Study of physics and applications of ions produced by medium intensity laser beam

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Abstract

The possibility of generation of ion beams by medium intensity repetitive lasers (up to 10^{12} W/cm^2) is important for the present and future technological applications, especially construction of different kinds of laser ion sources (LIS). At IPPLM extensive studies of processes of ion production in the laser-generated plasma and implantation of laser-generated ions directly or after additional electrostatic acceleration into semiconductor materials have been performed. The medium intensity repetitive laser system has been applied also for removal of co-deposited layer from surface of in-vessel components taken from tokamak chamber. The characterization of ablative plasma was performed by the diagnosis of ionic species emitted from the laser-irradiated co-deposits on a sample surface. The main ion stream parameters were measured in dependence on number of laser shots and the laser power density on the target surface. The parameters of laser-produced ion beams, estimated in the experiments described in this paper, were measured with the use of ion diagnostics based on the time-of-flight method (an electrostatic ion energy analyzer and various ion collectors).

1. Introduction

Studies of ions emitted from laser-produced plasma are directed towards the determination of physical processes in such a plasma as well as towards different applications – among others modification of properties of surface of different materials by ion implantation and analysis of the elemental content of the ablated layers of the target material.

The laser ion sources (LIS) thet can be advantageously used for various technological purposes and direct implantation of ions from laser-produced plasmas has already been successfully tested [1-3]. Depending on the target material and the parameters of the laser, LIS can deliver ions of different masses (any material can be evaporated and ionised) with multiple charge states and energies up to even the MeV region [4-6]. This paper describes preparation and application of laser ion source (with post acceleration system) for implantation of semiconductor materials in order to produce the nanostructures (nanocrystals). The acceleration/deflecting system developed at IPPLM permits additionally to remove the useless ions from the ion stream designed for implantation. This new method was applied at IPPLM for effective implantation of Ge ions into layer of SiO_2 for production of Ge nanocrystals. The properties of the modified semiconductors were estimated using different diagnostics. At IPPLM there were performed also investigation concerned on physical phenomena appearing during the laser induced co-deposited layer removal from the surface of tiles taken from the tokomak chamber. The ion diagnostics supplemented with optical spectrometry have been applied to control this process and to characterise the ablated material.

2. Experimental methods and results

The laser ion source prepared for implantation of ions into semiconductor substrates comprised experimental chamber, ion diagnostic devices (ion charge collectors and an electrostatic ion energy analyser) ([7]) and a repetitive rate laser system (pulse energy - 0.8 J, pulse duration - 3.5 ns, laser wavelength - 1.06 μm and pulse repetition rate up to 10 Hz). The stream of Ge ions emitted along the target normal measured at the distance of 6 cm from the laser irradiated Ge target was > 10^{16} ions/cm^2 (for ~1000 laser shots). Using the simple LIS (without post acceleration) the surface of the sample was deposited also by neutrals (atoms, debris, clusters) not recorded by the ion collector. The laser fluence was ~4.5 J/cm^2 at laser intensity of ~10^{10} W/cm^2 on the target surface. The maximum measured ion energy was ~3 keV. The Ge ions produced in ~1000 or in ~3000 laser shots were implanted into SiO_2 substrate of thickness of ~20 nm prepared on the Si single crystal. Another set of SiO_2 samples were implanted with Ge ions generated in 100, 200, 400 and 800 laser shots.

The analysis of the samples was performed with the use of the XPS + AES method and ion etching using beam of Ar+ ions (1-μA, 3 keV). On the basis of the XPS + AES spectra the depth profiles of different elements in the SiO_2 layer were estimated (Fig. 1).

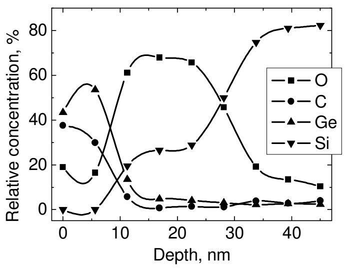

Fig. 1. The depth profiles of different elements in the layer of SiO_2 estimated on the basis of XPS + EES spectra.

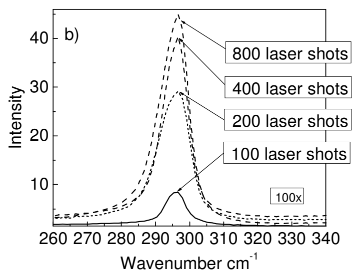

Fig. 2. The Raman spectra of SiO_2 samples implanted with Ge ions generated at different numbers of laser shots.

In the layer of < 4 nm the amount of deposited laser-produced Ge atoms is very high, in depth of ~2.5 nm more than 50% Ge atoms was estimated. In this layer there are also oxygen and carbon atoms (probably contaminants). In the SiO_2 layer the number of implanted Ge ions decreases down to several percent in depth of ~10 nm. It was shown that laser-produced Ge ions were implanted even at the maximum depth of 18 nm.

A sample result of Raman spectroscopy measurements of the surface of SiO_2 annealed at temperature of 600^0 previously implanted with laser-produced Ge ions is shown in Fig. 2. The Raman spectra of Ge structures were recorded at different numbers of laser shots. The obtained Raman spectra clearly display the band at 300 cm^{-1} that come from scattering of Ge nanocrystallites on the SiO_2 sample formed in the process of ion implantation and subsequent annealing. The line width (FWHM) of the Raman lines estimated for Ge crystalline structures on the investigated samples were 7.1-10.6 cm^{-1}.

The application of electrostatic fields for acceleration and deflection of laser-generated ion beam offers a control of the beam parameters in a broad energy range with maintaining a high level of the ion current density. The electrostatic system can be used to filter out the useless ions, ions of contaminations, neutrals and debris (Fig. 3).

The Fig. 4 shows ion outputs recorded by the ion collector at different accelerating potentials. A standard ion signal was 'cut' by gating system. The influence of the accelerating voltage 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 quasi-monoenergetic peaks.

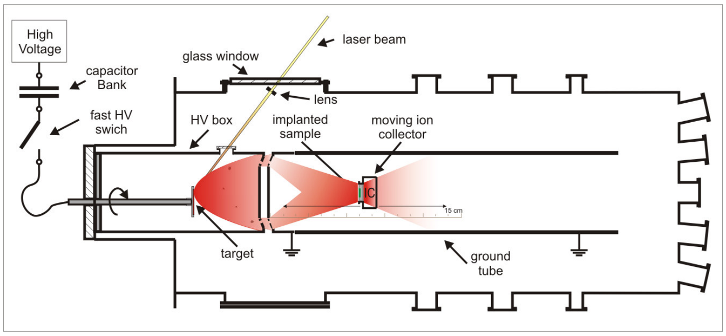

Fig. 3. The experimental arrangement for implantation of accelerated laser-produced ions into semiconductor materials.

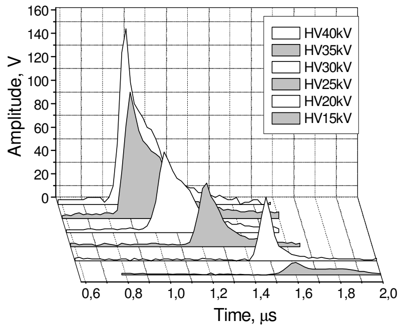

Fig. 4 The ion collector signals recorded for increasing accelerating potential (0 - 40 kV).

The laser-induced ablative removal of co-deposit from the in-vessel tokamak components has been extensively investigated and developed at IPPLM with the use of the same repetitive laser system. The ion measurements were carried out in a time-of-flight mode (ion collector and an electrostatic ion energy analyzer - IEA) [7]. The determination of ion mass and energy has been performed with an IEA. While the laser beam was scanning the target the spectroscopic system was independently recording the spectra for subsequent laser shots. The experimental set-up is shown in Fig. 5.

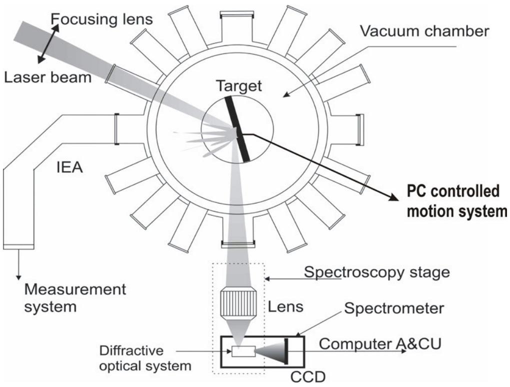

Fig. 5. The experimental arrangement for laser-induced removal of co-deposit.

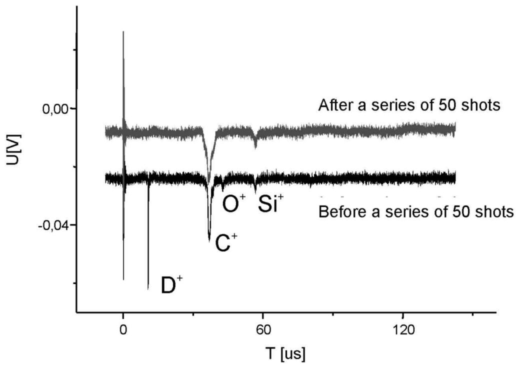

Fig. 6. The IEA ion spectra recorded for the co-deposited TEXTOR sample before and after a series of 50 laser pulses.

The main part of the experiment was aimed at performing subsequent scans on the target (TEXTOR limiter sample) with the laser beam in two different focusing regimes and at different velocities. In the experiment, the key effort was made for the surface layer characterization by the diagnosis of ionic species emitted from the laser-irradiated co-deposits using ion and spectroscopic diagnostics.

The efficiency of the removal process is demonstrated in Fig. 6 showing the IEA ion spectra recorded for the co-deposited TEXTOR sample before and after a series of 50 laser pulses. The spectroscopy results obtained for the scanning beam experiment proved the efficient removal of the co-deposit for the scanning velocities up to 5 mm/s. The drop in a ratio of Dα line to the CII line during subsequent laser shots during the scan was observed similarly as in the case ion diagnostic measurements. The efficiency of removal was also confirmed by material research methods and reported in [8]

3. Conclusions

The experimental arrangement with a repetitive Nd:YAG laser system has been effectively used in IPPLM for implantation of laser-produced Ge into the SiO_2 substrate. The properties of the semiconductor substrates implanted with Ge ions were analysed using different methods. The effective acceleration of laser-produced ions and selection of a specific group of ions with the original cylindrical electrodes system have been demonstrated.

The ion diagnostic methods were confirmed as a convenient tool for controlling the ablative laser removal of the co-deposited layers from the in-vessel tokomak components. The spectroscopy results were fully consistent with results of ion diagnostic measurements and post-mortem analyses of modified samples.

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