Theoretical and Experimental Investigations on Laser Induced Plasma Plume

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ABSTRACT

Investigations on a complex phenomenon of laser induced plasma plume dynamics - both experimental and theoretical – is presented in this poster. Experimentally plume dynamics has been investigated by employing different imaging techniques like space and time resolved fast photography and shadowgraphy. A Q-switched Nd:YAG laser (1064 nm of 10 mJ for 9-14 ns) is tightly focused on 4 N pure, annealed and fine polished metal samples (2cm x 2cm x 0.2 cm) at an angle of 45^{o} with the normal of the target surface was investigated by fast photography and shadowgraphy techniques. Time integrated images of these plumes are captured by CCD based computer-controlled image grabbing system which are then stored on computer, while time resolved plume imaging is accomplished using gated ICCD camera (gate time 10 ns and gate width 10 -20 ns) with a digital pulse generator. For the shadowgraphy of the laser induced plasma plume, Nd: YAG laser (532 nm, 8 ns, 53 mJ, 21 MW) as pump and probe beam. As the plasma plume exhibits variation in the refractive index, so the different density gradient regimes of the plasma are captured by the CCD based computer-controlled system on the computer. The experimental observations are then verified by different theoretical models i.e. Snowplow, Shockwave, Drag and Anisimov Models theoretically. These models help us to investigate the behavior of plasma plume expansion theoretically under different pressures, which exhibit different regimes of plume expansion. Initially, Plume expansion is and isothermal, the plume is spherical later on it becomes non-uniform. The plume is sharpened during these stages. Plasma intensity from copper, platinum and gold plumes is same i.e. 250 Arbitrary Units (A.U.) whereas it is 190 (A.U.) for silver and 180 (A.U.) for zinc plume. Plume lengths from targets range from 120 pixels to 900 pixels when delay time ranges from 530 ns to 2500 ns. During the initial stage of plume dynamics, a dark nucleus with a sharp boundary is formed that persists up to 75 ns. Plasma expands at a higher rate during this stage. A shock wave is clearly seen at higher pressure that remained progressing up to 500 ns. Expansion of plume is faster in radial direction than in axial direction. The plume dynamics depend on laser intensity.

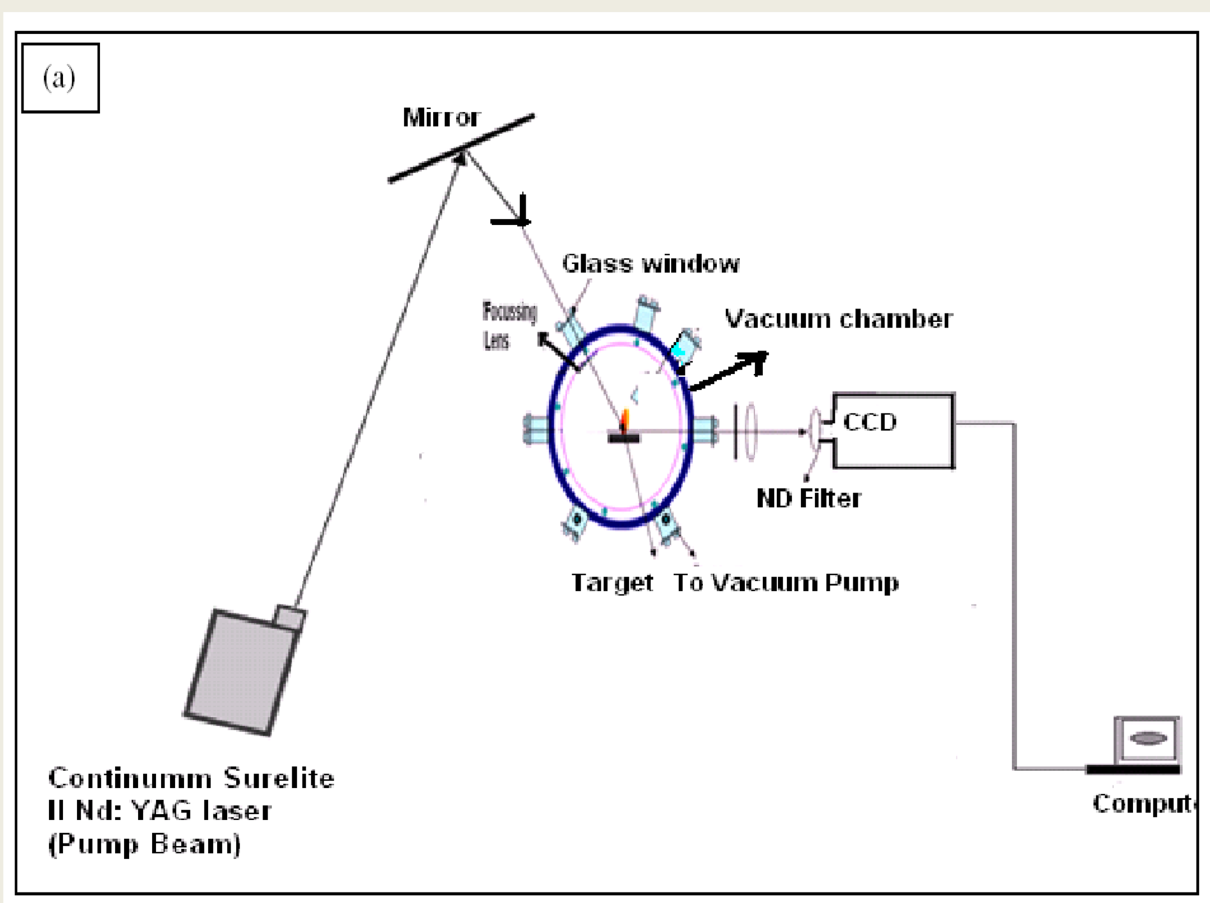
At very earlier times, the plume expands has a linear trend, whereas, at later times, the plasma-plume expansion is non-uniform.

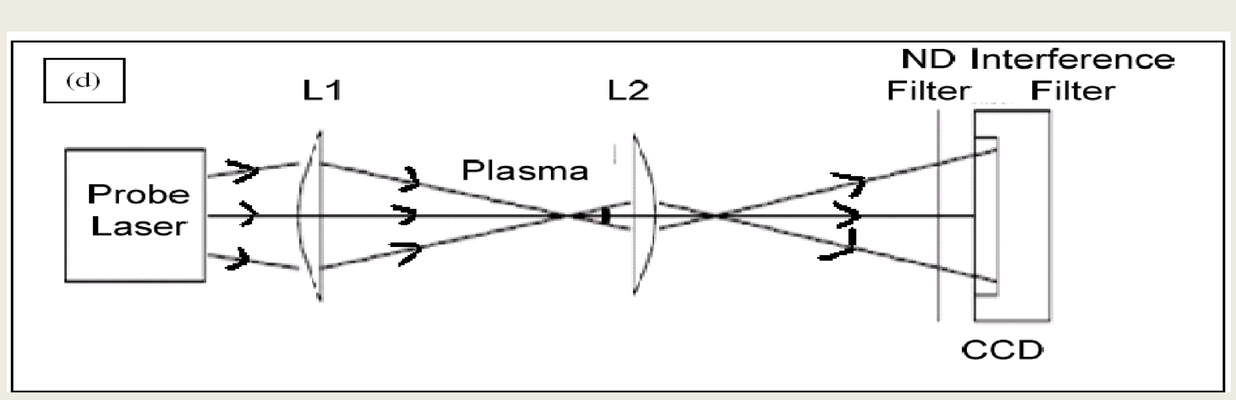
INTRODUCTION

The laser induced plasma [1-2] plume dynamics [3-4] has been studied widely which can be investigated by employing different spectroscopic emission techniques [5]. Because laser induced plasma [1-2] is usually characterized by temperature and refractive gradients [3], so different emission spectroscopic techniques like shadowgraphy and fast photography that employs a charged coupled device (CCD) and intensified CCD (used for two-dimensional imaging of the plume) [6-13].

The irradiance of matter by laser beam induces breakdown phenomenon [1], and by the absorption of this laser energy, electromagnetic energy is transformed into different types of energy, i.e. excitation of electrons occurs thus transforming this energy into thermal, chemical and mechanical energy [14], that results in different physical phenomenon like melting, vaporization [15], and finally, at the termination of a laser pulse, a cloud of ablated species is formed, that comprises shower of electrons, ions, excited or ground state neutrals (atoms and molecules), formally known to be plasma plume[3, 13]. This plasma plume moves away from the surface rapidly [1] that tends to grow in all directions, but it prefers to grow along the target normal [3]. These physical processes depend on physical parameters of matter as well as laser parameters [15].

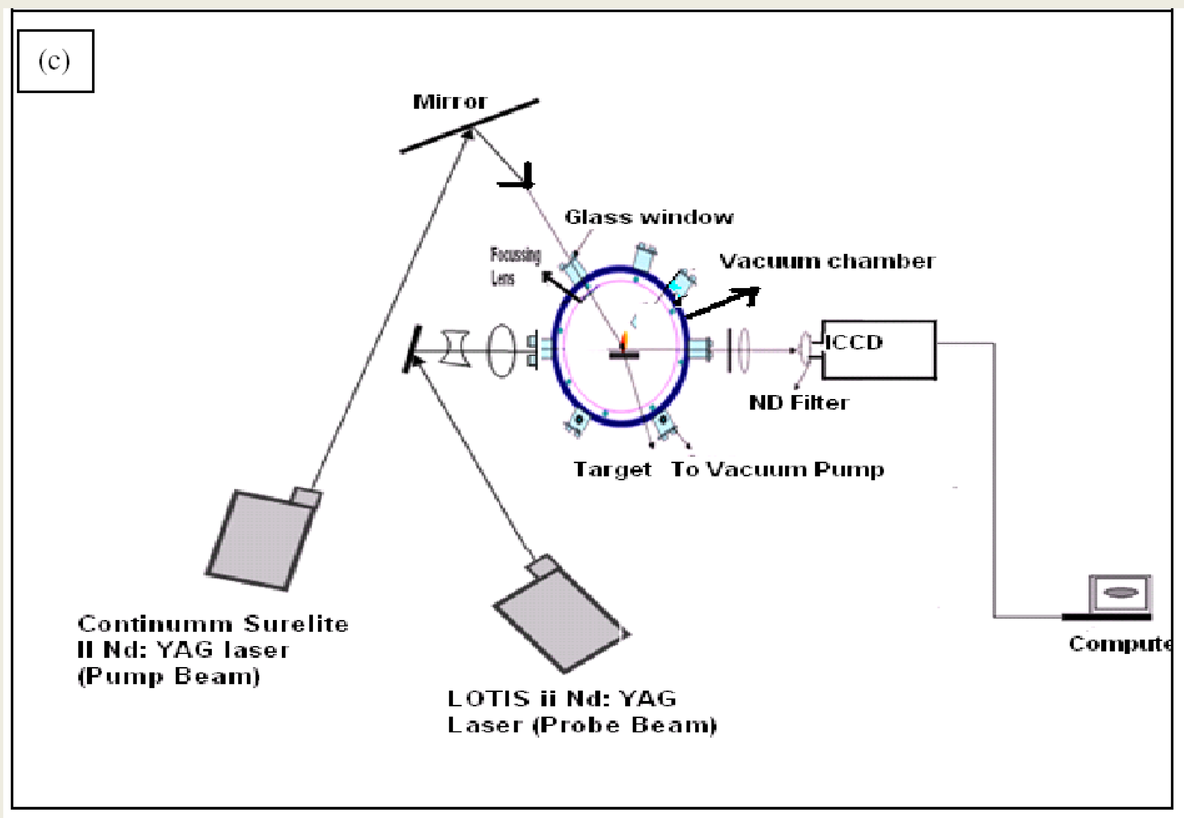
After the plasma formation, plume starts expanding which is a topic of great interest in the field of plasma sciences, in which plume expansion is studied under vacuum as well in ambient gas [6], so different physical processes seems to occur [13]. To explore plume expansion science a lot of research has been carried out both experimentally as well as theoretically [15].

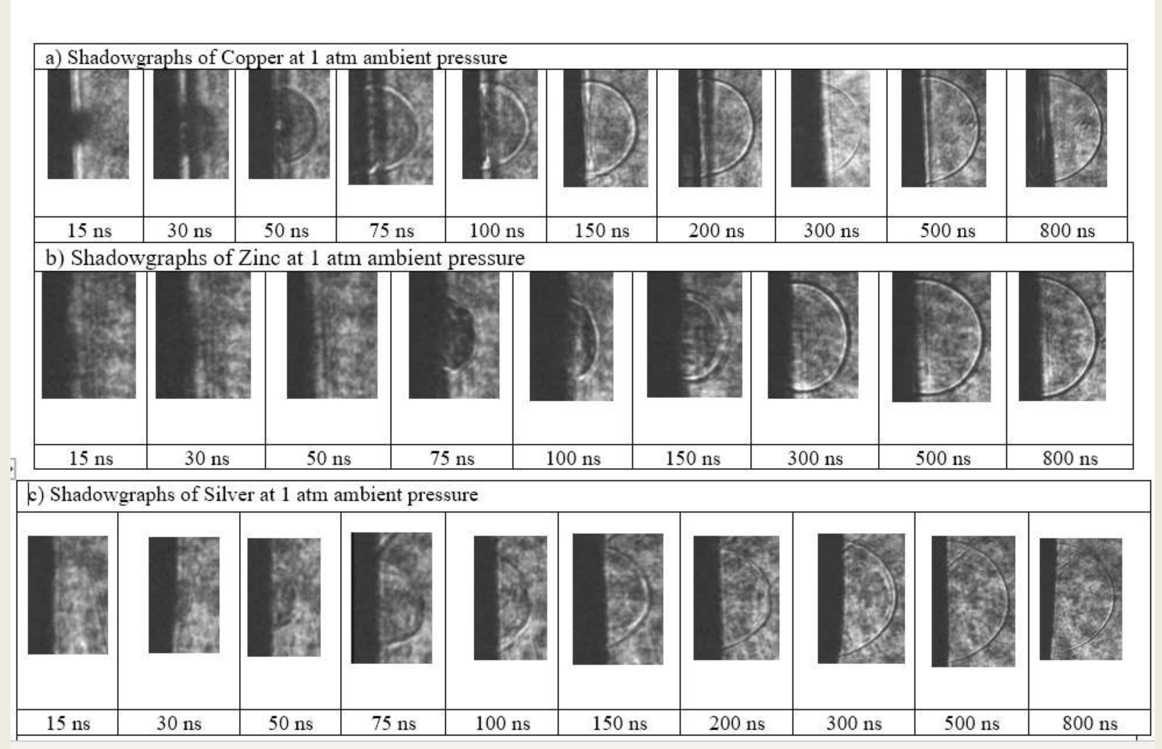




EXPERIMENTAL SETUP

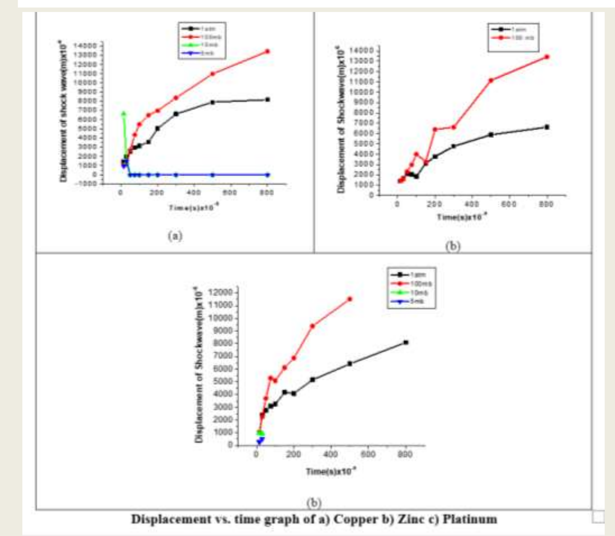
Experiments for ICCD image capturing, shadowgraphy and electromagnetic radiations (X-rays and EUV) emission from laser induced plasma were carried out . Nd: YAG laser at 1064 nm, 10 mJ, 9-14 ns and 1.1 MW is tightly focused (with the help of 17 cm IR plano-convex lens) on 4 N pure, annealed and fine polished samples (2cm x 2cm x 0.2 cm) at an angle of 45^{o} with the normal of the target surface to produce plasma . The targets are kept on a rotation to minimize the local heating and crater formation [9]. A digital pulse generator (Wavetek 50 MHz - 801 Generator) is used to control the delay between the laser pulse and the imaging system. To control the saturation for the camera light, neutral-density (ND) filters are used between the glass window of the vacuum chamber and the ICCD camera [9]. The schematic of experimental set up for time resolved plume dynamics image capturing system is shown in Figure 1 (b) The grabbed images are then analyzed using image J launcher and Matlab computer software. For shadowgraphy, two Nd: YAG lasers are employed via continuum surelite II laser (a pump beam laser) to create metallic plasmas and LOTIS ii (a probe beam) to make the shadow of the laser induced plasma plume instead of the Nitrogen pumped dye laser, that is used by other as a probe beam [9]. Probe laser is used at extremely high power to reduce the pulse width of the laser pulse. The beam is expanded by diverging the beam when it is passed through a concave lens and is collimated by passing through a convex lens. The different density gradient regions of the plasma are grabbed as they behave differently from one another. These changes are captured by the CCD based computer-controlled system on the computer.

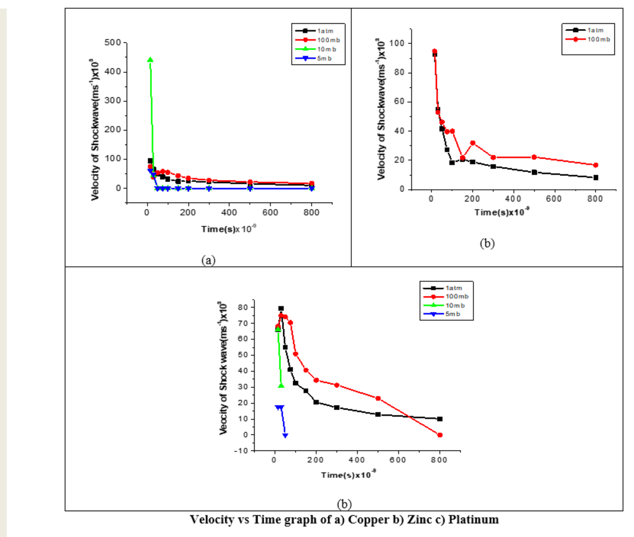


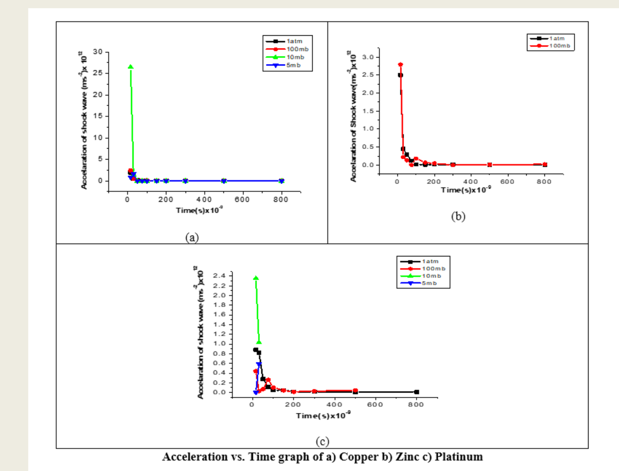


RESULTS

Figure shows the graphical representation of displacement of shock wave vs. time for different metals i.e. copper, zinc and silver. Each graph shows an exponential increase in the displacement of the shock wave with increase in time at different pressure. The velocity and acceleration graph also show an exponential decrease in time at different time and pressure.







CONCLUSIONS

The poster correlates the experimental and theoretical work together in order to investigate the laser induced plasma plume dynamics. Theoretical work includes verification of different models for plume expansion study while experimental work employs techniques of shadowgraphy and fast photography for the plume dynamics. So, the work shows a comparison between theoretical and experimental work.

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