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Craters and nanostructures with laser ablation of metal/metal alloy in air and liquid

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ABSTRACT

We report crater formation due to interaction of the high power laser pulse with the brass and aluminum in water and air ambient. The deposited nanostructures on brass near and away from the crater periphery are distinctly different with larger particle size (~3.5 μm) and broader particle size distribution with full width half maximum (FWHM) ~2.9 μm close to the crater compared to relatively smaller particle size (~2.5 μm) and narrower size distribution (FWHM ~1.7 μm) near the periphery of the crater in air ambient. The morphology of brass in water ambient shows nanosize particles (~55 nm) and narrow distribution (FWHM ~7.5 nm) away from the crater with nanorod shaped structures at crater periphery.

1. Introduction

The interaction of laser pulse with the solid target in air and liquid has importance both in fundamental and applied field of research due to various technological applications [1]. The interaction of pulsed laser with a solid target modifies the surface properties (i.e. hydrophobic properties, hardness, optical absorptivity etc.) which could be exploited for producing micro-components like micro lenses, optoelectronics circuits, cooling fins for aircraft engines etc. [2,3]. The ablation process in presence of liquid has been employed in the cleaning of contaminants [4,5], laser shock processing [6], microstructure fabrication [7], and nanoparticle formation [8]. The laser ablation process strongly depends upon the coupling of laser pulse with the target which in turn depends upon the ambient conditions in addition to laser parameters (pulse width, energy per pulse, wavelength etc.) and thermo physical properties of the target material. Therefore, it is imperative to study various metals and metal alloys in different ambient environment. It has been reported that energy coupling efficiency in air–water-target system is larger than the air-target system due to optical matching that enhances the ablation rate in water ambient [9]. The explosive ablation mechanism is prominent for all wavelength and wide range of laser fluences [10,11]. Dupont et al have shown the enhancement of material removal by means of interaction of several wavelength laser pulse with the water film on the treated surface [12]. The surface modification like large scale periodic structures, surface creases, cones or columns structures have been reported at low laser irradiation (~10^6 W/cm^2) [13]. At higher laser intensities significant mass removal occurs as a result of crater formation. The size and geometry of the crater depends on ablated materials as well as shape of the laser beam. The precise material removal and hence the crater structure affects the micromachining. In other words size of the carter is a control parameter for the micromachining. The ablation depth and crater formation have been discussed on the basis of phase explosion and without phase explosion depending on the laser fluence [14].

Laser ablation synthesis in liquid solution (LASiS) is a novel and simple technique for synthesis of NPs. It essentially involves of inducing physical modification of matter due to fragmentation from bulk into nanoparticulates. In several cases, chemical modification of material also occurs, i.e. the generation of new compounds and phases [15,16]. Therefore, LASiS may be considered as having some aspects of both chemical bottom-up and physical top-down synthetic schemes [17] for NPs formation. Large surface to volume ratio and other unique surface properties of nanoparticles highly influence the nano-applications in medical technology and nanotechnology. Laser ablation of solid target in liquid ambient is a simple way to generate NPs, the ejected NPs remain in the colloidal solution [18]. The mechanism of NPs formation is somewhat similar in different ambient. Assuming the pulse hits the target at time $t=0$, thus for $t<0$ pulse penetrates into the liquid and the laser energy is delivered to the target at $t=0$. The absorption of the laser pulse by the bulk solid target occurs from $t=0$ to τ_p (pulse width). The laser light penetrates into the target material of the order of skin depth and forms a molten pool of depth $(\kappa\tau_p)^{1/2}$ where κ the thermal diffusivity and τ_p is the laser pulse

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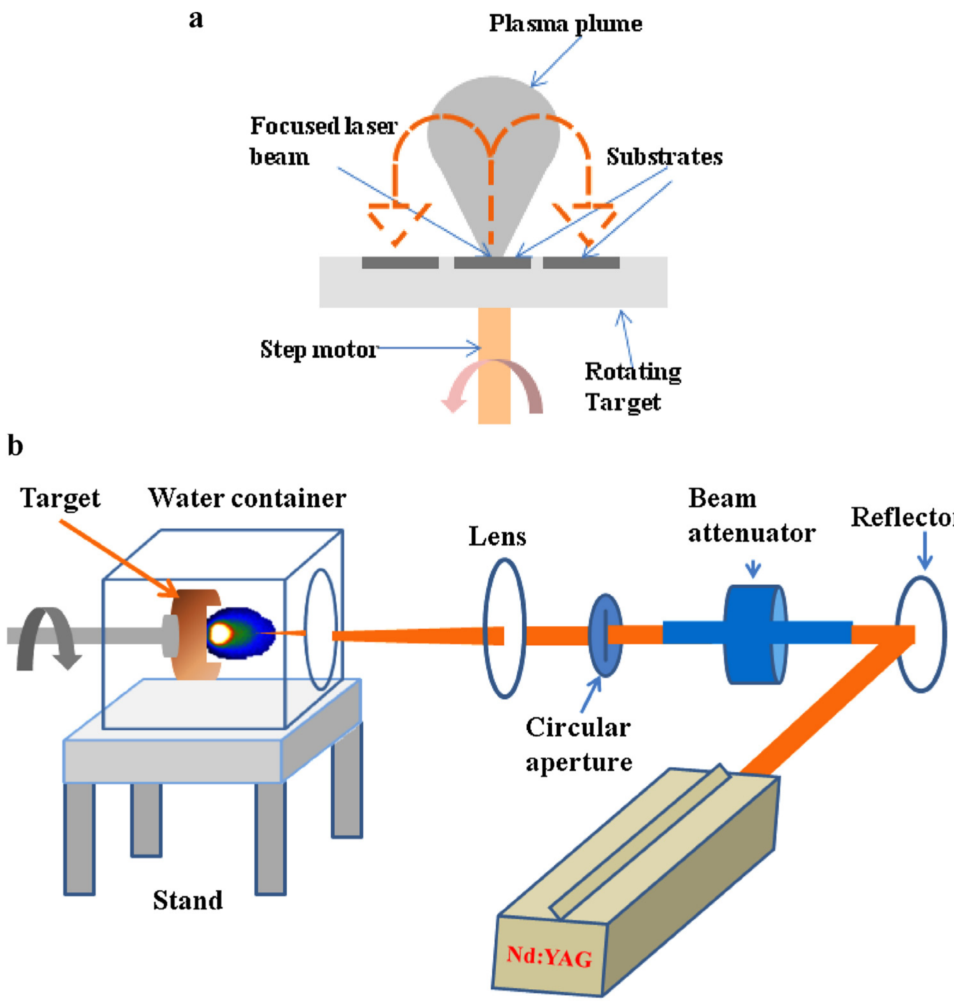

Fig. 1. (a) Schematic of IPLD geometry. (b) Schematic of experimental setup.

width. For ns laser pulse, thermal processes leads to melting, boiling, vaporization and eventually formation of plasma when the energy deposited approximately equals the latent heat of sublimation [19] $L_s = I{\tau_p}^{1/2}\rho^{-1}\kappa^{-1/2}$ where ρ is the density of the solid target and I is the laser intensity on the target. Thus the formed plasma plume containing the ablated material expands into the surrounding environment accompanied by the emission of a shockwave. During the expansion, the plasma plume cools and releases energy to the surrounding environment; cooling of plasma leads to the condensation of the vapor atoms that result in the formation of NPs [20,21]. Several techniques like aqueous chemical synthesis, hot themolysis/colloidal synthesis, photochemical synthesis, sol gel methods, ion implantation and sputtering, spray and laser pyrolysis etc. [22–25] have been proposed to synthesize nanoparticles (NPs). Different mechanism for smaller and larger particles has been reported [26]. It has been shown that smaller particles are formed by the nucleation and condensation of vapor while bigger particles may ejected from the melted liquid due to surface instability or recoil pressure from the expanding vapor plume [26]. The nucleation and growth kinetics of NPs are governed by laser parameters and external conditions such as pressure and temperature. The nucleation time of the nanostructures is related with the temperature and pressure [27]. The nucleation time is approximately double the laser pulse width used i.e. few nanoseconds (for ns laser) and with increase in pressure nucleation time decreases, and the growth velocity increases with temperature [27]. There are four main parameters whose profiles in time and space primarily decide the phase and structure of final nanomaterials: temperature, pressure, concentration of the ablated material and concentration of solution species [28]. The intricate point in LASiS is neither the uniformity in space nor constancy in time of the four parameters due to the hemispherical symmetry of the laser ablation phenomena [28]. The porous nanoparticles [29], magnetic nanoparticles for clinical imaging and cancer therapy [30] have been synthesized by laser ablation in liquids. The size distribution of nanoparticles which is of great importance in the biotechnology for diffusion in living cells, or in engineering for a tuned rheology of suspensions has been achieved by tuning the laser parameters [31]. The thin film deposition on the suitably placed substrate and back on the target has been discussed by several authors [32–34]. The process of deposition on the target or the substrate placed parallel to and very close to the target plane for the deposition is termed as inverse pulsed laser deposition (IPLD). IPLD has exhibited better morphological properties with deposited structure having significantly reduced droplets [35,36] compared to pulsed laser deposition (PLD). In a typical PLD system for depositing thin film, substrates are suitably placed in front of the expanding plasma. However, the scattering and back reflection of plasma species with the ambient dominates in IPLD. Fig. 1a shows the schematic of the IPLD geometry. The backward motion of the ablated species (Fig. 1a) gets deposited on the substrate placed on the target plane. In our experiment the target itself is used as a substrate where particles are deposited.

In the present work, we have reported the laser produced craters both in air and water of Brass and Al target. The ablation process of