IMPACT OF MATERIAL PROPERTIES ON ENERGY OF LASER INDUCED PLASMA IONS

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ABSTRACT: *Investigations have been performed to study the impact of material properties on the energy of laser induced plasma ions. Nd:YAG laser is employed on metallic surfaces (Al, Au, Ag) for constant 300 laser shots under vacuum~10^{-3}torr. Ions energy measurement has been performed by exploiting Thomson parabola technique. Calculations show that the energy of Al, Au and Ag ions is 114 keV, 27 keV and 23 keV respectively. Impact of ions irradiation on the surface modification has been observed by irradiating the surface of PET by the laser induced plasma ions of known energy. Surface modification after ions irradiation has been explored using optical microscope. It reveals that the aluminum ions (114keV) lead to the more destruction at the surface morphology of exposed substrate as compared to the gold and silver ions.*

Key words: Surface modification, ions irradiation, thomson parabola technique.

I: INTRODUCTION

Laser matter interaction is a very useful method to modify the material properties. Interaction of nanosecond laser pulse with matter generates different processes such as material melting, boiling and ejection of material by producing forwardly peaked plasma plume [1]. The self-generated electric field within the plasma plume is responsible for generating the high fluxes of energetic ion beams. Ions properties such as kinetic energy and charge states are highly influenced by the properties of incident laser beam and the target material [2].

The most fundamental feature about the interaction of nanosecond laser pulse is that the heat diffusion within the matter takes place during the pulse duration. Therefore, material modification takes place by the thermal process. Area in which the heat is conducted is known as the heat affected zone. Conduction of heat within the material initiates atoms excitations [3, 4]. These excitations cause temperature rise within the exposed part due to which material melting and boiling takes place. During the boiling phase, material is ejected out in the form of small liquid droplets. Further absorption of energy within these liquid droplets produces plasma plume at the surface [5-8].

Inside this plasma plume there is a self generated electric field which is responsible for the aniosotropic emission of ions. These laser induced plasma ions are further used to make various types of material modifications [9].

II: LITERATURE REVIEW

Irradiation with laser produced plasma ions of varying energies have various applications in the field of industry such as deposition of thin films is also carried out employing the phenomena of ion beam sputtering technique (IBS). IBS technique is also taken into account for the growth of nano scale structures such as holes, dots, ripples etc. In particular, electrical properties of nanowires may also be altered by the irradiation of energetic ions beams [10-12].

Present research project is dedicated to study the effect of metal properties such as atomic number, melting point and thermal conductivity on the energy of laser generated ions. Furthermore, laser produced plasma ions have been irradiated on the polymeric surface (PET) to study the surface modification after the exposure of ions of varying energy.

III: EXPERIMENTATION

Experimentation of this project comprises two steps. First step deals with the energy calculation of laser induced plasma ions of three metals (Al, Au, Ag) whereas irradiation of ions on PET substrate are performed in second step.

3.1: Ions energy calculation

Energy of ions has been calculated employing Thomson parabola technique. For this purpose, aluminum, gold and silver targets have been irradiated with Nd:YAG laser beam. The irradiation produces the plasma plume at the surface which is a rich source of ions. Ions emitting from plasma plume have been deflected by placing an assembly of two permanent magnets (0.08T) in the distance between target and the SSNTD. The deflection of ions is observed on SSNTD placed at a position perpendicular to the ions projection. This deflection of ions gives information about the ions energy. Schematic diagram of Thomson parabola technique is shown in fig. 1.

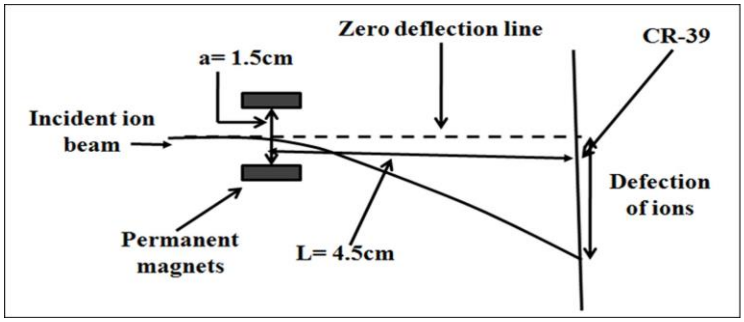

Figure 1: Schematic diagram of Thomson parabola technique.

Here, the radius of the circular magnetic field (a) generated between the permanent magnet is "1.5 cm", separation between the target and the SSNTD (L) is "4.5 cm" and the deflection of ions (D) is observed on SSNTD using optical microscope.

Calculation of ions energy is carried using relation given in equation (1) [13].

$\mathbf{E=e^2B^2R^2/2M}$ …………. (1)

Here "e" is the charge, "B" is the magnetic field strength, "R" is the radius of curvature and "M" is the atomic mass.

R is calculated using relation as follows [13]:

$\mathbf{R= a[x+\{x^2+1\}^{1/2}}$……… (2)

Where $\mathbf{X=L/D}$ ……… (3)

L is the distance between SSNTD from centre of the circular magnetic field region and D is the deflection of ions.

The deflection of ions on SSNTD (CR-39) has been observed by the optical microscope (Olympus STM6).

3.2: Ions irradiation

Schematic diagram to perform ions irradiations has been shown in fig. 2.

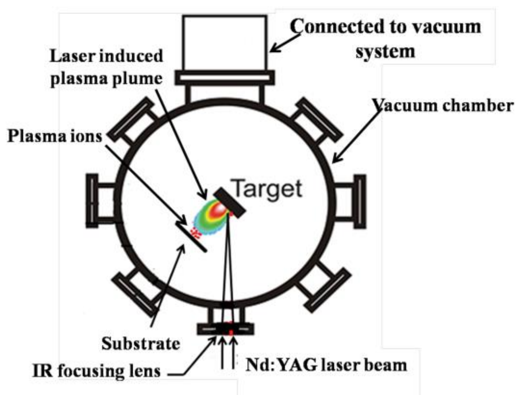

Figure 2: Schematic diagram of ions irradiations setup

Nd:YAG (1064nm, 10mJ, 9ns) laser beam has been focused on the metallic targets in an eight port vacuum chamber making an angle 45^0 with respect to normal to the target surface. Targets have been placed at tightly focused position. Fluence of laser pulse at tightly focused position is 3.1 J/cm^2 Irradiation of nanosecond laser pulses on the metallic targets produces plasma plume. Ions emitting from laser produced plasma plume are irradiated on PET substrate placed at 9mm away from the target. Whole experiment is performed in vacuum 10^{-3} torr.

Irradiation effects on polymeric surface (PET) are examined by the optical microscope (Olympus STM6).

IV: RESULTS AND DISCUSSION

4.1: Ions energy analysis

Values of the ions energy calculated through Thomson parabola technique have been tabulated in table 1.

It is clearly observed from table 1 that the energy of the aluminum ions is maximum in all these three metals (Al, Au, Ag). As the melting point (933.46K) , atomic number(13) and thermal conductivity (237 W/mK) of aluminum is lesser than that of gold and silver therefore, aluminum ions occupy highest energy. In case of gold and silver, eventhogh the melting point (1337.33K) and atomic number (79) of gold is higher than that of silver but as the thermal conductivity of silver (429 W/mK) is higher than gold (318 W/mK) that is why the energy of gold ions is higher than the silver ions. Higher thermal conductivity causes the penetration of more heat produced by the incident radiation within the substrate Surface morphology of PET after irradiation of ions of different energy has been shown in fig. 3material hence generating less plasma at the surface. Less plasma production leads to the emission of low energy ions [14].

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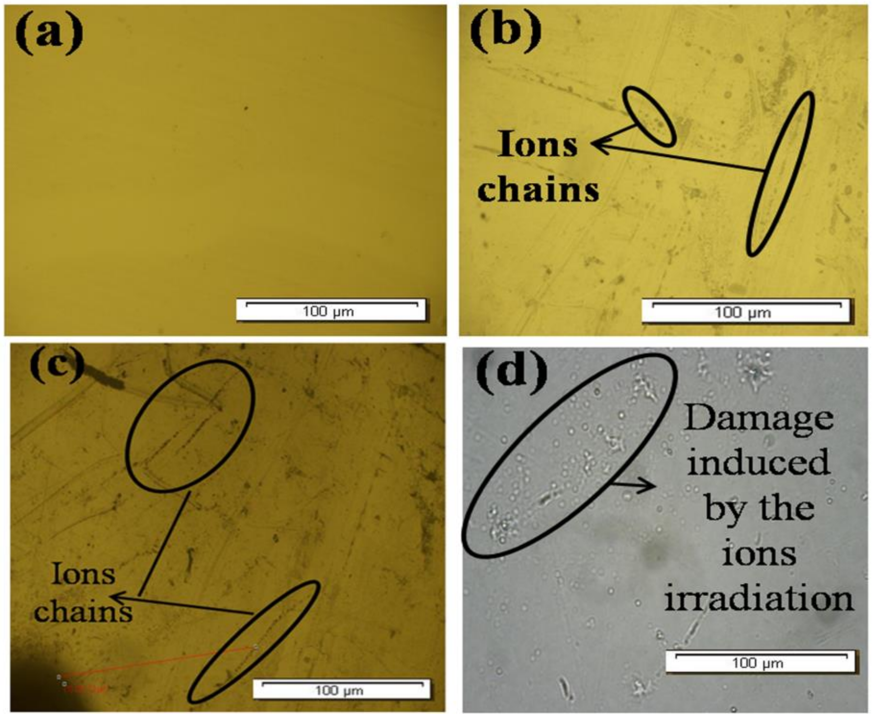

Figure 3: Optical micrographs of (a) pristine PET (b) Al ions, (c) Au ions, (d) Ag ions, irradiated on PET polymer.

4.2: Surface morphology of ions irradiated polymer

It is evident from the optical micrographs that the surface of pristine or un-exposed substrate is very smooth. It contains no damage at the surface. After the irradiation of ions, chain like damage trails appears at the surface morphology. Each damage trail consists of number small closely spaced dots. These damage trails are known as the ions chains while each tiny circular dot is called as the ions track. These circular tracks are formed at the surface when an ion interacts with the substrate surface. Vertex of an ion track is the point where ion meets the substrate atoms [15]. Size of ion track diameter gives information about its energy. When a more energetic ion collides with the substrate surface, it causes excitations in the more substrate atoms. These excitations result in the displacement of more atoms from their lattice positions hence leaving an ion track of greater diameter at the surface. Dependence of ions energy on track diameter is observed by the relation given in equation 4 [16].

$$\mathbf{E = (D)^{6.16}/1.0864} \ \ldots\ldots\ (4)$$

Here D is the ion track diameter.

When ions interact with the surface of the substrate they transfer their energy to the surface atoms by making collisions. A high energy ion makes large number of collisions before coming to its complete resting position. During the energy transfer process, atoms in the path of ion are first energized and then displaced from their initial lattice sites. In this way a cascade of collisions is generated which further leads to the material removal or sputtering of substrate [16]. An incident ion makes two types of collisions with the substrate atoms namely elastic collisions and inelastic collisions. These collisions are responsible for the appearance of thermal effects in structure [17].

Elastic collisions occur when an ions entering the substrate interacts with the nuclei of the atom hence experiences deflection. Deflection of ion causes other atoms to displace from their initial positions. The primary recoil atom further induces the cascade and sub- cascades of collisions that lead to the formation of thermal spike. This may cause the heating, melting and evaporation of the material atoms. Phonons are generated if the target atom does not acquire the energy enough to displace from its lattice site and hops back to its position. Such collisions are observed in material for the incident ions having energy 100 keV or below [18].

Inelastic collisions are observed for the ions of energy 1 MeV or greater than this. In these collisions an interaction between in-coming ion and target electrons takes place. After this interaction, electrons are energized and hence leave the atom. Electrons gain energy enough to generate the electron phonon interaction. Production of ionization by the energetic ion may lead to the coulomb explosion [19].

Travelling of ions below the skin layer continues until it gains thermal energy same as that of the substrate atom. Incident ion may become an interstitial or cause the replacement of atoms. Replacement of atom causes the atom to move at the interstitial site from its lattice site. Tangential stresses induced by the interstitials causes the alteration in structure [20, 21].

Relaxation in ions induced stresses occurs by two ways named as fast relaxation and slow relaxation. Annihilation of point defects induced by the interruption of ions results in the fast relaxation whereas; slow relaxation of stress occurs by the dislocation movements, transformation of defects and the shifting in crystal interface. Stress fields and shocks generated by the penetration of ions can be observed in depth twice than the ions range [22].

4.3: Comparison

A comparison between the optical micrographs of the PET irradiated with the ions of different energy shows that the aluminum ions of energy 114 keV produce maximum surface damage as compared to the ions of other two metals. Diameter of ions tracks is also maximum observed in case of aluminum ions irradiation. There are also some ions tracks which are not perfectly circular. Such de-shaped ions tracks show that the irradiation has produced a small amount of material melting as well. Rapid freezing of a material after melting is responsible for the irregular ions tracks. In case of gold ions irradiations, visibly linearly arranged arrays of ions tracks are observed. These ions chains confirm that the gold ions have been implanted within the substrate. For the silver ions irradiations, depending upon its energy, it leads to the minimum surface modification. Least number of ions chains appear at the surface.

V: CONCLUSIONS

Energy of laser produced aluminum ions is maximum than that of gold and silver metals. Surface damage produced by the irradiations highly depends upon the energy of ions. Damage induced by the irradiation of aluminum ions on PET surface is maximum as compared to that produced by the gold and silver ions irradiation. The ion track diameter of aluminum ions is maximum employing higher rate of cascade collisions.

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