Ge ION IMPLANT FROM ENERGETIC LASER-GENERATED PLASMA

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Abstract

At the PALS laboratories of Prague (Czech republic), IPPLM of Warsaw (Poland) and INFN-LNS of Catania (Italy) experimental tests have been carried out to implant Ge ions in Si substrates through laser-generated Ge-plasma. Si substrates were placed in a vacuum chamber at different distances and angles from the Ge-target.

Online measurements of ion energy were obtained by time of flight (TOF) techniques using an ion energy analyzer IEA which permitted to draw information about the charge states and the Ge ion's energies. Off-line measurements were obtained by Rutherford backscattering spectrometry (RBS) of 2.25 MeV He^{2+} beam at CEDAD Laboratory of Brindisi (Italy). RBS analysis permitted to evaluate the Ge implant in Si substrate in terms of concentration and ion depth profile. Moreover, the RBS spectra have given information about plasma ion yield and energy as a function of the laser intensity, distance from the target and angular position.

Results indicated that ion implants show high Ge ion energy and typical deep profiles only for substrates placed very near to the normal to the target surface and for high laser pulse intensity, while for low laser intensities and/or for substrates far from the normal to the target there is only a Ge deposition effect.

INTRODUCTION

Lasers at different intensities are used to generate hot plasmas by irradiating solid targets in vacuum. The plasma expands in vacuum at supersonic velocity along the normal to the target surface accelerating electrons, ions and neutrals. The high charge state and energetic ions follow a Boltzmann energy distribution [1].

Interesting information can be obtained by time-of-flight TOF measurements of ions, which indicate the presence of an high electrical field developed inside the plasma and responsible of the high ion acceleration along the normal direction to the target surface.

The ion energy and charge state can be measured by using an IEA (Ion Energy Analyzer) that gives information of TOF measurements of ions emitted from the plasma [2]. To confirm the measurements of ion energy, the 2.0 Mev alpha RBS analysis (Rutherford Backscattering Spectrometry) has been employed to investigate on the depth profiles of the implanted species [3].

Plasmas produced by pulsed energetic lasers find many applications in several scientific fields. In this work laser ablation of Ge was investigated, particularly for the implantation of Ge in silicon substrates. Si-Ge alloy is often used in microelectronic and optical fields because shows peculiar properties. The Ge implantation, in fact, may produce changes in the optical (transmission, absorption), in the electrical (conductibility specially for polymers, hole and electron's mobility, resistivity), in the mechanical (hardness, wetting, friction, elastic constant) and in the thermal surface properties (thermal conductibility) depending on the used implanted dose [4].

EXPERIMENTAL SECTION

Laser ablation of Ge targets have been produced at LNS of Catania (Italy) and IPPLM of Warsaw (Poland) both using a Nd:YAg laser in the first harmonic at 1064 nm with 9 ns pulse duration and 900 mJ maximum pulse energy, 10 Hz repetition rate. The laser spot was 1 mm^2 in diameter and the incidence angle was 33°. The intensity of pulse was approximately around 10^{12} W/cm^2. The ablation occurred in a vacuum chamber at 10^{-6} mbar and the substrates were placed at 9 cm and at an angle between 0° and 50°.

Laser ablation of Ge targets have been produced at PALS laboratory of Prague (Czech Republic) by using an iodine laser emitting a fundamental wavelength of 1315 nm. The duration of the laser pulse is 400 ps and the used laser pulse energy was maintained at about 38 J. The Ge target was placed in the vacuum chamber at 10^{-6} mbar. The incidence angle of the laser beam was 30° and the laser spot diameter was 70 μm, at which an intensity of about 10^{15} W/cm^2 was employed.

Fig. 1 (a) shows a typical experimental setup used for the Ge ion ablation and for the implantation in silicon substrates. Fig 1 (b) shows a scheme of the Ion Energy Analyzer (IEA) for the measures of the ion components of the laser-generated plasma.

Rutherford Backscattering Spectrometry (RBS) analyses were performed at CEDAD of

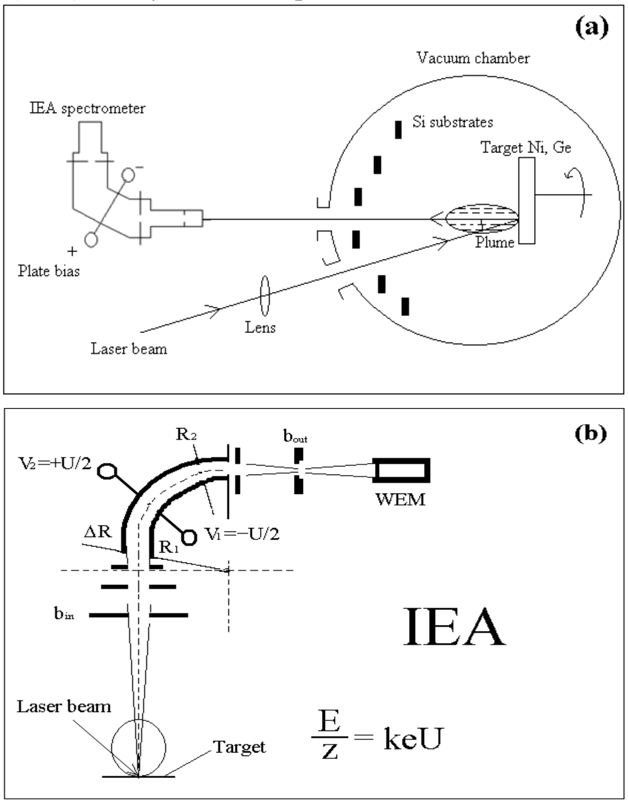

Fig. 1. (a) Scheme of the experimental setup. (b) Scheme of the Ion Energy Analyzer (IEA).

Brindisi (Italy) by using 2.25 MeV helium beam with a backscattering angle of 160°.

With this technique it is possible to measure the amount of implanted specie N_t by using the following relation [3]:

$$(Nt)_i = \frac{Y_i}{H_M} \frac{Z_M^2}{Z_i^2} \frac{\delta E}{[\varepsilon]_M} \qquad (1)$$

here i denotes the implanted specie, M the substrate, Y_i the yield of the implanted peak, H_M the height of the signal of the substrate, Z_M and Z_i are the atomic numbers relative to the substrate and to the implanted specie, respectively, δE, expressed in keV/channels, is the energy resolution of the detector and $[\varepsilon]_M$ is the stopping cross-section factor for the alpha particles in the substrate.

The depth t of the implanted specie or deposited thin films was calculated through the following relation:

$$t = \frac{\Delta E}{N[\varepsilon]_M} \qquad (2)$$

where ΔE is the alpha energy loss (keV) given by the RBS spectrum and N the substrate matrix density (atoms/cm^3).

RUSULTS

Fig. 2 shows a typical TOF spectra obtained through the use of an IEA at the IPPLM of Warsaw using a Nd:YAg at the first harmonic (1064 nm) wavelengths with 550 mJ pulse energy. The spectra were obtained by varying the bias U of the instrument. The figure reports the results for U = ±250 V (a) and U = ± 90 V (b).The spectra show the maximum charge state presence of 9 charge states. Fig.

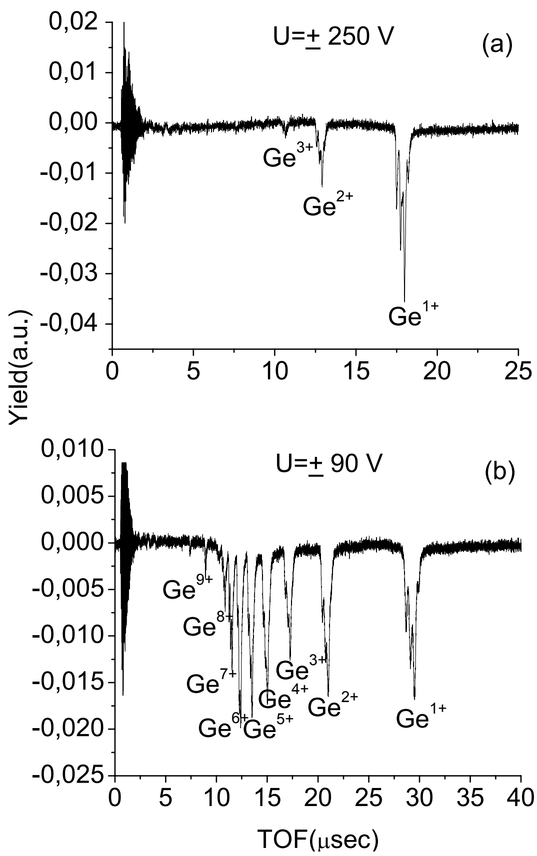

Fig. 2. Ge ion yield vs. TOF of emitted ions analyzed with a plate bias of ± 250 V (a) and ± 90 V (b).

3(a) shows the ion velocity distribution obtained at IPPLM of Warsaw. This distribution was fitted with a Coulomb-Boltzmann shifted function:

$$F(v_x, V_F) = A\left(\frac{m}{2\pi KT}\right)^2 v_x^3 \exp\left[-\left(\frac{m}{2KT}\right)(v_x - V_F)^2\right] \quad (3)$$

where

$$v_x = \sqrt{\frac{3\,KT}{m}}$$

is the thermal velocity, and V_F is a fit parameter depending on charge state and containing the adiabatic and Coulombian terms [5].

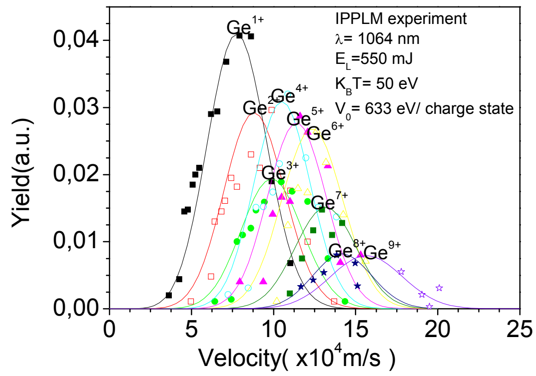

Fig. 3. Ion velocity distribution obtained at IPPLM of Warsaw

The fit indicate a plasma equivalent temperature of 50 eV and a Coulomb energy shift of 633 eV/charge state. The Ge ion energy for the charge state 1 is 2.1 keV while in the charge state 9 the energy is 8 keV.

Fig. 4a shows a RBS spectrum related to a Ge implantation in a silicon substrate at IPPLM by using 2000 laser pulses of 550 mJ and a peak power density of 10^{12} W/cm^2. The silicon substrate was placed at 9 cm distance and 15° to the respect to the target normal. In this case the low Ge ion energy produces only a simple surface deposition in the silicon surface because ions can not penetrate into the bulk. The amount of deposited specie N_t, by using relation (1), is $3.8\text{x}10^{15}$ Ge atoms/cm^2, corresponding to $1.59\text{x}10^{15}$ Ge atoms/cm^2/pulse.

Fig. 4b shows a RBS spectrum obtained implanting Ge ions of high energy in silicon substrates, placed at 16 cm distance and 40° angle with respect to the target normal, by using 12 laser pulses of 38 J with a power density of 10^{15} W/cm^2. The spectrum shows a typical ion implant profile with a depth profile, measured by using the formula (2), of 5300 Å, an amount of implanted specie of $3.2\text{x}10^{15}$ Ge atoms/cm^2, corresponding to $2.67\text{x}10^{14}$ Ge atoms/cm^2/pulse.

The Ge ion energy is of 750 keV, and the penetration is good measurable from RBS.

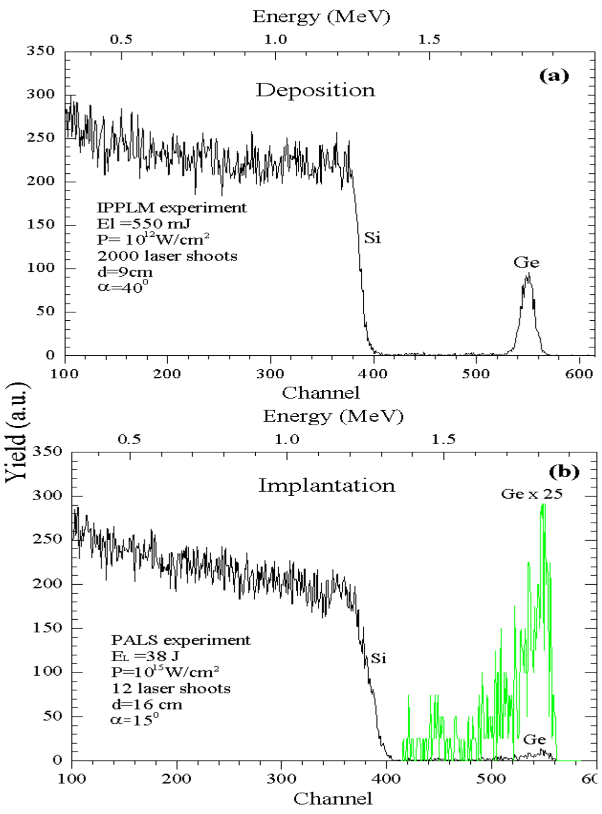

Fig. 4. RBS spectrum of deposited Ge film at IPPLM (a); RBS spectrum of implanted Ge ions at PALS (b).

Fig. 5a indicates the ablation yield vs. the angle with respect to the target normal. These, and other RBS measurements [6,7], show that the average implanted dose depends strongly on the angle with respect to the target normal at which the implanted sample is placed and on the target-substrate distance.

Both in the IPPLM experiment and in the PALS experiment it is possible to notice that the maximum amount of specie is present for an angular aperture of about ±15°.

Fig. 5b shows the Ge kinetic energy obtained at PALS, as a function of the angle with respect to the normal target direction. Results indicate that the high Ge ion energy is acquired only within an angular aperture of about ± 10°. Thus, only substrates placed within this angular aperture are effectively depth implanted, while substrates exposed at larger angles are only deposited, i.e. covered by a thin Ge film.

DISCUSSION AND CONCLUSIONS

Results show that the ion implantation is successfully obtained by using the multi-energetic Ge ions emitted by high intensity laser pulses (PALS experiment), while only a thin superficial film deposition can be obtained low intensity laser pulses

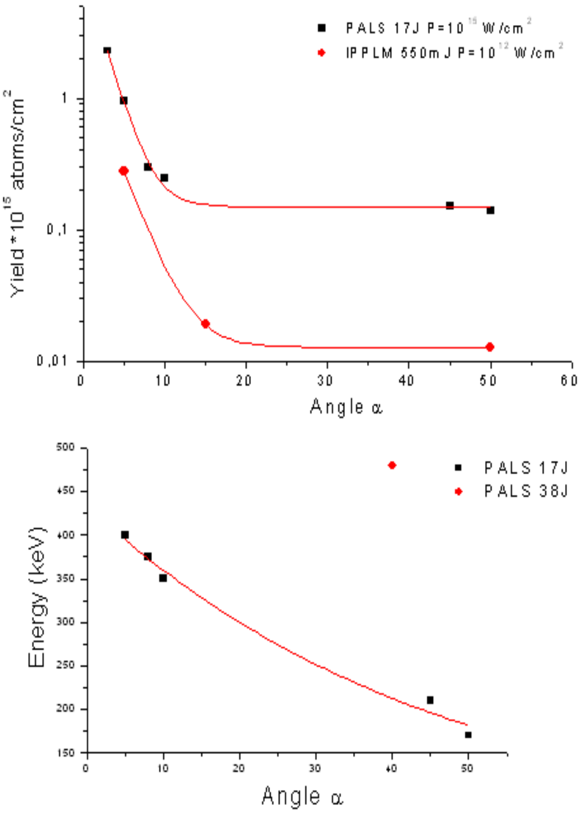

Fig. 5. Ge yield vs. angle for IPPLM and PALS experiment (a) and Ge ion energy vs. angle for PALS experiment at two laser energies.

(IPPLM and INFN-LNS experiments) producing very low energetic ions.

In these experiments was not used the post-acceleration methods. But in a next experiment the laser-generated ions will be submitted to an external acceleration by using an high electric field directed along the target normal direction. RBS analysis show, in fact, that the angular distribution of ions has a maximum yield in such direction with an angular aperture of about ±15°. In this way it will be possible to accelerate ions at energies of interest for ion implantation (50-300 keV) maintaining high the ion current and the implanted doses.

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