Optimisation of laser ion source with acceleration and deflection system for implantation of Ge ions into SiO_2 substrate

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Introduction

Application of laser-produced ions for implantation technology has recently drawn interest as an efficient method for the preparation of nanostructured materials. The major advantage of the laser ion implantation method is the possibility to use a large variety of solid material [1, 2]. On the other hand, its drawback is the relatively broad energy spread of the implanted beams together with implantation of contaminants present in the material used as the projectile. In this paper, the application of a carefully designed electrostatic field configuration which allowed to accelerate and focus on the sample only selected groups of ions was proposed and tested. This approach leads to filtering out the contamination as well as to equalize the energy of the selected accelerated ions which, in turn, leads to the formation of quasi-monoenergetic ion streams. The above procedure has been successfully applied at the IPPLM laboratory, obtaining to implant quasi-monoenergetic Ge ions, onto SiO_2 substrates [2,3]. Our efforts in this direction led to the development of a new shape for the electrodes which guaranteed a better transparency for selected ion groups. In this work, the results of in-situ diagnostics and post-mortem material investigations used for the characterization of the ion implantation setup are presented and discussed.

Experimental set-up

A scheme of the laser-induced ion implantation is presented in Figure 1. It consists of a repetitive Nd:YAG laser (λ = 1.06 μm, t_{pulse} = 3.5 ns, E_{pulse} = 0.5 J, reprate = 10 Hz), a vacuum chamber, and an electrostatic acceleration/deflection system. The germanium target has been irradiated by the focused laser beam with a power density of 10^{10} W/cm^2, which results in hot plasma formation with temperature and densities of the order of tens of eV and 10^{17}

electrons/cm^3 [5-9]. In the new experimental setup the electrode has a spherical grid shape. The central region of the electrode is blocked by a single plate to filter the fast contamination ions which cannot be properly deflected by the system. The potential of the electrode, controlled by an HV pulse generator, was varied from 0 to +40 kV with a period range down to ~1.5 μs. The focal point of the deflected and accelerated ion beam is fixed by the geometry and the electrostatic potential applied to the electrode.

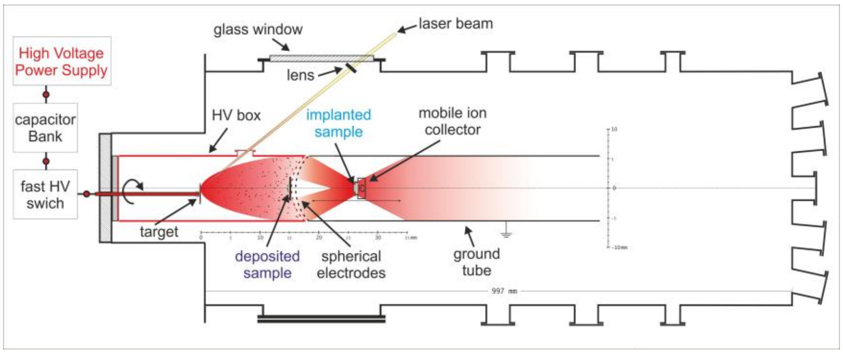

Fig. 1 Experimental set-up.

Hence, its application to carry out the implantation of Ge ions with well-defined energy at a fixed charged-state can be obtained by placing the substrate in the focal point, at an appropriate potential and ion energy values. After the setup optimization, the Ge ions were implanted on the SiO_2 substrates varying the number of laser shots. Details about the other experimental setup are reported in Ref. 10.

Results

In order to optimize the experimental parameters, the trajectories of the Ge ions characterized by different energy and placed at different potentials have been numerically simulated with the use of the OPERA 3D code. A sample result is presented in Fig. 2. Based on the simulations, the geometry (see Fig. 1) of the setup applied in the experiments has been carefully designed to obtain the ion stream parameters suitable for desired implanted layers properties (i.e., quasi-monoenergetic streams with low contamination level).

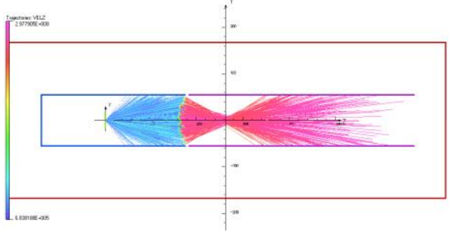

Fig. 2. The ion stream trajectories calculated by OPERA 3D for V=30 kV, E_{Ge+1}=500 eV.

In Fig. 3 is shown the behavior of the ion current vs. the time, detected by means of an ion collector placed in front of the target behind the spherical electrode, when the gating signal is connected to the electrode. A sample signal is presented in Figure 3. A normal ion signal (signed by left arrow in Figure 3(a)) has been chopped and amplified by the HV signal (dashed line) into quasi-monoenergetic pulses (right arrow). A closeup of a single ion pulse resulted from an HV pulse, is clearly shown in Figure 3(b). As it can be seen, the formation of short, quasi-monoenergetic ion-streams occurs.

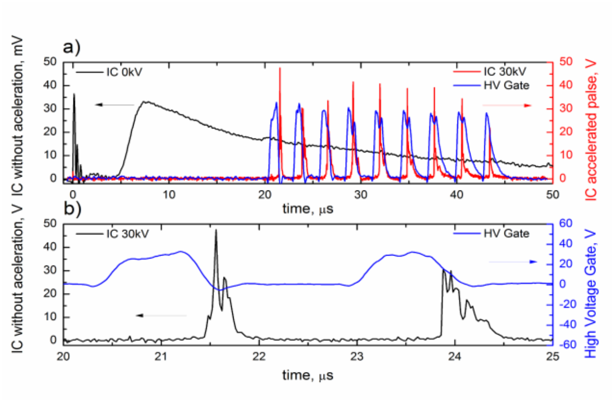

Fig. 3. Ion collector signals a) full signal after one laser shot b) magnification of a single ion group accelerated by the HV pulse.

All the prepared and thermal annealed samples were characterized by means of Rutherford back-scattering. The trends evidence the increase of the implanted Ge ions signal upon increasing the delivered laser shots. The goal of Raman and X-ray photoelectron spectroscopies analysis was to investigate the formation of a Ge crystalline phase and/or an amorphous one in both the deposited and the implanted samples, before and after the thermal annealing treatments.

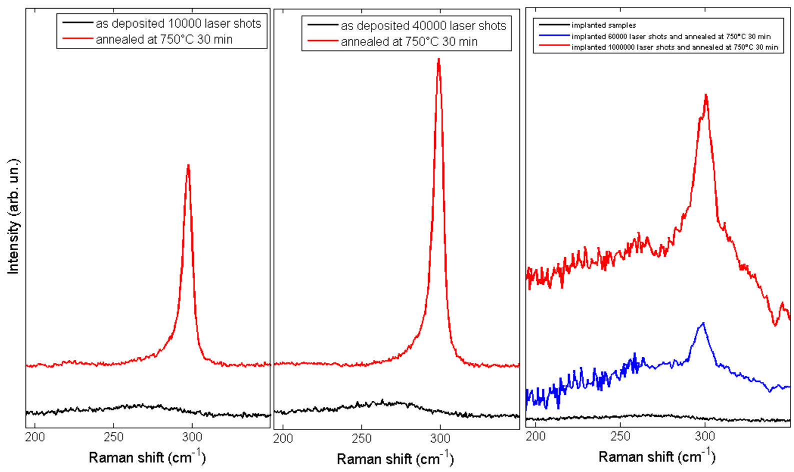

Fig. 4 Raman spectra of all the investigated samples.

As it is shown in Fig. 4, the Raman spectra of all the deposited/implanted samples without annealing are characterized only by a broad band around 250 cm^{-1}, while the Raman spectra of the annealed samples show a peak at around 298 cm^{-1} and a "tail" at around 250 cm^{-1}, attributed to the modes of the Ge crystalline and amorphous germanium contributions, respectively. It emerges that the increase in the annealing temperature facilitates development of both crystalline and amorphous Ge phases. These effects are more enhanced in the samples prepared at the higher number of laser shots. A softening and an asymmetric broadening of the Raman peak can be observed. These behaviors indicate that a phonon confinement inside crystallites having dimensions of few nanometers could occur.

Conclusions

The progress in the set-up for laser-assisted ion implantation made it possible to obtain a high quality of the implantation process which may appear useful for microelectronics and nanotechnology. The existence of implanted Ge layers and possibility of nanocrystal formation have been shown with the use of various methods. Further study should be aimed at the implantation of the layers with precisely given parameters and at the influence of the annealing on the nanocrystal formation for better understanding this process.

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