JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 12, No. 3, March 2010, p. 762 - 765

Application of electrostatic acceleration and deflection system for sophisticated laser-produced ion implantation

M. ROSINSKI*, P. GASIOR, P. PARYS, J. WOŁOWSKI
Institute of Plasma Physics and Laser Microfusion, 23 Hery Str. 01-497 Warsaw, Poland

Precise and efficient ion implantation process is not a straightforward task due to relatively wide spread of energies of ions generated in interaction of nanosecond laser pulses with solid targets. To make it possible to implant the ions with energy in the narrow band the electrostatic system for acceleration and deflection of low energy laser-produced ions can be used. This contribution includes description of the experiments performed at IPPLM which were purposed on implantation of Ge ions from a narrow energy band onto SiO_2/Si substrates. As the source of irradiation there was Nd:YAG laser system used with pulse duration of 3.5 ns and pulse energy:~ 0.5 J which gave power density of 10^{10} W/cm^2. The electrostatic acceleration and deflection system consisted of high-voltage pulse generator which could provide up to 40 kV pulses of down to hundreds of nanoseconds FWHM. In this set-up the ions implanted into the substrate were provided in even lower than 200 ns pulses. The mean energy of packs of ions was at the level of ~10 keV.

(Received June 30, 2009; accepted October 23, 2009)

Keywords:

1. Introduction

The plasmas generated with laser beams of low and medium intensity found important applications not only in surface modification by laser ablation and laser-induced material deposition [1-4] but it also in production of semiconductor materials doped with given elements by the means of implantation of laser generated ions This novel and competitive method can be especially useful when ion implantation is aimed on production of semiconductor nanocrystals [5-9]. The method offers a control of the beam parameters in a broad energy range with maintaining a high level of ion current density provided by the application of electrostatic fields for acceleration and deflection of laser-generated ion beam. The deflecting feature of the electrostatic system can be used to filter out the ions with energies from outside of the desired range which is especially useful in order to eliminate contaminations.

The paper is focused on the ion emission from a plasma produced by low energy repetitive laser as well as on the preparation, tests and application of a tabletop laser ion source with parameters controllable with the use of acceleration and deflection system. The investigation concerns the implantation of laser-produced Ge ions directly or after acceleration/deflection into SiO_2 substrates in perspective of production of Ge nanocrystals. The experiments were aimed on the optimization of acceleration/deflection systems, namely, the amplitude and shaping of the high voltage pulses, the delay of the the system and position of the sample. The obtained ion streams had an average energy up to 10 keV while for freely expanding ions the average energy was at the level of ~ 1 keV.

2. Experimental

The experimental set-up consisted of the repetitive Nd:YAG laser system (1.06 µm, 3.5 ns, <0.8 J, <10 Hz), vacuum interaction chamber, and the electrostatic acceleration/deflection system. The laser beam was focused onto a pure germanium target surface to the diameter

D_f = 3 mm which resulted in intensity on the target of ~2.5×10^9 W cm^{-2} and allowed for the effective production of Ge ions. The implanted sample is protected against neutral particles sputtered from the sample by the HV box which allows only deflected ions to reach its surface through the slit (Fig. 1).

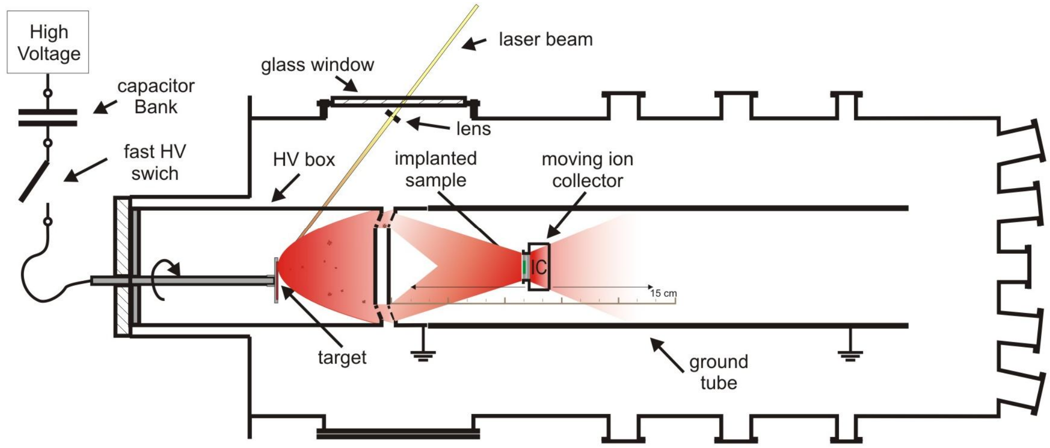

Fig. 1. Experimental set-up.

The distance between the diaphragm and the grid was about 1 cm. The ions passing through the diaphragm were accelerated by the potential difference formed between the box and the grounded cylindrical electrode. The gating signal was provided by a high-voltage pulse generator with the frequency up to ~ 666 KHz and the asymmetric amplitude up to +40 kV. The accelerating potential was applied to electrodes with the use of a fast switch at different time delays in respect to the laser pulse It allowed to remove contaminant ions from the ion stream directed on sample and strongly influenced the ion energy and temporal distribution. Besides of the time delay, the properties of the ion beam depended strongly on the potential of the accelerating voltage. The influence of this voltage has been investigated in a wide range (15 to 40 kV in amplitude).

As the main diagnostics ion collector (IC) was used. The IC was located on the axis of the grounded electrode at the distance of ~ 30 cm from the target (2 – 15 cm from the grid) and allowed for the characterization of the parameters of the ion streams, namely their energy (based on the time of flight) and relative concentration (based on the integrated ion current).

Shape of the accelerating electrodes, the distance of the diaphragm from the target, the diaphragm diameter and the gap width were adjusted to optimise the system.

3. Results

The presented experiments on implantation of Ge ions into SiO_2 substrate with the use laser ion source conducted at IPPLM were focused on:

- Maximization of the energy of ions which reach the implanted sample,
- Narrowing of the energy distribution of ion groups,
- Filtration of the contaminating ions.

In order to obtain monoenergetic ion peaks of high intensity, the influence of the delay of the switching (accelerating) signal has been tested in a range from 2 μs up to 16 μs. Due to interaction of the accelerating force, the ion form groups which are visible in the ion signal as peaks The peaks are 'cut' from the envelope of a standard ion signal [2] and then shifted in time and amplified. The influence of the potential leads to a shift of ion energies towards the values given by a delay time which transforms the wide energy spectra of laser induced ions into a comb of quasi-monoenergetic peaks.

The difference in behavior of laser-generated ion-streams can be clearly seen in Fig. 2. The original broad ion-pulse recorded by an ion collector under the influence of the accelerating potential of 25 kV forms intense quasi-monoenergetic peaks. The amplitudes of the peaks are significantly higher than the amplitude of the original signal which indicates that the energies of ion groups have been shifted and constricted to values given by the accelerating potential.

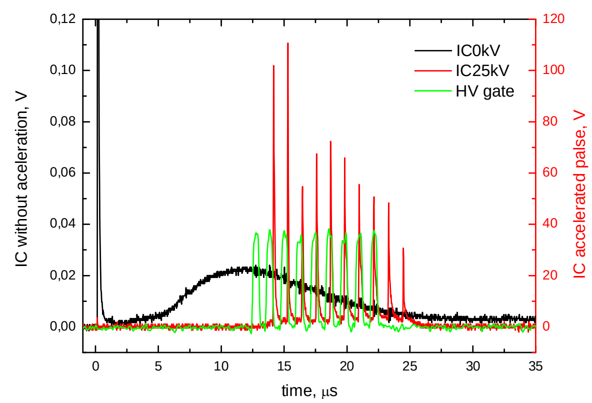

Fig. 2. Comparition of an original ion signal and a signal resulted from gating. (HV gate is High Voltage gating signal scaled in a.u. and is plotted only as a time reference).

The best results were obtained for a medium delay range (10 μs - 14 μs). A proper, monoenergetic pulse obtained for the delay of 12.4 μs is presented in Fig. 3. The main part of the signal consists of monoenergetic peak contributed to Ge^{+1} ions of energy reaching the level of 10 keV which was calculated based on time of flight method.

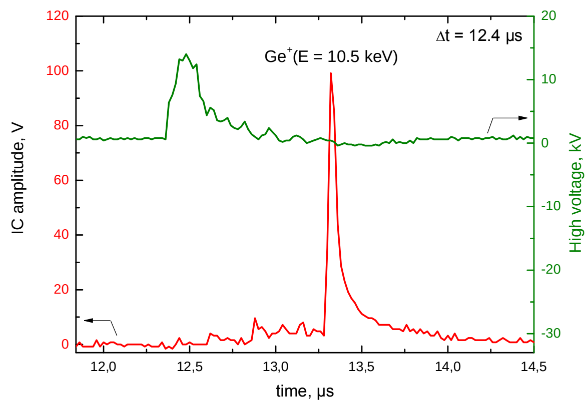

Fig. 3. Monoenergetic ion pulse recorded by ion collector for 12.4 µs delay and an electric pulse applied to the accelerating/deflecting system.

The signal of Ge^{+2} ions is considerably smaller and the contaminations are completely filtered out. A sample of the too slightly delayed signal is shown in Fig. 4 taken for the delay of 7.1 µs. In the figure both contaminations and Ge^{+2} peaks are comparable in amplitude to the main Ge^{+1} peak. In the signal the components corresponding to contaminations (H and C) can be clearly seen. In both figures the pulse of the switching voltage is marked in grey.

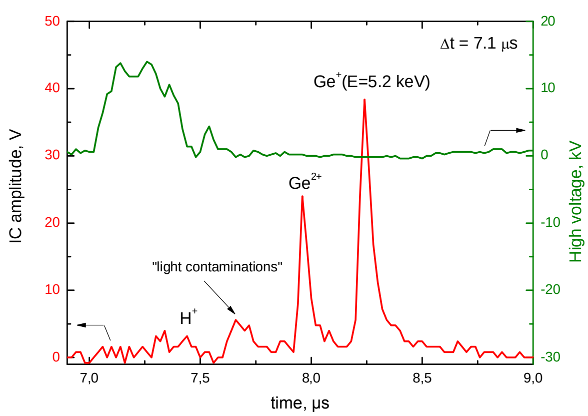

Fig. 4. Ion pulse recorded by ion collector for 7.1 µs delay and an electric pulse applied to the accelerating/deflecting system.

Using delays higher than 16 µs allows for elimination of the contaminants but also results in the decrease of the signal magnitude. The accelerating potential was at the level of 30 kV.

The influence of the amplitude of the potential of the accelerating system for a constant delay time of 12.4 µs is illustrated in Fig. 5. As it can be seen, well-shaped ion peaks with a narrow energy distribution, can be formed when the potential is at level of 20 kV and higher. The increase of the amplitude of the gating signal significantly increases the concentration of the ions but also results in a slight broadening of their energy distribution which can be especially seen for the amplitude of 40 kV.

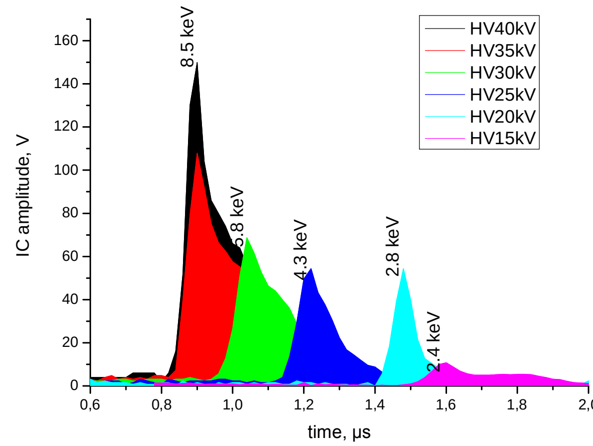

Fig. 5. Influence of the electrostatic potential applied to the accelerating/deflecting system on the ion pulses.

4. Conclusions

The experiments have proved the possibility of optimization of the generation of Ge^{+1} ions by the use of the electrostatic acceleration/deflection system. The gating signal of the amplitude up to 40 kV allowed to obtain quasi-monoenergetic ion groups of energy in the range of 10 keV which would not be possible in a standard set-up based only on a direct implantation method. The application of the acceleration/deflection system not only makes it possible to obtain higher energy and narrower energy distribution of ions but also may be used to filter out contaminations. The obtained high intensity streams of monoenergetic ions allow for flexible and controllable ion implantation.

References

[1] F. P. Boody, R. Höpfl, H. Hora, Laser Part. Beams, **14,** 443 (1996).

[2] E. Woryna, J. Wołowski, B. Králiková, J. Krása, L. Láska, M. Pfeifer, K. Rohlena, J. Skála, V. Perina, F. P. Boody, R. Höpfl, H. Hora, Rev. Sci. Instrum. **71,** 949 (2000).

[3] L. Láska., L. Juha, J. Krása, K. Mašek, M. Pfeifer, K. Rohlena, B. Králiková, J. Skála, V. Peřina, V. Hnatowicz, E. Woryna, J. Wolowski, P. Parys, F. P. Boody, R. Höpfl, H. Hora, Czech. J. Phys. 50 Suppl. **3**, 81 (2000).

[4] J. Wołowski, Badziak, F. P. Boody, S. Gammino, H. Hora, K. Jungwirth, J. Krása, L. Láska, P. Parys, M. Pfeifer, K. Rohlena, A. Szydłowski, L. Torrisi, J. Ullschmied, E. Woryna, Plasma Phys. Control. Fusion **45,** 1087 (2003).

[5] K. Masuda, M. Yamamoto, M. Kanaya, Y. Kanemitsu, J. Non-Cryst. Solids **299-300**, 1079 (2002).
[6] M. Carrada, C. Bonafos, G. Ben Assayaga, D. Chassainga, P. Normandb, D. Tsoukalasb, V. Soncini, A. Claverie, Physica E **17,** 513 (2003).
[7] P. Normand, P. Dimitrakisa, E. Kapetanakisa, D. Skarlatosa, K. Beltsiosb, D. Tsoukalasc, C. Bonafosd, H. Coffind, G. Benassayagd, A. Claveried, V. Soncinie, A. Agarwalf, Ch. Sohlf, M. Ameenf, Microelectr. Engin. **73-74,** 730 (2004).
[8] J. Wołowski, J. Badziak, F. P. Boody, S. Gammino, H. Hora, K. Jungwirth, J. Krása, L. Láska, P. Parys, M. Pfeifer, K. Rohlena, A. Szydłowski, L. Torrisi, J. Ullschmied, E. Woryna., Plasma Phys. Control. Fusion **45,** 1087 (2003).
[9] A. Lorusso, V. Nassisi, G. Congedo, N. Lovergine, L. Velardi, P. Prete, App. Surf. Sci **255,** 5401 (2009).

*Corresponding author: rosinski@ifpilm.waw.pl