin, M. Meunier, Fragmentation of colloidal nanoparticles by femtosecond laser-induced supercontinuum generation, Appl. Phys. Lett. 89 (23) (2006) 233122, , https://doi.org/10.1063/1.2402944.

[26] D. Werner, A. Furube, T. Okamoto, S. Hashimoto, Femtosecond laser-induced size reduction of aqueous gold nanoparticles: in situ and pump-probe spectroscopy investigations revealing coulomb explosion, J. Phys. Chem. C 115 (17) (2011) 8503–8512, https://doi.org/10.1021/jp112262u.

[27] D. Werner, S. Hashimoto, Improved working model for interpreting the excitation wavelength- and fluence-dependent response in pulsed laser-induced size reduction of aqueous gold nanoparticles, J. Phys. Chem. C 115 (12) (2011) 5063–5072, https://doi.org/10.1021/jp109255g.

[28] K. Maximova, A. Aristov, M. Sentis, A.V. Kabashin, Size-controllable synthesis of bare gold nanoparticles by femtosecond laser fragmentation in water, Nanotechnology 26 (6) (2015) 065601, , https://doi.org/10.1088/0957-4484/26/6/065601.

[29] M. Kawasaki, K. Masuda, Laser fragmentation of water-suspended gold flakes via spherical submicroparticles to fine nanoparticles, J. Phys. Chem. B 109 (19) (2005) 9379–9388, https://doi.org/10.1021/jp0442044.

[30] L. Delfour, T.E. Itina, Mechanisms of ultrashort laser-induced fragmentation of metal nanoparticles in liquids: numerical insights, J. Phys. Chem. C 119 (24) (2015) 13893–13900, https://doi.org/10.1021/acs.jpcc.5b02084.

[31] A.R. Ziefuss, S. Reichenberger, C. Rehbock, I. Chakraborty, M. Gharib, W.J. Parak, S. Barcikowski, Laser fragmentation of colloidal gold nanoparticles with high-intensity nanosecond pulses is driven by a single-step fragmentation mechanism with a defined educt particle-size threshold, J. Phys. Chem. C 122 (38) (2018) 22125–22136, https://doi.org/10.1021/acs.jpcc.8b04374.

[32] H. Usui, T. Sasaki, N. Koshizaki, Optical transmittance of indium tin oxide nanoparticles prepared by laser-induced fragmentation in water, J. Phys. Chem. B 110 (26) (2006) 12890–12895, https://doi.org/10.1021/jp061866f.

[33] H. Zeng, S. Yang, W. Cai, Reshaping formation and luminescence evolution of ZnO quantum dots by laser-induced fragmentation in liquid, J. Phys. Chem. C 115 (12) (2011) 5038–5043, https://doi.org/10.1021/jp109010c.

[34] B.K. Pandey, A.K. Shahi, J. Shah, R.K. Kotnala, R. Gopal, Optical and magnetic properties of $Fe_2O_3$ nanoparticles synthesized by laser ablation/fragmentation technique in different liquid media, Appl. Surf. Sci. 289 (2014) 462–471, https://doi.org/10.1016/j.apsusc.2013.11.009.

[35] M. Amin, J. Tomko, J.J. Naddeo, R. Jimenez, D.M. Bubb, M. Steiner, J. Fitz-Gerald, S.M. O'Malley, Laser-assisted synthesis of ultra-small anatase TiO2 nanoparticles, Appl. Surf. Sci. 348 (2015) 30–37, https://doi.org/10.1016/j.apsusc.2014.12.191.

[36] F. Waag, B. Goekce, C. Kalapu, G. Bendt, S. Salamon, J. Landers, U. Hagemann, M. Heidelmann, S. Schulz, H. Wende, N. Hartmann, M. Behrens, S. Barcikowski, Adjusting the catalytic properties of cobalt ferrite nanoparticles by pulsed laser fragmentation in water with defined energy dose, Sci. Rep. 7 (2017) 13161, , https://doi.org/10.1038/s41598-017-13333-z.

[37] C. Chubilleau, B. Lenoir, S. Migot, A. Dauscher, Laser fragmentation in liquid medium: a new way for the synthesis of PbTe nanoparticles, J. Colloid Interface Sci. 357 (1) (2011) 13–17, https://doi.org/10.1016/j.jcis.2011.01.057.

[38] P. Blandin, K.A. Maximova, M.B. Gongalsky, J.F. Sanchez-Royo, V.S. Chirvony, M. Sentis, V.Y. Timoshenko, A.V. Kabashin, Femtosecond laser fragmentation from water-dispersed microcolloids: toward fast controllable growth of ultrapure Si-based nanomaterials for biological applications, J. Mat. Chem. B 1 (19) (2013) 2489–2495, https://doi.org/10.1039/c3tb20285b.

[39] G.L. Plautz, I.L. Graff, W.H. Schreiner, A.G. Bezerra, Evolution of size distribution, optical properties, and structure of Si nanoparticles obtained by laser-assisted fragmentation, Appl. Phys. A Mater. Sci. Process. 123 (5) (2017) 359, https://doi.org/10.1007/s00339-017-0961-y.

[40] R. Kihara, S. Imada, T. Kawai, T. Asahi, Fabrication of nanorods colloids of copper hexadecafluorophthalocyanine by nanosecond-pulse laser fragmentation in organic solvents, Appl. Surf. Sci. 478 (2019) 532–538, https://doi.org/10.1016/j.apsusc.2019.01.221.

[41] V. Merk, C. Rehbock, F. Becker, U. Hagemann, H. Nienhaus, S. Barcikowski, situ non-DLVO stabilization of surfactant-free, plasmonic gold nanoparticles: effect of Hofmeister's anions, Langmuir 30 (15), (2014), pp. 4213–4222, https://doi.org/10.1021/la404556a.

[42] C. Pfeiffer, C. Rehbock, D. Hühn, C. Carrillo-Carrion, D. Jimenez de Aberasturi, V. Merk, S. Barcikowski, W.J. Parak, Interaction of colloidal nanoparticles with their local environment: the (ionic) nanoenvironment around nanoparticles is different from bulk and determines the physico-chemical properties of the nanoparticles, J. R. Soc. Interface 11 (2014) 20130931, , https://doi.org/10.1098/rsif.2013.0931.

[43] A. Letzel, B. Goekce, P. Wagener, S. Ibrahimkutty, A. Menzel, A. Plech, S. Barcikowski, Size quenching during laser synthesis of colloids happens already in the vapor phase of the cavitation bubble, J. Phys. Chem. C 121 (9) (2017) 5356–5365, https://doi.org/10.1021/acs.jpcc.6b12554.

[44] J.B. Wang, Q.X. Liu, G.W. Yang, The preparation of cubic $C_3N_4$ by pulsed-laser inducing reaction on liquid-solid interface, Chem. J. Chin. Univ.-Chin. 19 (1998) 1719.

[45] G.W. Yang, J.B. Wang, Carbon nitride nanocrystals having cubic structure using pulsed laser induced liquid-solid interfacial reaction, Appl. Phys. A Mater. Sci. Process. 71 (2000) 343, https://doi.org/10.1007/s003390000590.

[46] A. Tamura, A. Matsumoto, K. Fukami, N. Nishi, T. Sakka, Simultaneous observation of nascent plasma and bubble induced by laser ablation in water with various pulse durations, J. Appl. Phys. 117 (17) (2015) 173304, , https://doi.org/10.1063/1.4919729.

[47] A. Matsumoto, A. Tamura, T. Honda, T. Hirota, K. Kobayashi, S. Katakura, N. Nishi, K.-i. Amano, K. Fukami, T. Sakka, Transfer of the species dissolved in a liquid into laser ablation plasma: an approach using emission spectroscopy, J. Phys. Chem. C 119 (47) (2015) 26506–26511, https://doi.org/10.1021/acs.jpcc.

5b07769.
[48] P. Melinon, V. Paillard, V. Dupuis, A. Perez, P. Jensen, A. Hoareau, M. Broyer, J.L. Vialle, M. Pellarin, B. Baguenard, J. Lerme, From free clusters to cluster-assembled materials, Int. J. Mod. Phys. B 9 (4–5) (1995) 339–397, https://doi.org/10.1142/S021797929500015X.
[49] J.B. Wang, G.W. Yang, C.Y. Zhang, X.L. Zhong, Z.H.A. Ren, Cubic-BN nanocrystals synthesis by pulsed laser induced liquid-solid interfacial reaction, Chem. Phys. Lett. 367 (2003) 10, https://doi.org/10.1016/S0009-2614(02)01656-1.
[50] Q.X. Liu, G.W. Yang, J.X. Zhang, Phase transition between cubic-BN and hexagonal BN upon pulsed laser induced liquid-solid interfacial reaction, Chem. Phys. Lett. 373 (2003) 57, https://doi.org/10.1016/S0009-2614(03)00580-3.
[51] P. Liu, Y.L. Cao, X.Y. Chen, G.W. Yang, Trapping high-pressure nanophase of ge upon laser ablation in liquid, Cryst. Growth Des. 9 (3) (2009) 1390–1393, https://doi.org/10.1021/cg800633j.
[52] N.V. Tarasenko, A.V. Butsen, A.A. Nevar, Laser ablation of gadolinium targets in liquids for nanoparticle preparation, Appl. Phys. A Mater. Sci. Process. 93 (4) (2008) 837–841, https://doi.org/10.1007/s00339-008-4737-2.
[53] S.K. Singh, K. Kumar, S.B. Rai, Synthesis and spectroscopy of transparent colloidal solution of $Gd_2O_3$:$Er^{3+}$,$Yb^{3+}$ spherical nanocrystals by pulsed laser ablation, Mater. Sci. Eng. B 166 (2) (2010) 180–184, https://doi.org/10.1016/j.mseb.2009.11.018.
[54] J. Liu, X. Tian, H. Chen, Y. Shao, G. Yang, D. Chen, Near-infrared to visible and near-infrared upconversion of monoclinic $Gd_2O_3$:$Yb^{3+}$/$Tm^{3+}$ nanoparticles prepared by laser ablation in liquid for fluorescence imaging, Appl. Surf. Sci. 348 (2015) 60–65, https://doi.org/10.1016/j.apsusc.2014.11.105.
[55] A. Tymoczko, M. Kamp, O. Prymak, C. Rehbock, J. Jakobi, U. Schuermann, L. Kienle, S. Barcikowski, How the crystal structure and phase segregation of Au-Fe alloy nanoparticles are ruled by the molar fraction and size, Nanoscale 10 (35) (2018) 16434–16437, https://doi.org/10.1039/c8nr03962c.
[56] M. Kamp, A. Tymoczko, U. Schuermann, J. Jakobi, C. Rehbock, K. Raetzke, S. Barcikowski, L. Kienle, Temperature-dependent ultrastructure transformation of Au-Fe nanoparticles investigated by in situ scanning transmission electron microscopy, Cryst. Growth Des. 18 (9) (2018) 5434–5440, https://doi.org/10.1021/acs.cgd.8b00809.
[57] L. Yang, P.W. May, L. Yin, R. Brown, T.B. Scott, Direct growth of highly organized crystalline carbon nitride from liquid-phase pulsed laser ablation, Chem. Mat. 18 (2006) 5058, https://doi.org/10.1021/cm061485e.
[58] L. Yang, P.W. May, L. Yin, J.A. Smith, K.N. Rosser, Ultra fine carbon nitride nanocrystals synthesized by laser ablation in liquid solution, J. Nanopart. Res. 9 (6) (2007) 1181–1185, https://doi.org/10.1007/s11051-006-9192-4.
[59] J.S. Golightly, A.W. Castleman, Analysis of titanium nanoparticles created by laser irradiation under liquid environments, J. Phys. Chem. B 110 (40) (2006) 19979–19984, https://doi.org/10.1021/jp062123x.
[60] I.L. Liu, P. Shen, S.Y. Chen, $H^+$- and $Al^{2+}$-codoped $Al_2O_3$ nanoparticles with spinel-type related structures by pulsed laser ablation in water, J. Phys. Chem. C 114 (2010) 7751, https://doi.org/10.1021/jp1002325.
[61] M. Muniz-Miranda, C. Gellini, E. Giorgetti, Surface-enhanced Raman scattering from copper nanoparticles obtained by laser ablation, J. Phys. Chem. C 115 (12) (2011) 5021–5027, https://doi.org/10.1021/jp1086027.
[62] A. Nath, A. Khare, Size induced structural modifications in copper oxide nanoparticles synthesized via laser ablation in liquids, J. Appl. Phys. 110 (4) (2011) 043111, , https://doi.org/10.1063/1.3626463.
[63] V. Amendola, P. Riello, S. Polizzi, S. Fiameni, C. Innocenti, C. Sangregorio, M. Meneghetti, Magnetic iron oxide nanoparticles with tunable size and free surface obtained via a “green” approach based on laser irradiation in water, J. Mater. Chem. 21 (46) (2011) 18665–18673, https://doi.org/10.1039/c1jm13680a.
[64] V. Piriyawong, V. Thongpool, P. Asanithi, P. Limsuwan, Preparation and characterization of alumina nanoparticles in deionized water using laser ablation technique, J. Nanomater. (2012) (2012) 819403, , https://doi.org/10.1155/2012/819403.
[65] S.A. Al-Mamun, R. Nakajima, T. Ishigaki, Tuning the size of aluminum oxide nanoparticles synthesized by laser ablation in water using physical and chemical approaches, J. Colloid Interface Sci. 392 (2013) 172, https://doi.org/10.1016/j.jcis.2012.10.027.
[66] Y. Ishikawa, Y. Shimizu, T. Sasaki, N. Koshizaki, Boron carbide spherical particles encapsulated in graphite prepared by pulsed laser irradiation of boron in liquid medium, Appl. Phys. Lett. 91 (16) (2007) 161110, , https://doi.org/10.1063/1.2799786.
[67] N. Takada, T. Sasaki, K. Sasaki, Synthesis of crystalline TiN and Si particles by laser ablation in liquid nitrogen, Appl. Phys. A Mater. Sci. Process. 93 (4) (2008) 833–836, https://doi.org/10.1007/s00339-008-4748-z.
[68] S. Dolgaev, A. Simakin, V. Voronov, G. Shafeev, F. Bozon-Verduraz, Nanoparticles produced by laser ablation of solids in liquid environment, Appl. Surf. Sci. 186 (1–4) (2002) 546–551, https://doi.org/10.1016/S0169-4332(01)00634-1.
[69] H. Bao, H. Zhang, L. Zhou, G. Liu, Y. Li, W. Cai, Large area alpha-Cu2S particle-stacked nanorod arrays by laser ablation in liquid and their strong structurally enhanced and stable visible photoelectric performances, ACS Appl. Mater. Interfaces 10 (22) (2018) 19027–19036, https://doi.org/10.1021/acsami.8b03520.
[70] H.Y. Kwong, M.H. Wong, C.W. Leung, Y.W. Wong, K.H. Wong, Formation of core/shell structured cobalt/carbon nanoparticles by pulsed laser ablation in toluene, J. Appl. Phys. 108 (3) (2010) 034304, , https://doi.org/10.1063/1.3457216.
[71] S.A. Davari, J.L. Gottfried, C. Liu, E.L. Ribeiro, G. Duscher, D. Mukherjee, Graphitic coated al nanoparticles manufactured as superior energetic materials via laser ablation synthesis in organic solvents, Appl. Surf. Sci. 473 (2019) 156–163, https://doi.org/10.1016/j.apsusc.2018.11.238.
[72] H.J. Jung, M.Y. Choi, One-pot synthesis of graphitic and nitrogen-doped graphitic layers on nickel nanoparticles produced by pulsed laser ablation in liquid: solvent as the carbon and nitrogen source, Appl. Surf. Sci. 457 (2018) 1050–1056, https://doi.org/10.1016/j.apsusc.2018.07.036.
[73] G. Marzun, H. Boennemann, C. Lehmann, B. Spliethoff, C. Weidenthaler, S. Barcikowski, Role of dissolved and molecular oxygen on Cu and PtCu alloy particle structure during laser ablation synthesis in liquids, ChemPhysChem 18 (9, SI) (2017) 1175–1184. https://doi.org/10.1002/cphc.201601315.
[74] S. Sakaki, H. Ikenoue, T. Tsuji, Y. Ishikawa, N. Koshizaki, Pulse-width dependence of the cooling effect on sub-micrometer ZnO spherical particle formation by pulsed-laser melting in a liquid, ChemPhysChem 18 (9, SI) (2017) 1101–1107. https://doi.org/10.1002/cphc.201601175.
[75] T. Tsuji, Y. Higashi, M. Tsuji, Y. Ishikawa, N. Koshizaki, Preparation of submicron-sized spherical particles of gold using laser-induced melting in liquids and low-toxic stabilizing reagent, Appl. Surf. Sci. 348 (2015) 10–15, https://doi.org/10.1016/j.apsusc.2015.02.057.
[76] G. Gonzalez-Rubio, A. Guerrero-Martinez, L.M. Liz-Marzan, Reshaping, fragmentation, and assembly of gold nanoparticles assisted by pulse lasers, Accounts Chem. Res. 49 (4) (2016) 678–686, https://doi.org/10.1021/acs.accounts.6b00041.
[77] G. Gonzalez-Rubio, P. Diaz-Nunez, A. Rivera, A. Prada, G. Tardajos, J. Gonzalez-Izquierdo, L. Banares, P. Llombart, L.G. Macdowell, M. Alcolea Palafox, L.M. Liz-Marzan, O. Pena-Rodriguez, A. Guerrero-Martinez, Femtosecond laser reshaping yields gold nanorods with ultranarrow surface plasmon resonances, Science 358 (6363) (2017) 640–644, https://doi.org/10.1126/science.aan8478.
[78] H. Fujiwara, R. Niyuki, Y. Ishikawa, N. Koshizaki, T. Tsuji, K. Sasaki, Low-threshold and quasi-single-mode random laser within a submicrometer-sized ZnO spherical particle film, Appl. Phys. Lett. 102 (6) (2013) 061110, , https://doi.org/10.1063/1.4792349.
[79] R. Niyuki, H. Fujiwara, T. Nakamura, Y. Ishikawa, N. Koshizaki, T. Tsuji, K. Sasaki, Double threshold behavior in a resonance-controlled ZnO random laser, APL Photonics 2 (3) (2017) 036101, , https://doi.org/10.1063/1.4974334.
[80] V. Amendola, I. Fortunati, C. Marega, A. L. Abdelhady, M. I. Saidaminov, O. M. Bakr, High-purity hybrid organolead halide perovskite nanoparticles obtained by pulsed-laser irradiation in liquid, ChemPhysChem 18 (9, SI) (2017) 1047–1054. https://doi.org/10.1002/cphc.201600863.
[81] M. Kondo, N. Shishido, S. Kamiya, A. Kubo, Y. Umeno, Y. Ishikawa, N. Koshizaki, High-strength sub-micrometer spherical particles fabricated by pulsed laser melting in liquid, Part. Part. Syst. Charact. 35 (7) (2018) 1800061, , https://doi.org/10.1002/ppsc.201800061.
[82] F. Mafune, J. Kohno, Y. Takeda, T. Kondow, H. Sawabe, Formation and size control of sliver nanoparticles by laser ablation in aqueous solution, J. Phys. Chem. B 104 (2000) 9111, https://doi.org/10.1021/jp001336y.
[83] H. Zeng, W. Cai, Y. Li, J. Hu, P. Liu, Composition/structural evolution and optical properties of ZnO/Zn nanoparticles by laser ablation in liquid media, J. Phys. Chem. B 109 (39) (2005) 18260–18266, https://doi.org/10.1021/jp052258n.
[84] H. Usui, Y. Shimizu, T. Sasaki, N. Koshizaki, Photoluminescence of ZnO nanoparticles prepared by laser ablation in different surfactant solutions, J. Phys. Chem. B 109 (2005) 120, https://doi.org/10.1021/jp046747j.
[85] Z. Yan, R. Bao, D.B. Chrisey, Generation of $Ag_2O$ micro-/nanostructures by pulsed excimer laser ablation of Ag in aqueous solutions of polysorbate 80, Langmuir 27 (2) (2011) 851–855, https://doi.org/10.1021/la104331p.
[86] A. Kabashin, M. Meunier, Synthesis of colloidal nanoparticles during femtosecond laser ablation of gold in water, J. Appl. Phys. 94 (12) (2003) 7941–7943, https://doi.org/10.1063/1.1626793.
[87] T. Tsuji, K. Iryo, N. Watanabe, M. Tsuji, Preparation of silver nanoparticles by laser ablation in solution: influence of laser wavelength on particle size, Appl. Surf. Sci. 202 (1–2) (2002) 80–85, https://doi.org/10.1016/S0169-4332(02)00936-4.
[88] E.V. Barmina, S.V. Gudkov, A.V. Simakin, G.A. Shafeev, Stable products of laser-induced breakdown of aqueous colloidal solutions of nanoparticles, J. Laser Micro Nanoeng. 12 (3) (2017) 254–257, https://doi.org/10.2961/jlmn.2017.03.0014.
[89] J. Barta, L. Prochazkova, V. Vanecek, M. Kuzar, M. Nikl, V. Cuba, Photochemical synthesis of nano- and micro-crystalline particles in aqueous solutions, Appl. Surf. Sci. 479 (2019) 506–511, https://doi.org/10.1016/j.apsusc.2019.02.087.
[90] M.G. John, K.M. Tibbetts, One-step femtosecond laser ablation synthesis of sub-3nm gold nanoparticles stabilized by silica, Appl. Surf. Sci. 475 (2019) 1048–1057, https://doi.org/10.1016/j.apsusc.2019.01.042.
[91] R. Torres-Mendieta, O. Havelka, M. Urbanek, M. Cvek, S. Waclawek, V.V.T. Padil, D. Jasikova, M. Kotek, M. Cernik, Laser-assisted synthesis of Fe-Cu oxide nanocrystals, Appl. Surf. Sci. 469 (2019) 1007–1015, https://doi.org/10.1016/j.apsusc.2018.11.058.
[92] T. Okamoto, K. Mitamura, T. Hamaguchi, K. Matsukawa, T. Yatsuhashi, Synthesis of fluorine-doped hydrophilic carbon nanoparticles from hexafluorobenzene by femtosecond laser pulses, ChemPhysChem 18 (9, SI) (2017) 1007–1011. https://doi.org/10.1002/cphc.201600602.
[93] T. Okamoto, T. Nakamura, R. Kihara, T. Asahi, K. Sakota, T. Yatsuhashi, Synthesis of bare iron nanoparticles from ferrocene hexane solution by femtosecond laser pulses, ChemPhysChem 19 (19) (2018) 2480–2485, https://doi.org/10.1002/cphc.201800436.
[94] M. Condorelli, V. Scardaci, L. D'Urso, O. Puglisi, E. Fazio, G. Compagnini, Plasmon sensing and enhancement of laser prepared silver colloidal nanoplates, Appl. Surf. Sci. 475 (2019) 633–638, https://doi.org/10.1016/j.apsusc.2018.12.265.
[95] S. Wu, J. Liu, Y. Ye, Z. Tian, P. Li, Y. Cai, Y. Lin, C. Liang, In-situ reactive loading of platinum onto tin oxide nanocrystals with superior catalytic performance for hydrogenation of 4-nitrophenol, Appl. Surf. Sci. 471 (2019) 469–474, https://doi.

org/10.1016/j.apsusc.2018.12.035.
[96] Q. Chen, C. Zhang, J. Liu, Y. Ye, P. Li, C. Liang, Solvent molecules dominated phase transition of amorphous Se colloids probed by in-situ Raman spectroscopy, Appl. Surf. Sci. 466 (2019) 1000–1006, https://doi.org/10.1016/j.apsusc.2018.10.080.
[97] H. Zhang, Y. Li, G. Duan, G. Liu, W. Cai, Tungsten oxide nanostructures based on laser ablation in water and a hydrothermal route, Crystengcomm 16 (12) (2014) 2491–2498, https://doi.org/10.1039/c3ce42320d.
[98] J. Liu, C. Liang, Z. Tian, S. Zhang, G. Shao, Spontaneous growth and chemical reduction ability of Ge nanoparticles, Sci. Rep. 3 (2013) 1741, https://doi.org/10.1038/srep01741.
[99] A. Kanitz, D.J. Förster, J.S. Hoppius, R. Weber, A. Ostendorf, E.L. Gurevich, Pump-probe microscopy of femtosecond laser ablation in air and liquids, Appl. Surf. Sci. 475 (2019) 204–210, https://doi.org/10.1016/j.apsusc.2018.12.184.
[100] M. Domke, S. Rapp, M. Schmidt, H.P. Huber, Ultra-fast movies of thin-film laser ablation, Appl. Phys. A Mater. Sci. Process. 109 (2) (2012) 409–420, https://doi.org/10.1007/s00339-012-7072-6.
[101] B. Kumar, D. Yadav, R.K. Thareja, Growth dynamics of nanoparticles in laser produced plasma in liquid ambient, J. Appl. Phys. 110 (7) (2011) 074903, , https://doi.org/10.1063/1.3642968.
[102] W. Soliman, N. Takada, K. Sasaki, Growth processes of nanoparticles in liquid-phase laser ablation studied by laser-light scattering, Appl. Phys. Express 3 (3) (2010) 035201, , https://doi.org/10.1143/APEX.3.035201.
[103] A. De Giacomo, M. Dell'Aglio, A. Santagata, R. Gaudiuso, O. De Pascale, P. Wagener, G.C. Messina, G. Compagnini, S. Barcikowski, Cavitation dynamics of laser ablation of bulk and wire-shaped metals in water during nanoparticles production, Phys. Chem. Chem. Phys. 15 (2013) 3083, https://doi.org/10.1039/c2cp42649h.
[104] M. Takeuchi, K. Sasaki, Spectrum of laser light scattered by nanoparticles in an ablation-induced cavitation bubble, Appl. Phys. A Mater. Sci. Process. 122 (4) (2016) 312, https://doi.org/10.1007/s00339-016-9927-8.
[105] H. Oguchi, T. Sakka, Y.H. Ogata, Effects of pulse duration upon the plume formation by the laser ablation of cu in water, J. Appl. Phys. 102 (2007) 023306, , https://doi.org/10.1063/1.2759182.
[106] K. Saito, K. Takatani, T. Sakka, Y.H. Ogata, Observation of the light emitting region produced by pulsed laser irradiation to a solid-liquid interface, Appl. Surf. Sci. 197 (2002) 56, https://doi.org/10.1016/S0169-4332(02)00303-3.
[107] B. Kumar, R.K. Thareja, Synthesis of nanoparticles in laser ablation of aluminum in liquid, J. Appl. Phys. 108 (2010) 064906, , https://doi.org/10.1063/1.3486517.
[108] M. Dell'Aglio, A. Santagata, G. Valenza, A. De Stradis, A. De Giacomo, Study of the effect of water pressure on plasma and cavitation bubble induced by pulsed laser ablation in liquid of silver and missed variations of observable nanoparticle features, ChemPhysChem 18 (9, SI) (2017) 1165–1174. https://doi.org/10.1002/cphc.201601231.
[109] K. Hirata, S. Masai, T. Sakka, Y.H. Ogata, Mechanism of laser ablation in liquid media investigated by using long-lasting lanthanide emission as a probe, Photon Processing in Microelectronics and Photonics IV, vol. 5713 of Proceedings of the Society of Photo-optical Instrumentation Engineers, 2005, p. 311, , https://doi.org/10.1117/12.587477.
[110] T. Tsuji, Y. Okazaki, Y. Tsuboi, M. Tsuji, Nanosecond time-resolved observations of laser ablation of silver in water, Jpn. J. Appl. Phys. 46 (2007) 1533, https://doi.org/10.1143/JJAP.46.1533.
[111] T. Tsuji, D.-H. Thang, Y. Okazaki, M. Nakanishi, Y. Tsuboi, M. Tsuji, Preparation of silver nanoparticles by laser ablation in polyvinylpyrrolidone solutions, Appl. Surf. Sci. 254 (2008) 5224, https://doi.org/10.1016/j.apsusc.2008.02.048.
[112] T. Sakka, S. Masai, K. Fukami, Y.H. Ogata, Spectral profile of atomic emission lines and effects of pulse duration on laser ablation in liquid, Spectroc. Acta Pt. B 64 (2009) 981, https://doi.org/10.1016/j.sab.2009.07.018.
[113] K. Sasaki, N. Takada, Liquid-phase laser ablation, Pure Appl. Chem. 82 (2010) 1317, https://doi.org/10.1351/PAC-CON-09-10-23.
[114] J. Tomko, J.J. Naddeo, R. Jimenez, Y. Tan, M. Steiner, J.M. Fitz-Gerald, D.M. Bubb, S.M. O'Malley, Size and polydispersity trends found in gold nanoparticles synthesized by laser ablation in liquids, Phys. Chem. Chem. Phys. 17 (25) (2015) 16327–16333, https://doi.org/10.1039/c5cp01965f.
[115] M. Dell'Aglio, R. Gaudiuso, O.D. Pascale, A.D. Giacomo, Mechanisms and processes of pulsed laser ablation in liquids during nanoparticle production, Appl. Surf. Sci. 348 (2015) 4–9, https://doi.org/10.1016/j.apsusc.2015.01.082.
[116] J. Lam, J. Lombard, C. Dujardin, G. Ledoux, S. Merabia, D. Amans, Dynamical study of bubble expansion following laser ablation in liquids, Appl. Phys. Lett. 108 (7) (2016) 074104, , https://doi.org/10.1063/1.4942389.
[117] J. Tomko, S.M. O'Malley, C. Trout, J.J. Naddeo, R. Jimenez, J.C. Griepenburg, W. Soliman, D.M. Bubb, Cavitation bubble dynamics and nanoparticle size distributions in laser ablation in liquids, Colloid Surf. A 522 (2017) 368–372, https://doi.org/10.1016/j.colsurfa.2017.03.030.
[118] P. Wagener, S. Ibrahimkutty, A. Menzel, A. Plech, S. Barcikowski, Dynamics of silver nanoparticle formation and agglomeration inside the cavitation bubble after pulsed laser ablation in liquid, Phys. Chem. Chem. Phys. 15 (9) (2013) 3068, https://doi.org/10.1039/c2cp42592k.
[119] S. Ibrahimkutty, P. Wagener, T. d. S. Rolo, D. Karpov, A. Menzel, T. Baumbach, S. Barcikowski, A. Plech, A hierarchical view on material formation during pulsed-laser synthesis of nanoparticles in liquid, Sci. Rep. 5 (2015) 16313. https://doi.org/10.1038/srep16313.
[120] S. Zhu, Y.F. Lu, M.H. Hong, X.Y. Chen, Laser ablation of solid substrates in water and ambient air, J. Appl. Phys. 89 (2001) 2400, https://doi.org/10.1063/1.1342200.
[121] H. Jin, J.-W. Kim, J.-A. Son, J.-G. Choi, An acoustic based, laser induced breakdown method for determining the sizes and concentrations of nanoparticles, Phys. Chem. Chem. Phys. 12 (20) (2010) 5199–5202, https://doi.org/10.1039/b924933h.
[122] A. De Giacomo, M. Dell'Aglio, O. De Pascale, M. Capitelli, From single pulse to double pulse ns-laser induced breakdown spectroscopy under water: elemental analysis of aqueous solutions and submerged solid samples, Spectroc. Acta Pt. B 62 (2007) 721, https://doi.org/10.1016/j.sab.2007.06.008.
[123] T. Sakka, S. Iwanaga, Y.H. Ogata, A. Matsunawa, T. Takemoto, Laser ablation at solid-liquid interfaces: an approach from optical emission spectra, J. Chem. Phys. 112 (2000) 8645, https://doi.org/10.1063/1.481465.
[124] T. Sakka, K. Saito, Y.H. Ogata, Emission spectra of the species ablated from a solid target submerged in liquid: vibrational temperature of $C_2$ molecules in water-confined geometry, Appl. Surf. Sci. 197 (2002) 246, https://doi.org/10.1016/S0169-4332(02)00373-2.
[125] K. Saito, T. Sakka, Y.H. Ogata, Rotational spectra and temperature evaluation of $C_2$ molecules produced by pulsed laser irradiation to a graphite-water interface, J. Appl. Phys. 94 (2003) 5530, https://doi.org/10.1063/1.1614431.
[126] T. Sakka, K. Saito, Y.H. Ogata, Confinement effect of laser ablation plume in liquids probed by self-absorption of $C_2$ Swan band emission, J. Appl. Phys. 97 (2005) 014902, , https://doi.org/10.1063/1.1828214.
[127] T. Sakka, H. Yamagata, H. Oguchi, K. Fukami, Y.H. Ogata, Emission spectroscopy of laser ablation plume: composition analysis of a target in water, Appl. Surf. Sci. 255 (2009) 9576, https://doi.org/10.1016/j.apsusc.2009.04.086.
[128] A. De Giacomo, A. De Bonis, M. Dell'Aglio, O. De Pascale, R. Gaudiuso, S. Orlando, A. Santagata, G.S. Senesi, F. Taccogna, R. Teghil, Laser ablation of graphite in water in a range of pressure from 1 to 146 atm using single and double pulse techniques for the production of carbon nanostructures, J. Phys. Chem. C 115 (12) (2011) 5123–5130, https://doi.org/10.1021/jp109389c.
[129] D. Amans, A.-C. Chenus, G. Ledoux, C. Dujardin, C. Reynaud, O. Sublemontier, K. Masenelli-Varlot, O. Guillois, Nanodiamond synthesis by pulsed laser ablation in liquids, Diam. Relat. Mat. 18 (2009) 177, https://doi.org/10.1016/j.diamond.2008.10.035.
[130] D. Amans, C. Malaterre, M. Diouf, C. Mancini, F. Chaput, G. Ledoux, G. Breton, Y. Guillin, C. Dujardin, K. Masenelli-Varlot, P. Perriat, Synthesis of oxide nanoparticles by pulsed laser ablation in liquids containing a complexing molecule: impact on size distributions and prepared phases, J. Phys. Chem. C 115 (12) (2011) 5131–5139, https://doi.org/10.1021/jp109387e.
[131] W.A. de Heer, The physics of simple metal clusters: experimental aspects and simple models, Rev. Mod. Phys. 65 (1993) 611–676, https://doi.org/10.1103/RevModPhys.65.611.
[132] M. Ehbrecht, B. Kohn, F. Huisken, M.A. Laguna, V. Paillard, Photoluminescence and resonant Raman spectra of silicon films produced by size-selected cluster beam deposition, Phys. Rev. B 56 (11) (1997) 6958–6964, https://doi.org/10.1103/PhysRevB.56.6958.
[133] C.-Y. Shih, M.V. Shugaev, C. Wu, L.V. Zhigilei, Generation of subsurface voids, incubation effect, and formation of nanoparticles in short pulse laser interactions with bulk metal targets in liquid: molecular dynamics study, J. Phys. Chem. C 121 (30) (2017) 16549–16567, https://doi.org/10.1021/acs.jpcc.7b02301.
[134] C.-Y. Shih, R. Streubel, J. Heberle, A. Letzel, M.V. Shugaev, C. Wu, M. Schmidt, B. Gökce, S. Barcikowski, L.V. Zhigilei, Two mechanisms of nanoparticle generation in picosecond laser ablation in liquids: the origin of the bimodal size distribution, Nanoscale 10 (2018) 6900–6910, https://doi.org/10.1039/C7NR08614H.
[135] J. Sylvestre, A. Kabashin, E. Sacher, M. Meunier, Femtosecond laser ablation of gold in water: influence of the laser-produced plasma on the nanoparticle size distribution, Appl. Phys.A 80 (4) (2005) 753–758, https://doi.org/10.1007/s00339-004-3081-4.
[136] G. Marzun, J. Nakamura, X. Zhang, S. Barcikowski, P. Wagener, Size control and supporting of palladium nanoparticles made by laser ablation in saline solution as a facile route to heterogeneous catalysts, Appl. Surf. Sci. 348 (2015) 75–84, https://doi.org/10.1016/j.apsusc.2015.01.108.
[137] L. Escobar-Alarcòn, J. Iturbe-García, F. González-Zavala, D. Solis-Casados, R. Pérez-Hernández, E. Haro-Poniatowski, Hydrogen production by ultrasound assisted liquid laser ablation of Al, Mg and Al-Mg alloys in water, Appl. Surf. Sci. 478 (2019) 189–196, https://doi.org/10.1016/j.apsusc.2019.01.213.
[138] E.V. Barmina, A.V. Simakin, G.A. Shafeev, Hydrogen emission under laser exposure of colloidal solutions of nanoparticles, Chem. Phys. Lett. 655 (2016) 35–38, https://doi.org/10.1016/j.cplett.2016.05.020.
[139] E. Barmina, A. Simakin, G. Shafeev, Balance of O2 and H2 content under laser-induced breakdown of aqueous colloidal solutions, Chem. Phys. Lett. 678 (2017) 192–195, https://doi.org/10.1016/j.cplett.2017.04.045.
[140] A. Neumeister, J. Jakobi, C. Rehbock, J. Moysig, S. Barcikowski, Monophasic ligand-free alloy nanoparticle synthesis determinants during pulsed laser ablation of bulk alloy and consolidated microparticles in water, Phys. Chem. Chem. Phys. 16 (43) (2014) 23671–23678, https://doi.org/10.1039/c4cp03316g.
[141] S. Jendrzej, B. Goekce, M. Epple, S. Barcikowski, How size determines the value of gold: economic aspects of wet chemical and laser-based metal colloid synthesis, ChemPhysChem 18 (9, SI) (2017) 1012–1019. https://doi.org/10.1002/cphc.201601139.
[142] H. Wender, M.L. Andreazza, R.R.B. Correia, S.R. Teixeira, J. Dupont, Synthesis of gold nanoparticles by laser ablation of an Au foil inside and outside ionic liquids, Nanoscale 3 (3) (2011) 1240–1245, https://doi.org/10.1039/c0nr00786b.
[143] H.P.S. Castro, V.S. Souza, J.D. Scholten, J.H. Dias, J.A. Fernandes, F.S. Rodembusch, R. dos Reis, J. Dupont, S.R. Teixeira, R.R.B. Correia, Synthesis and characterisation of fluorescent carbon nanodots produced in ionic liquids by laser ablation, Chem.-Eur. J. 22 (1) (2016) 138–143, https://doi.org/10.1002/

chem.201503286.
[144] N. Tabatabaie, D. Dorranian, Effect of fluence on carbon nanostructures produced by laser ablation in liquid nitrogen, Appl. Phys. A Mater. Sci. Process. 122 (5) (2016) 558, https://doi.org/10.1007/s00339-016-0091-y.
[145] T. Kato, S. Stauss, S. Kato, K. Urabe, M. Baba, T. Suemoto, K. Terashima, Pulsed laser ablation plasmas generated in $CO_2$ under high-pressure conditions up to supercritical fluid, Appl. Phys. Lett. 101 (22) (2012) 224103, , https://doi.org/10.1063/1.4767839.
[146] E.B. Gordon, A.V. Karabulin, V.I. Matyushenko, V.D. Sizov, I.I. Khodos, The nanostructures produced by laser ablation of metals in superfluid helium, J. Low Temp. Phys. 172 (1–2) (2013) 94–112, https://doi.org/10.1007/s10909-012-0849-3.
[147] X. Buelna, E. Popov, J. Eloranta, Dynamics of laser ablation in superfluid, J. Low Temp. Phys. 186 (3–4) (2017) 197–207, https://doi.org/10.1007/s10909-016-1668-8.
[148] A. Singh, T. Salminen, M. Honkanen, J. Vihinen, L. Hyvarinen, E. Levanen, Multiphase TixOy nanoparticles by pulsed laser ablation of titanium in supercritical CO2, Appl. Surf. Sci. 476 (2019) 822–827, https://doi.org/10.1016/j.apsusc.2019.01.172.
[149] S. Kohsakowski, R. Streubel, I. Radev, V. Peinecke, S. Barcikowski, G. Marzun, S. Reichenberger, First PEM fuel cell based on ligand-free, laser-generated platinum nanoparticles, Appl. Surf. Sci. 467-468 (2019) 486–492, https://doi.org/10.1016/j.apsusc.2018.10.145.
[150] Y.-J. Wang, N. Zhao, B. Fang, H. Li, X.T. Bi, H. Wang, Carbon-supported pt-based alloy electrocatalysts for the oxygen reduction reaction in polymer electrolyte membrane fuel cells: particle size, shape, and composition manipulation and their impact to activity, Chem. Rev. 115 (9) (2015) 3433–3467, https://doi.org/10.1021/cr500519c.
[151] L. Wu, A. Mendoza-Garcia, Q. Li, S. Sun, Organic phase syntheses of magnetic nanoparticles and their applications, Chem. Rev. 116 (18) (2016) 10473–10512, https://doi.org/10.1021/acs.chemrev.5b00687 SI.
[152] K. D. Gilroy, A. Ruditskiy, H.-C. Peng, D. Qin, Y. Xia, Bimetallic nanocrystals: syntheses, properties, and applications, Chem. Rev. 116 (18, SI) (2016) 10414–10472. https://doi.org/10.1021/acs.chemrev.6b00211.
[153] V. Amendola, M. Meneghetti, O.M. Bakr, P. Riello, S. Polizzi, D.H. Anjum, S. Fiameni, P. Arosio, T. Orlando, C. de Julian Fernandez, F. Pineider, C. Sangregorio, A. Lascialfari, Coexistence of plasmonic and magnetic properties in Au89Fe11 nanoalloys, Nanoscale 5 (2013) 5611–5619, https://doi.org/10.1039/C3NR01119D.
[154] P. Wagener, J. Jakobi, C. Rehbock, V.S.K. Chakravadhanula, C. Thede, U. Wiedwald, M. Bartsch, L. Kienle, S. Barcikowski, Solvent-surface interactions control the phase structure in laser-generated iron-gold core-shell nanoparticles, Sci. Rep. 6 (2016) 23352, , https://doi.org/10.1038/srep23352.
[155] V. Amendola, S. Scaramuzza, F. Carraro, E. Cattaruzza, Formation of alloy nanoparticles by laser ablation of Au/Fe multilayer films in liquid environment, J. Colloid Interface Sci. 489 (SI) (2017) 18–27, https://doi.org/10.1016/j.jcis.2016.10.023.
[156] O. Prymak, J. Jakobi, C. Rehbock, M. Epple, S. Barcikowski, Crystallographic characterization of laser-generated, polymer-stabilized 4 nm silver-gold alloyed nanoparticles, Mater. Chem. Phys. 207 (2018) 442–450, https://doi.org/10.1016/j.matchemphys.2017.12.080.
[157] G. Marzun, A. Levish, V. Mackert, T. Kallio, S. Barcikowski, P. Wagener, Laser synthesis, structure and chemical properties of colloidal nickel-molybdenum nanoparticles for the substitution of noble metals in heterogeneous catalysis, J. Colloid Interface Sci. 489 (SI) (2017) 57–67, https://doi.org/10.1016/j.jcis.2016.09.014.
[158] J.G. Walter, S. Petersen, F. Stahl, T. Scheper, S. Barcikowski, Laser ablation-based one-step generation and bio-functionalization of gold nanoparticles conjugated with aptamers, ChemPhysChem 8 (2010) 21–31, https://doi.org/10.1186/1477-3155-8-21.
[159] V. Amendola, M. Meneghetti, S. Fiameni, S. Polizzi, G. Fracasso, A. Boscaini, M. Colombatti, Sers labels for quantitative assays: application to the quantification of gold nanoparticles uptaken by macrophage cells, Anal. Methods 3 (2011) 849–856, https://doi.org/10.1039/C0AY00660B.
[160] F. Correard, K. Maximova, M.-A. Esteve, C. Villard, M. Roy, A. Al-Kattan, M. Sentis, M. Gingras, A.V. Kabashin, D. Braguer, Gold nanoparticles prepared by laser ablation in aqueous biocompatible solutions: assessment of safety and biological identity for nanomedicine applications, Int. J. Nanomedicine 9 (2014) 5415–5430, https://doi.org/10.2147/IJN.S65817.
[161] K.P. Tamarov, L.A. Osminkina, S.V. Zinovyev, K.A. Maximova, J.V. Kargina, M.B. Gongalsky, Y. Ryabchikov, A. Al-Kattan, A.P. Sviridov, M. Sentis, A.V. Ivanov, V.N. Nikiforov, A.V. Kabashin, V.Y. Timoshenko, Radio frequency radiation-induced hyperthermia using Si nanoparticle-based sensitizers for mild cancer therapy, Sci. Rep. 4 (2014) 7034, https://doi.org/10.1038/srep07034.
[162] T. Ikehata, Y. Onodera, T. Nunokawa, T. Hirano, S.-I. Ogura, T. Kamachi, O. Odawara, H. Wada, Photodynamic therapy using upconversion nanoparticles prepared by laser ablation in liquid, Appl. Surf. Sci. 348 (2015) 54–59, https://doi.org/10.1016/j.apsusc.2014.12.097.
[163] A. Nastulyavichus, S. Kudryashov, N. Smirnov, I. Saraeva, A. Rudenko, E. Tolordava, A. Ionin, Y. Romanova, D. Zayarny, Antibacterial coatings of Se and Si nanoparticles, Appl. Surf. Sci. 469 (2019) 220–225, https://doi.org/10.1016/j.apsusc.2018.11.011.
[164] W. Dong, S. Reichenberger, S. Chu, P. Weide, H. Ruland, S. Barcikowski, P. Wagener, M. Muhler, The effect of the Au loading on the liquid-phase aerobic oxidation of ethanol over Au/TiO2 catalysts prepared by pulsed laser ablation, J. Catal. 330 (2015) 497–506, https://doi.org/10.1016/j.jcat.2015.07.033.
[165] J. Zhang, M. Chaker, D. Ma, Pulsed laser ablation based synthesis of colloidal metal nanoparticles for catalytic applications, J. Colloid Interface Sci. 489 (SI) (2017) 138–149, https://doi.org/10.1016/j.jcis.2016.07.050.
[166] M. Lau, S. Reichenberger, I. Haxhiaj, S. Barcikowski, A.M. Mueller, Mechanism of laser-induced bulk and surface defect generation in ZnO and $TiO_2$ nanoparticles: effect on photoelectrochemical performance, ACS Appl. Energ. Mater. 1 (10) (2018) 5366–5385, https://doi.org/10.1021/acsaem.8b00977.
[167] E. Bertin, A. Münzer, S. Reichenberger, R. Streubel, T. Vinnay, H. Wiggers, C. Schulz, S. Barcikowski, G. Marzun, Durability study of platinum nanoparticles supported on gas-phase synthesized graphene in oxygen reduction reaction conditions, Appl. Surf. Sci. 467-468 (2019) 1181–1186, https://doi.org/10.1016/j.apsusc.2018.10.061.
[168] J. Johny, S.S. Guzman, B. Krishnan, J.A.A. Martinez, D.A. Avellaneda, S. Shaji, $SnS_2$ nanoparticles by liquid phase laser ablation: effects of laser fluence, temperature and post irradiation on morphology and hydrogen evolution reaction, Appl. Surf. Sci. 470 (2019) 276–288, https://doi.org/10.1016/j.apsusc.2018.11.157.
[169] B.M. Hunter, J.D. Blakemore, M. Deimund, H.B. Gray, J.R. Winkler, A.M. Mueller, Highly active mixed-metal nanosheet water oxidation catalysts made by pulsed-laser ablation in liquids, J. Am. Chem. Soc. 136 (38) (2014) 13118–13121, https://doi.org/10.1021/ja506087h.
[170] V. Amendola, S. Scaramuzza, S. Agnoli, G. Granozzi, M. Meneghetti, G. Campo, V. Bonanni, F. Pineider, C. Sangregorio, P. Ghigna, S. Polizzi, P. Riello, S. Fiameni, L. Nodari, Laser generation of iron-doped silver nanotruffles with magnetic and plasmonic properties, Nano Res. 8 (12) (2015) 4007–4023, https://doi.org/10.1007/s12274-015-0903-y.
[171] C. Ma, J. Yan, Y. Huang, G. Yang, Directional scattering in a germanium nanosphere in the visible light region, Adv. Opt. Mater. 5 (24) (2017) 1700761, , https://doi.org/10.1002/adom.201700770.
[172] E. Kymakis, G.D. Spyropoulos, R. Fernandes, G. Kakavelakis, A.G. Kanaras, E. Stratakis, Plasmonic bulk heterojunction solar cells: the role of nanoparticle ligand coating, ACS Photonics 2 (6) (2015) 714–723, https://doi.org/10.1021/acsphotonics.5b00202.
[173] C. Petridis, K. Savva, E. Kymakis, E. Stratakis, Laser generated nanoparticles based photovoltaics, J. Colloid Interface Sci. 489 (SI) (2017) 28–37, https://doi.org/10.1016/j.jcis.2016.09.065.
[174] S. Shaji, V. Vinayakumar, B. Krishnan, J. Johny, S.S. Kanakkillam, J.F. Herrera, S.S. Guzman, D. Avellaneda, G.C. Rodriguez, J.A. Martinez, Copper antimony sulfide nanoparticles by pulsed laser ablation in liquid and their thin film for photovoltaic application, Appl. Surf. Sci. 476 (2019) 94–106, https://doi.org/10.1016/j.apsusc.2019.01.072.
[175] L. Jonusauskas, M. Lau, P. Gruber, B. Goekce, S. Barcikowski, M. Malinauskas, A. Ovsianikov, Plasmon assisted 3D microstructuring of gold nanoparticle-doped polymers, Nanotechnology 27 (15) (2016) 154001, , https://doi.org/10.1088/0957-4484/27/15/154001.
[176] C. Donate-Buendia, F. Froemel, M.B. Wilms, R. Streubel, J. Tenkamp, T. Hupfeld, M. Nachev, E. Gökce, A. Weisheit, S. Barcikowski, F. Walther, J.H. Schleifenbaum, B. Gökce, Oxide dispersion-strengthened alloys generated by laser metal deposition of laser-generated nanoparticle-metal powder composites, Mater. Des. 154 (2018) 360–369, https://doi.org/10.1016/j.matdes.2018.05.044.
[177] E. Maurer, S. Barcikowski, B. Gökce, Process chain for the fabrication of nanoparticle polymer composites by laser ablation synthesis, Chem. Eng. Technol. 40 (9, SI) (2017) 1535–1543. https://doi.org/10.1002/ceat.201600506.
[178] G. Compagnini, A. Scalisi, O. Puglisi, Ablation of noble metals in liquids: a method to obtain nanoparticles in a thin polymeric film, Phys. Chem. Chem. Phys. 4 (12) (2002) 2787–2791, https://doi.org/10.1039/b109490d.
[179] T. Baati, A. Al-Kattan, M.-A. Esteve, L. Njim, Y. Ryabchikov, F. Chaspoul, M. Hammami, M. Sentis, A.V. Kabashin, D. Braguer, Ultrapure laser-synthesized Si-based nanomaterials for biomedical applications: in vivo assessment of safety and biodistribution, Sci. Rep. 6 (2016) 25400, , https://doi.org/10.1038/srep25400.
[180] C. Streich, L. Akkari, C. Decker, J. Bormann, C. Rehbock, A. Mueller-Schiffmann, F.C. Niemeyer, L. Nagel-Steger, D. Willbold, B. Sacca, C. Korth, T. Schrader, S. Barcikowski, Characterizing the effect of multivalent conjugates composed of a beta-specific ligands and metal nanoparticles on neurotoxic fibrillar aggregation, ACS Nano 10 (8) (2016) 7582–7597, https://doi.org/10.1021/acsnano.6b02627.
[181] R. Streubel, G. Bendt, B. Goekce, Pilot-scale synthesis of metal nanoparticles by high-speed pulsed laser ablation in liquids, Nanotechnology 27 (20) (2016) 205602, , https://doi.org/10.1088/0957-4484/27/20/205602.
[182] R. Streubel, S. Barcikowski, B. Goekce, Continuous multigram nanoparticle synthesis by high-power, high-repetition-rate ultrafast laser ablation in liquids, Opt. Lett. 41 (7) (2016) 1486–1489, https://doi.org/10.1364/OL.41.001486.
[183] http://particular.eu/start.html.
[184] http://nano.imra.com/.
[185] Advanced Nanoparticle Generation and Excitation by Lasers in Liquids (ANGEL), http://www.angel-conference.org.
[186] Selected papers from ANGEL 2010 https://pubs.acs.org/toc/jpccck/115/12.
[187] Selected papers from ANGEL 2012 https://doi.org/10.1039/C3CP90014B.

[188] Selected papers from ANGEL 2014 https://www.sciencedirect.com/journal/applied-surface-science/vol/348?sdc=1.
[189] Selected papers from ANGEL 2016 https://onlinelibrary.wiley.com/toc/14397641/18/9.
[190] Special issue on laser synthesis in liquids https://www.sciencedirect.com/journal/journal-of-colloid-and-interface-science/vol/489/suppl/C?sdc=1.
[191] Selected papers from ANGEL 2018 https://www.sciencedirect.com/journal/applied-surface-science/special-issue/10ZJZ1T9MTB.
[192] A. Kanitz, M.-R. Kalus, E.L. Gurevich, A. Ostendorf, S. Barcikowski, D. Amans, Generation of nanoparticles during laser ablation in liquids: a review on critical processes occurring at the early stage, submitted to Plasma Sources Sci, Technol (2019).

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