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Forward Peaking of Laser Induced Plasma Plume

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Abstract

This paper represents the results of forward peaking in ion flux distribution of laser induced plasma plume of Ag. Ion flux distribution of silver plasma was detected using SSNTDs (CR-39), detector were placed at different angles from the normal of the target. The bunch of ions was received by the detector at 0°, which indicates the maximum concentration of ions along the normal of the target, which named as forward peaking. Cu substrate was irradiated by Al ions, while Al, substrate was irradiated by Cu ions. In both cases substrate was placed along the normal of the target. There was a circular damage of ions at the surface of both substrates, which exhibits the forward peaking in laser induced plasma ions.

Introduction

Plasma emission begins on the target surface soon after the laser photon reseated the target surface [1]. Plasma ions angularly distributed with respect to energy and charge states due to the mutual interaction and collisions with neutral atoms ions or with nano particles. M. Khaleeq-ur-Rahman et al. [3] measured energy of ions emitted from Nd: YAG laser induced plasma. For this purpose solid-state nuclear track detector (CR-39/PM-355) were used. The ion flux was high in the axial direction and reduced in the radial direction. The maximum energy of ions was found to be 20 keV.

In this paper angular distribution of ions and why maximum concentration is along the normal of the target. The maximum concentration of ions along the normal of the target in the form of a collimated beam is termed as forward peaking.

Experimental Setup

In the first experiment laser pulses were focused on polished copper target in air at 15° from the normal of the target. The Aluminum substrate was placed along the normal of the target at a distance of 6 cm from the point where the laser was focused on the Copper target. It was then irradiated by 600 pulses of Nd: YAG

(1.064 µm, 1.1 MW, 10mJ) laser. Then copper target was replaced by Aluminum target and Aluminum substrate was replaced by Copper substrate. In the second experiment laser pulses were focused on Silver target with thickness of 40 micrometer, at 45° from the normal of the target. Silver target was irradiated by 600 laser pulses. Six CR-39 (SSNTDs) detectors were placed at –17.5, 0^o, 17.5^o, 30^o, 60^o and 90^o from the normal of the target in vacuum chamber at a pressure of 10^{-3} torr.as A schematic of the overall experimental arrangement is as shown in the figure 1.

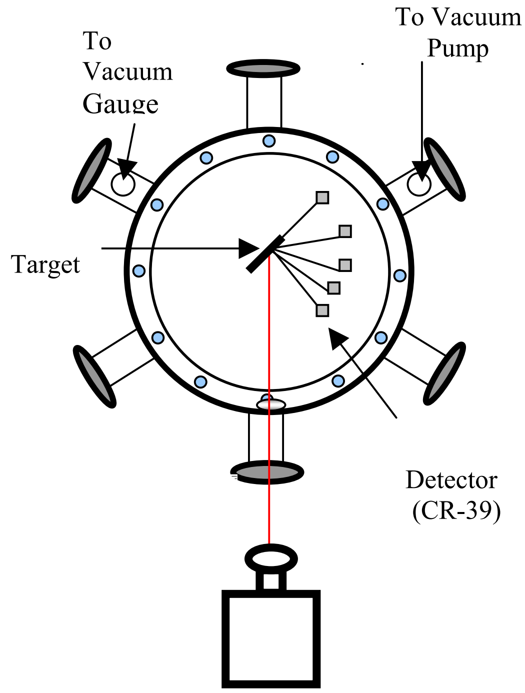

Figure 1: A schematic of the Experimental arrangement

Results and Discussion

Plasma is formed when the laser intensity increased the threshold intensity of the material. Very near to the surface of the target the concentration of the plasma species (electrons, ions, atoms and vapor) is very high forming Knudsen layer. Within this layer ions interact with each other and they also generated more ionization states by collisions. Electrons are much more mobile than ions and neutral atom but at the same time electrons are restricted from escaping the plume, due to the strong space charge field, due to collectively moving away from the ions [2].

This is the basis for the space charge acceleration model for the ions in the plume. The coulomb's attraction of the ions by electrons that nearly escape at the plume boundary, producing a space charge field that tends to accelerate the ions according to their charge, Ze [4-6]. The space charge of electrons also named the plasma sheath, which is responsible for ions acceleration along the normal of the target. Ions accelerated from the target surface (Ablation Layer) form a cone. This cone formation is due to the angular distribution of the ions; angular distribution of ions may also be described in terms of the "half angle" of the distribution cone, $\theta_{1/2}$ that is defined as the value of the θ at which the flux is half of its maximum [2].

Numerous studies have shown that the angular distribution of the laser-generated flux is often (but not always) much more strongly forward peaked than the flux obtained from small area effusive sources operating under collisionless conditions. This forward peaking phenomenon arise due to collision of plume species among themselves [2]. But in the presence of the ambient gas at low pressure or in the air (1 atm) the scattering of ions by gas atoms must be considered.

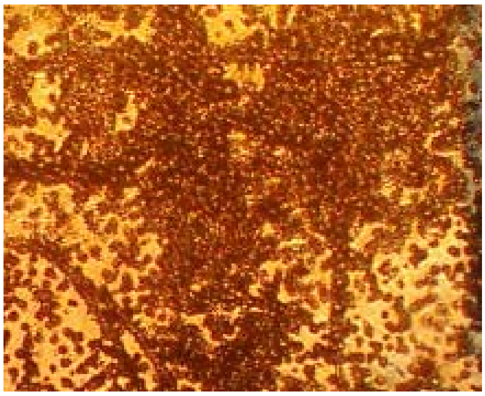

Figure 2: Detector at 0° showing very clearly the bunch of ions.

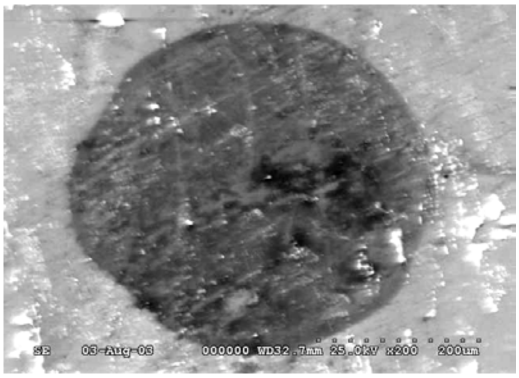

Figure 3: SEM Micrograph of Al surface at magnification × 200 of the circular region
of radius 230 μm, circular damage is a

Similar results were obtained in the silver ion detection experiment, a bunch of ions can be seen very clearly at the detector placed at 0° from the normal of the target as shown in the figure . The ion bunch was of 0.4 mm in diameter. It was also clear from detector analysis that ions in the bunch were of same average energy with high concentration and higher energy. So ions of greater energy moves along the normal of the target surface. Forward peaking is always a result of plasma plume regardless of conditions under which the plasma is produced, in air or in vacuum. This was conformed by the laser produced plasma ions sputtering experiments in air. In these experiments, circular damage of 0.1mm and 0.14mm in diameter were analyzed on the surface of Al substrate. The sample was placed along the normal of the target as shown in the figure 3. Thus a collimated beam of plasma ions of greater energy formed along the normal of the target. At the edge of the Knudsen layer a bunch of high concentration might be formed, that is, then accelerated away from the target, due to isothermal expansion of plasma. During its flight away from the target, ion concentration decreases due to scattering by mutual interaction or with electrons or atoms of plasma that resulted in angular distribution of plasma plume. When this bunch of ions reaches the critical layer, where laser plasma interactions are maximum due to same frequency of both plasma and laser. Electrons might gain energy by inverse bremsstrahlung and accelerated backward due to ponder motive forces of laser radiations. This phenomenon is responsible for cascade ionization, which results in angular distribution and thermodynamical expansion of the plasma plume. These affects decrease the concentration of bunch of ions. Further decrease in ion concentration of bunch is due to the plasma decay (recombination) and scattering with ambient gas if present.

The results of above mentioned experiments support the formation of bunch of ions very initially in the plasma plume, but its concentration decreases due to scattering, recombination, mutual interaction of ions and plume angular distribution.

Conclusion

It is concluded that a bunch of ions of high concentration in the beginning of the plasma plume formation moves along the normal to the target surface. During its flight away from the target surface, due to diffusion or scattering of ions in the end.

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