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Pulsed laser ablation of Germanium under vacuum and hydrogen environments at various fluences

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ABSTRACT

Laser fluence and ambient environment play a significant role for the formation and development of the micro/nano-structures on the laser irradiated targets. Single crystal (1 0 0) Germanium (Ge) has been ablated under two environments of vacuum (10^{-3} Torr) and hydrogen (100 Torr) at various fluences ranging from 4.5 J cm^{-2} to 6 J cm^{-2}. For this purpose KrF Excimer laser with wavelength of 248 nm, pulse duration of 18 ns and repetition rate of 20 Hz has been employed. Surface morphology has been observed by Scanning Electron Microscope (SEM). Whereas, structural modification of irradiated targets was explored by Fourier Transform Infrared Spectroscopy (FTIR) and Raman spectroscopy. Electrical conductivity of the irradiated Ge is measured by four probe method. SEM analysis exhibits the formation of laser-induced periodic surface structures (LIPSS), cones and micro-bumps in both ambient environments (vacuum and hydrogen). The formation as well as development of these structures is strongly dependent upon the laser fluence and environmental conditions. The periodicity of LIPSS or ripples varies from 38 μm to 60 μm in case of vacuum whereas in case of hydrogen environment, the periodicity varies from 20 μm to 45 μm. The difference in number of ripples and periodicity as well as in shape and size of cones and bumps in vacuum and hydrogen is explained on the basis of confinement and shielding effect of plasma. FTIR spectroscopy reveals that no new bands are formed for laser ablated Ge under vacuum, whereas C—H stretching vibration band is formed for two moderate fluences (5 J cm^{-2} and 5.5 J cm^{-2}) in case of ablation in hydrogen. Raman spectroscopy shows that no new bands are formed in case of ablation in both environments; however a slight Raman shift is observed which is attributed to laser-induced stresses. The electrical conductivity of the irradiated Ge increases with increasing fluence and is also dependent upon the environment as well as grown structures.

1. Introduction

Laser ablation has been emerged as an effective and reliable mechanism for material's modification. It is preferable processing technique due to small heat affected zone, high precision, controlled laser energy and contamination free ablation processes [1,2]. Lasers are extensively utilized in industry for cutting, drilling, welding and surface modification [3]. Laser ablation in the ambient environment of gas has attracted much attentions because of its numerous applications like nano-particle generation, thin film deposition and laser induced break down spectroscopy [4–6]. Laser irradiation in gaseous environments increases the ablation efficiency due to confinement effects and enhanced energy coupling to the lattice [7,8]. After confinement, the plasma becomes thick enough which shields the target from laser radiation called shielding effect [9,10]. The presence of gaseous environment in laser material processing also causes rapid cooling of target and efficiently expels away the waste material. A lot of work on laser ablation in the presence of gaseous background environment has been reported by several groups [11–14].

Medvid et al. [15] observed the growth of nano and micro-cones on Ge, Si and SiGe after laser irradiation. The mechanism of nanocones is explained on the basis of mechanical compressive stresses induced by the absorption of laser radiation. Their shape and size is controlled by laser parameters. Pedraza et al. [16] reported the formation of conical spikes on the silicon surface after irradiation

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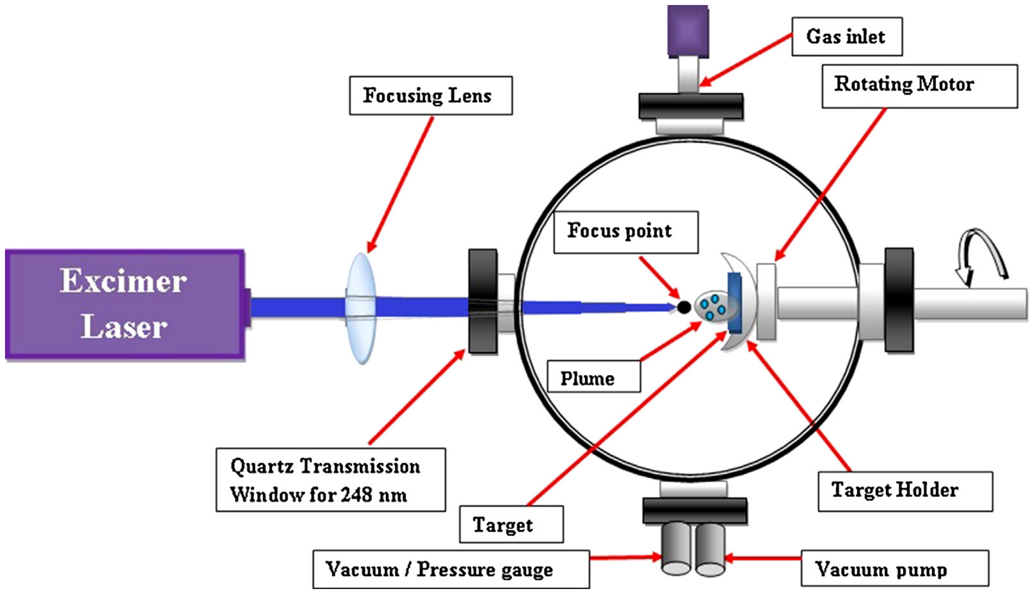

Fig. 1. The schematic of experimental set up for laser ablation of Ge under vacuum 10^{-3} Torr and hydrogen environment at a pressure of 100 Torr.

by excimer laser (wavelength of 248 nm, pulse duration of 25 ns). It has been observed that the diameter of the conical spikes significantly increased in ambient environment of SF_6 than air. Nayak et al. [17] observed the phenomena of spontaneous formation of nearly regular arrays of nano-spikes microstructures by exposing a Ge surface to femtosecond laser pulses in an environment of SF_6. The nano-spikes around 2 μm high having a tip radius of 100 nm are formed. Higher laser fluence and fewer shots favor the formation of nano-spikes. The Ge samples turn completely black after laser processing, i.e. they exhibit greatly reduced reflectivity throughout the visible spectrum.

The aim of the present work is to investigate the effect of laser fluence and ambient environment on surface, structural and electrical properties of Ge. KrF excimer laser as a source of irradiation was employed to expose the Ge samples in vacuum and hydrogen environments. Surface morphology was characterized by SEM. Laser-induced surface structures are correlated with structural modification of Ge explored by FTIR and Raman spectroscopy. Electrical conductivity of the irradiated Ge samples was measured by four probe method. The electrical behavior of irradiated Ge is also associated with surface and structural modifications.

2. Experimental details

Commercially polished Ge single crystal (1 0 0) in the form of wafer was selected as a target material. After cutting and ultrasonically cleaning, the Ge target of dimension 10 mm × 10 mm × 1 mm were placed into the target holder inside the vacuum chamber which was evacuated to base pressure of 10^{-3} Torr. KrF excimer laser (EX GAM USA 200) with wavelength of 248 nm, repetition rate of 20 Hz, maximum energy of 150 mJ, pulse duration of 18 ns and rectangular spot size of 11 mm × 7 mm was employed to perform the experiment. The beam hit the target surface after passing through focusing lens of focal length 50 cm. The targets were exposed at 2 cm away from the focus position. The laser spot size at 2 cm away from the focus point was 2.2 mm × 0.9 mm (spot area = 0.0198 cm^2) and it was measured by SEM analysis. The schematic of experimental setup is shown in Fig. 1.

Following two sets of experiments were performed.

1) In the first set of experiment, Ge targets were exposed to four different laser energies of 90 mJ, 100 mJ, 110 mJ and 120 mJ under vacuum condition (10^{-3} Torr). These energies were controlled by changing voltage of HV power supply of excimer laser system with the help of software. The energies were measured by power energy meter. This gives corresponding laser fluence of 4.5 J cm^{-2}, 5 J cm^{-2}, 5.5 J cm^{-2} and 6 J cm^{-2} respectively.
2) In the second set of experiment, hydrogen gas was filled in the vacuum chamber at a pressure of 100 Torr. This pressure was measured by precisionable pressure gauge. The four Ge targets were exposed exactly under the same conditions as has been employed for 1st set of experiment except with the change of environment.

There is the possibility of contaminations at such high pressure of 10^{-3} Torr. The aim of the work was to compare the ablation processes of Ge in two environments. One at low pressure of 10^{-3} Torr and second one in the presence of hydrogen at a significantly higher pressure of 100 Torr as compared to vacuum. The confinement effects, energy coupling and shielding effects of environmental gas (hydrogen) significantly influence the ablation processes of Ge which is responsible for the dissimilar surface morphological modifications of Ge in two different environments. There are large number of research groups which have reported their work at such high pressure (10^{-3} Torr) [18,19]. According to their results, first few pulses of laser are sufficient to remove contaminations from the surface of the irradiated target and following pulses cause real ablation [20].

All exposures were performed with constant number of 500 pulses and repetition rate of 20 Hz. The surface modification with lower number of pulses can grow various features such as bumps as well as conical structures (As has been seen in the peripheral ablated areas). But at higher number of pulses, all kinds of surface features i.e. ripples, cones and bumps are distinctly grown and can be easily categorized into three regions. (1) Central abated area with maximum energy deposition with an appearance of ripples. (2) Inner boundaries with moderate energy deposition representing expelled out material in the form of conical spikes at distance of 390–400 μm from center. (3) Outer boundaries with lowest energy deposition represent the growth of bumps at distance of 830–850 μm from center. The basic aim of the work is to explore surface and structural modification of Ge in different environmental conditions. Therefore number of pulses was kept constant at 500 and only fluence was varied for both environments.