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Ion implantation from post-acceleration laser-generated plasma

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Abstract

A Nd:YAG laser, 1064 nm wavelength, 9 ns pulse width, 300-900 mJ pulse energy and 10^{10} W/cm^2 intensity is employed to ablate solid targets (Ti, Ge and Cu) in high vacuum. The laser-generated plasma was characterized through ion energy and optical spectroscopy. Equivalent plasma temperature, density and ion energy distribution were measured properly. The plasma is generated inside an extraction chamber which can be connected, together the target holder, to a high positive bias. The ion emission from the target plasma expands in vacuum adiabatically. The extraction chamber permits the ion extraction through a 6 mm diameter axial noose. 0-30 kV voltage bias can be applied between the extraction noose and the final grounded collimator placed at 10 cm distance.

The ion ejected from the laser-generated plasma and submitted to the post-acceleration, just after the noose, have a high directionality, energy and current. Ion energy increases proportionally to the ion charge state and to the positive bias voltage. 30 keV monoenergetic protons and 30-180 keV multi-energetic Ti ions were detected with high current. Ion collector, ion energy analyzer and ion implantation technique on different substrates (Si, Al, C) are employed to analyze the post-accelerated ions. Evaluation of the implanted dose per laser shoot, ion range versus bias voltage, time-of-flight ion detection and RBS surface analysis of implanted substrates are presented and discussed.

Introduction: The ion acceleration process can be obtained with new techniques of acceleration by using a laser ion source (LIS), an ion extraction system and a post acceleration apparatus. At laser intensities of the order of 10^{10} W/cm^2, so as obtainable by using the Nd:Yag laser of LNS of Catania, generally the plasma core temperature is higher than 10 eV and the plasma density, in the first instants of the laser-matter interaction, is of the order of 10^{17}/cm^3 [1]. Nanosecond laser operating with energy below than one joule per pulse may accelerate ions at energies of the order of 0.1 keV/amu and current densities of the order of 10 mA/cm^2 operating at 1-30 Hz repetition rate [2]. Special high voltage supply and extractor systems geometry must be employed to couple LIS with the first stage of post acceleration. The post accelerated ions are characterized by multi-energetic energy distributions. One of the advantage of the multi-energy of the beam concerns its applicability in the field of the ion implantation. Ions can be implanted at different depths from the surface modifying the chemical and physical properties of surface layers of different materials [3]. Other advantages of this post ion acceleration method consist in the production of a large number of ions per laser shot, in the possibility to use high repetition rate lasers, to generated any type of ions, to obtain high charge states and high ion directivity along the normal to the target surface and to use economical and compact new accelerator systems. The main disadvantages concerns the limitative ion energy acceleration, generally below 1 MeV, and the multi-energetic nature of the extracted ion beams. In order to increase the energy of the extracted ions, an externally high positive voltage can be applied to the target. In this work preliminary results on different kind of ions are presented by using a LIS sources coupled to a post acceleration system of 30 KV. The ion beam diagnostics is based on time-of-flight (TOF) analysis techniques and RBS analysis of implanted substrates.

Materials and methods: A pulsed Nd:Yag operating at 1064 nm fundamental wavelength, with 9 ns pulse duration , 0.9 J maximum pulse energy and 1-30 Hz repetition rate, was focused, though a glass window, on the target (Ti, Ge, Cu) placed inside a vacuum chamber (10^{-6} mbar). The incidence angle of the laser beam was 30° and the ion diagnostic technique (or the implanted substrates) was placed along the normal to the target surface. The accelerating set-up consists of a near close plasma expansion chamber, with a parallelepiped shape (26 cm length and 11 cm side square base). At the centre of the parallelepiped chamber is placed the target. A lateral input hole permits to the laser to incoming and to hit the target. The target and the expansion chamber are placed at the same electrical potential, that can be set between 0 and +30 kV by a power high voltage supply (FUG generator with 65 KV and 10 mA). The extraction-acceleration voltage was applied to the system through a constant electric field generated by 12 parallel discs placed along the extraction nose-ground distance of 60 mm. Opera 3D simulations [4] were employed to study the electrical field lines, the iso-potential lines in the extraction zone and the ion trajectories of the particles ejected from the target and arriving in the extraction-acceleration zone. Fig. 1a shows a photo of the experimental set-up, Fig. 1b shows an example of simulation program obtained accelerating Ti ions at 30 kV. Simulations demonstrate that only about 6 % of the total emitted ions from the target goes though the nose collimator hole and reaches the acceleration zone. An electrostatic ion energy analyzer (IEA) was employed to measure the energy-to-charge ratio of the detected particles emitted from the plasma and post-accelerated along the normal direction to the target surface [5]. RBS analysis obtained by using 2 MeV alpha particles were employed to investigate on the ion implantation processes in different substrates (C, Si, Al).

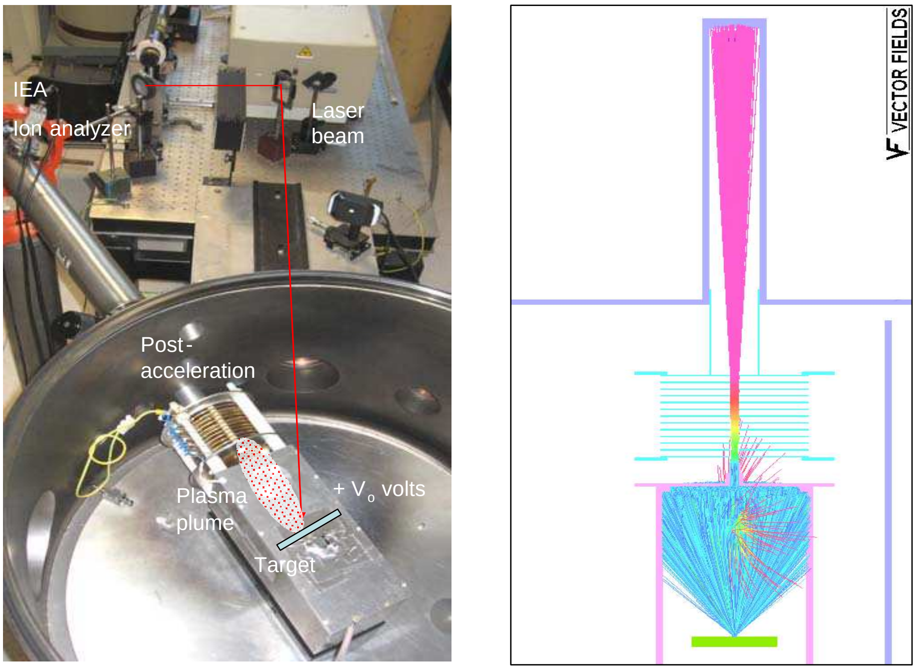

Fig. 1: Photo of the experimental set-up (a) and simulation of 30 kV post-accelerated Ti ions (b).

Results and discussion: The ion energy distributions, obtained by varying the IEA deflection plate bias, indicate that the mean ion energy produced by LIS, without post acceleration, is about 100 eV/charge and that charge states up to about 8+ can be obtained. Ions have Boltzmann distributions which are shifted towards high energy increasing the charge state, in agreement with literature [2]. The post acceleration increases the ion energy of the quantity zeV_0, where z is the charge state, e the electron charge and V_0 the post-acceleration voltage. The ion energy of the post-accelerated beam was monitored "in situ" by the IEA instrument by using TOF technique, as reported by the typical IEA spectrum of Fig. 2 obtained by using 30 kV acceleration bias. Five charge states are induced in Ti plasma by using a laser pulse energy of 200 mJ; thus the 30 kV post acceleration produces a multi-energetic ion beam containing ions from about 30 keV to about 150 keV. Seven charge states are induced in Ge plasma by using a laser pulse of 400 mJ, thus in this case the multi-energetic ion beam contains Ge ions from 30 keV up to about 210 keV. The RBS "off line" analysis of implanted substrates demonstrate the maximum ion energy by the maximum depth of the implanted species and the evaluation of the implanted dose from the RBS yield of the implanted species.

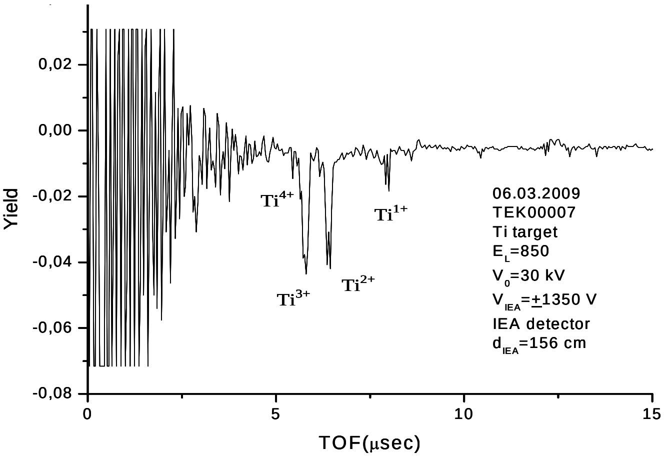

Fig. 2: Typical IEA-TOF spectrum of 30 kV Ti accelerated ions

Fig. 3 shows two typical RBS spectra obtained with 30 kV post acceleration implanting Ge ions (a) and Ti ions (b) in silicon by using 1000 laser shots.

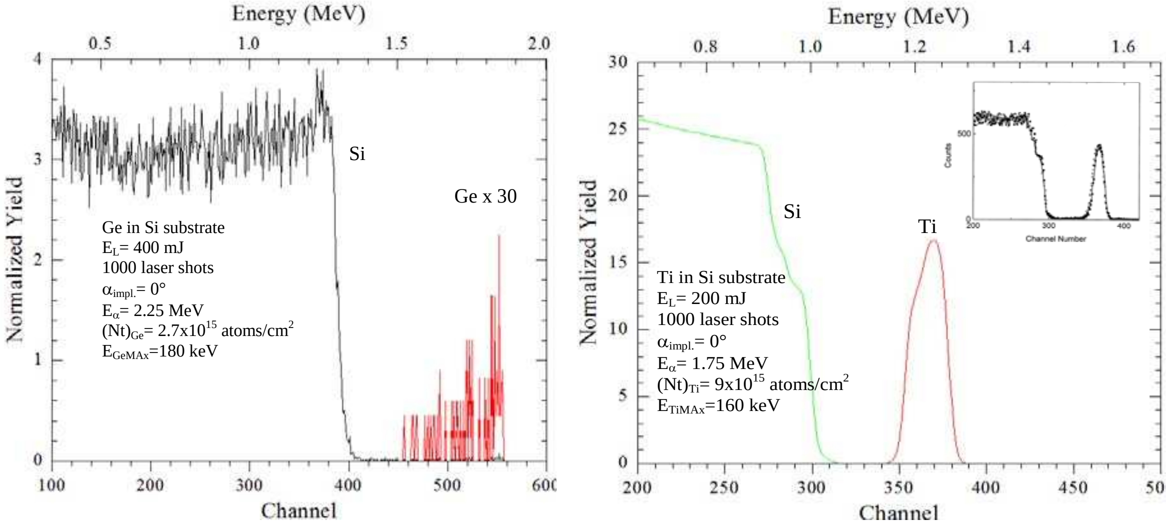

Fig.3: Typical RBS spectra of 30 kV post accelerated Ge (a) and Ti (b) ions implanted in Si.

The RBS analisys are in agreement with IEA measurements.

Results demonstrate that the multi-energy ion beams can be employed with success in the field of ion implantation. High ion doses may modify the physical and chemical surface properties, as demonstrated in recent literature [3].

References

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