Estimation of electron temperature for SiO_2 plasma induced by laser

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Abstract

In this work; Silicon dioxide (SiO_2) were fabricated by pulsed laser ablation (PLA). The electron temperature was calculated by reading the data of I-V curve of Langmuir probe which was employed as a diagnostic technique for measuring plasma properties. Pulsed Nd:YA Glaser was used for measuring the electron temperature of SiO_2 plasma plume under vacuum environment with varying both pressure and axial distance from the target surface. The electron temperature has been measured experimentally and the effects of each of pressure and Langmuir probe distance from the target were studied. An inverse relationship between electron temperature and both pressure and axial distance was observed.

Key words

Laser induced plasma, Langmuir probe, electron temperature, SiO_2 thin film.

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تقدير درجة حرارة الالكترونات في بلازما SiO_2 المحتثة بالليزر

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الخلاصة

في هذا البحث؛ تم تحضير غشاء SiO_2 بطريقة القشط بالليزر. تم حساب درجة حرارة الإلكترون من خلال قراءة البيانات الخاصة بمنحنى لانكمور الذي تم استعماله لقياس خصائص البلازما. واستعمل ليزر Nd:YAG لقياس درجة حرارة الإلكترون لمركب SiO_2 في عمود البلازما تحت الفراغ مع اختلاف كل من ضغط الفراغ والمسافة المحورية من سطح الهدف. وقد تم قياس درجة حرارة الإلكترون تجريبيا وتمت دراسة آثار كل من ضغط الفراغ ومسافة مجس لانكمور من سطح مادة الهدف على قيم درجة حرارة الالكترونات. وقد لوحظ وجود علاقة عكسية بين درجة حرارة الإلكترون وكل من ضغط الفراغ والمسافة المحورية.

Introduction

Laser matter interaction has explored many dimensions on the basis of laser ablation in fundamental studies and technological applications including thin films deposition, production of microclusters, cutting, drilling, surface treatment, laser patterning, fabrication of micro and nano-electronic devices, magneto hydrodynamic generators, etc. Laser solid interaction leads to the formation of laser induced plasma after a number of energy conversions, provided that energy of incident laser exceeds the ablation threshold of the solid. Plasma ejectants consist of a mixture of atoms, molecules, electrons, ions, clusters, micron-sized particles and molten globules. Laser induced plasma is transient in nature whose characteristics depend on laser parameters, target material and ambient conditions, which may vary radically along axial and radial direction [1]. The plasma buildup in nanosecond time scale is schematically described in literature as a two-step process. If the laser intensity is high enough, the target material undergoes normal vaporization. The subsequent interaction of the dense vapor with the laser beam, in proximity of the sample surface, leads to strong heating and ionization of the vapor, namely plasma formation. Although some species can be directly vaporized as ionized fragments, plasma formation can be mainly ascribed to a number of processes taking place in the second step. The minimum fluence needed to detect charged species in the vaporized material is defined as the ablation threshold, approximately between 1 and 10^2 J/cm^2 [2]. Successively the vaporized material expands in vacuum at super- sonic velocities[2]. The luminous expanding plume consists of electrons, atoms of different species and ions[3]. In laser induced plasmas (LIPs), equilibrium in the radiation process is hardly achieved because the plasma is normally thin and most of the radiated photons cannot be reabsorbed by the plasma. In this case, the plasma is described by local thermodynamic equilibrium (LTE) in which deviation from radiation equilibrium is neglected [4]. Laser–matter interaction is responsible for the creation of plasma whose characteristics are strongly dependent upon several parameters, including laser intensity, pulse duration, wavelength, target material and pressure of ambient gas [5]. Mostly, the characteristics of the plume are governed primarily by electron contributions to temperature and density. There are several diagnostic techniques employed for the determination of these parameters including Langmuir probe, mass spectroscopy, optical emission spectroscopy, laser absorption spectroscopy, microwave interferometry, laser interferometry, Thomson scattering, laser-induced fluorescence, beam deflectometry, etc. Langmuir probe is an electrostatic diagnostic technique for the investigation of low-temperature plasmas. The probe measurements are based on the estimation of I–V curve of a circuit consisting of metallic electrode that is immersed in the plasma under study. Conventional Langmuir probe theory assumes collisionless movement of charge carriers in the space charge sheath around the probe that forms a sheath. The sheath boundary is well-defined and beyond this boundary the plasma is completely undisturbed by the presence of the probe. This means that electric field caused by the difference between the potential of probe and plasma potential is limited to the volume inside the boundary of probe sheath [5,6]. In this research, the electron temperature in laser induced plasma has been investigated under the influence of the vacuum pressure and the axial distance.

Experimental

The target of the laser induced plasma (LIP) process was SiO_2 powder with purity 99.999%, and compressed under the pressure (10 tons) in order to make it shaped liked disc with a diameter of 3cm and then sintered to temperature of 500^{o}C for 2 hours to ensure the compactness and hardening of the target disc. LIP experiment was achieved under pressure (0.1mbar by using Varian DS219 Rotary pump). The beam of Nd:YAG laser with fundamental harmonic frequency (λ=1064nm, 10ns, 6Hz and 1mm spot diameter) was focused onto SiO_2 target with quartz lens (f=10cm), the target was kept onto rotating motor (speed 4 rev/min) to prevent fast drilling. The LIP experiment was performed at room temperature. LIP setup scheme with the electric circuit of the Langmuir probe has been shown in Fig.1. Cylindrical single Langmuir probe was made from Tungsten material with diameter 0.3 mm and length 10mm. Electron temperature was calculated by analyzing the I-V data of the Langmuir probe. The SiO_2 target was ablated by

1000 pulses. The pressure was varied from 0.04 to 0.2 mbar, also the distances between the SiO_2 target and the tip of the Langmuir probe was changed from 0.5 to 1.5 cm to study its effects on the value of electron temperature.

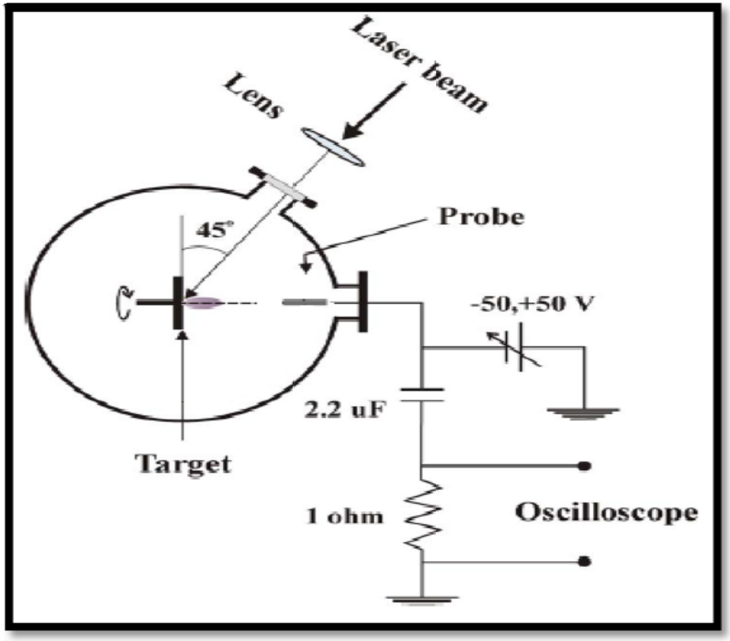

Fig. 1: Schematic diagram of the LIP experimental setup.

Results and discussion

Electron temperature in laser induced plasma depends strongly on the pressure of SiO_2 target. For the purpose of measuring the electron temperature (T_e) laser pulse energy has been set constant at 500mJ and vacuum pressure has been varied by using needle valve. Electron temperature has been calculated by using I-V curve of Langmuir probe data as shown in Fig.2, (i.e. from the slope of the electronic saturation region). Electron temperature T_e against pressure ranged from $4x10^{-2}$ to $2x10^{-1}$ mbar using fundamental wavelength of Nd: YAG laser has been illustrated in Fig. 3.

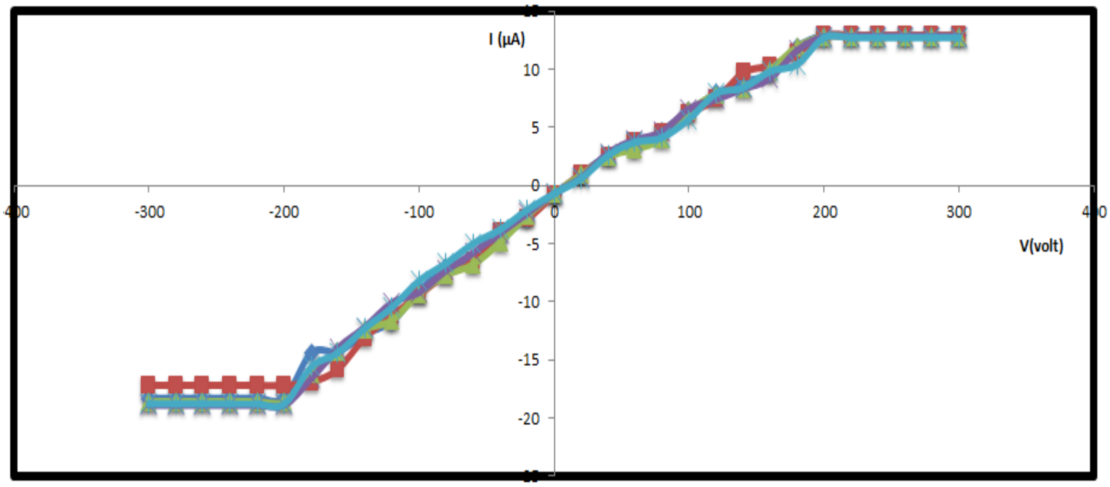

Fig. 2: I-V chart of langmuir probe.

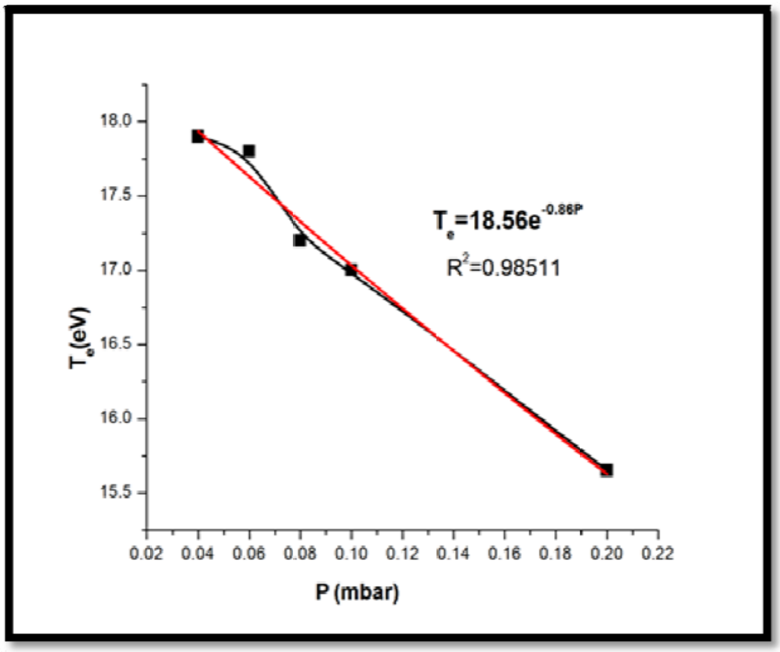

Fig.3: Electron temperature versus different pressure by using Nd:YAG laser wavelength 1064nm, laser pulse energy 500 mJ.

It is clear from the above figure that the electron temperature (T_e) decreases with increasing vacuum pressure. The symbol R^2 in the Fig. 3 refers to coefficient of determination. The decreasing of T_e with increasing of vacuum pressure is caused by the increasing of electron collisions with neutral atoms. This behavior will lead to decreasing of electron energy. Our results here agree with M. A. Hafez, et al.[7]. Fig. 4 shows also the inverse relationship between the electron temperature and the axial distance from the SiO_2 target.

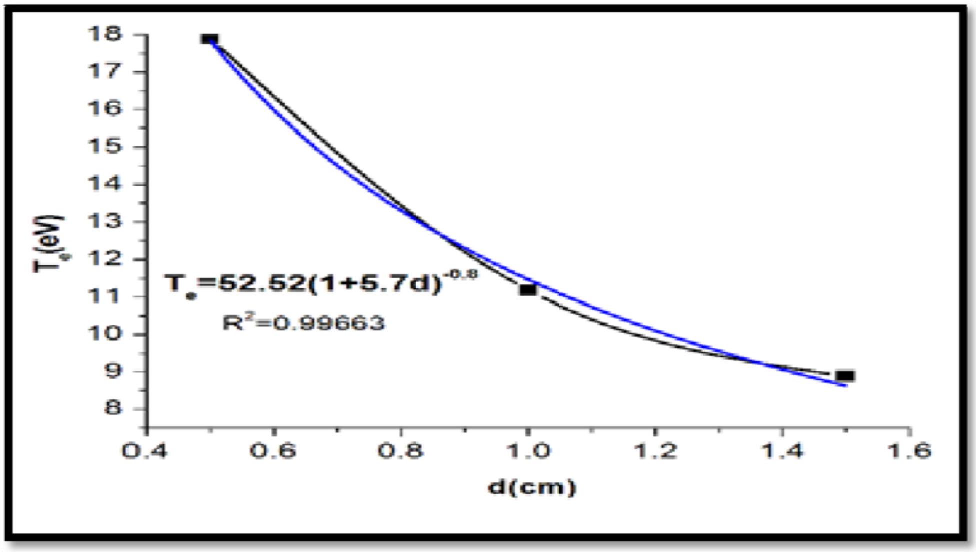

Fig. 4: Electron temperature versus different axial distance from the target by using Nd:YAG laser wavelength 1064nm, laser pulse energy 500 mJ.

As the axial distance from the SiO_2 target surface increases the electron temperature decreases i.e. inverse proportionality between them. The electron energy decreases with increasing of vacuum pressure may be due to the fact that the increasing of distance will increase the electron collisions and then which lead to decrease its energy and the second reason is due to the recombination of the electrons with the ions i.e. ion-electron recombination at large distances from the target surface.

Conclusions

The electron temperature of laser induced plasma of SiO_2 target depends strongly on pressure and axial distance from the target surface. The electron temperature decreased with increasing vacuum pressure. This is probably due to the confinement phenomenon of the plasma plume in a very small area. The electron temperature decreases also with increasing the axial distance from the SiO_2 target due to decrease in the thermal velocity and energy of the electrons and the recombination of the ions at large distances from the target.

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