ION IMPLANTATION VIA LASER ION SOURCE*

F. Belloni#, D. Doria, A. Lorusso and V. Nassisi,
Laboratory of Applied Electronics, Department of Physics, INFN, Lecce, Italy

Abstract

We report a new implantation technique via laser ion source. By applying a high voltage on the accelerating gap, this compact device was able to accelerate towards a substrate ions from ablation plasma. The occurrence of arcs during the extraction phase was a major problem to overcome. A pulsed KrF laser was utilized to produce plasma by ablation from solid targets. Radiation wavelength and pulse duration were 248 nm and 20 ns, respectively. The laser beam, 70 mJ per pulse, was focused, by a 15 cm focal length lens, onto different targets in a spot of about 1 mm^2 in surface, obtaining an irradiance value of about 3.5 x 10^8 W/cm^2. The implanted samples were characterized by energy dispersive X-ray spectroscopy, Rutherford backscattering spectrometry and X-ray photoelectron spectrometry. Implantations of Al, Cu and Ge on Si substrates were carried out up to 80 nm in depth, operating at 40 kV acceleration voltage. Ion dose was estimated by Faraday cup diagnostics. It was of the order of 10^{10} $ions/cm^2$ per pulse.

INTRODUCTION

Ion implantation is a process by which ions are accelerated toward a target at energies high enough to bury them just below the target surface, without inducing wide damage or amorphization in the target lattice. In the early 1970s, it was found that ion implantation could improve mechanical, thermal, electric, and optical properties of several materials. The development of high intensity laser beams has allowed to improve the ion production by laser etching [1, 2]. The laser ion source (LIS) technique produces an exploding plasma plume consisting in a high production of ionized matter. From 80's many developments have been made in this field and worked out also variations of such technique. The plasma source ion implantation (PSII) technique has been shown to be very efficient for superficial modification of several materials. Furthermore, this technique has the advantage to work at low temperature avoiding diffusion of implanted ions inside substrate surface, to generate ions directly from any solid material, even refractory and compound; and to obtain high doses of ions per laser pulse close to the target, about 10^{14} $ions/cm^2$.

Such ions can be led forward substrates for direct ion implantation or by an accelerating voltage [3-6]. In this last case, this method of implantation presents the disadvantage in formation of arcs during the accelerating process, reducing implanted dose and depth of implanted ions. Therefore, in this work we report also the efforts done to avoid arcs. A typical range of the electrostatic accelerating voltage was 20–100 kV.

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#fabio.belloni@le.infn.it

EXPERIMENTAL SETUP

Our implantation system consists in an UV laser and a vacuum chamber made of stainless steel. The laser active mean was made of KrF able to provide a laser beam of 248 nm wavelength with a pulse duration of 20 ns. In this experiment a pulse energy of about 70 mJ was focused on a spot of about 1 mm^2 by a lens of 15 cm focal length. By these conditions a laser irradiance of about $3.5 \cdot 10^8$ W/cm^2 was obtained. Figure 1 shows the implantation chamber.

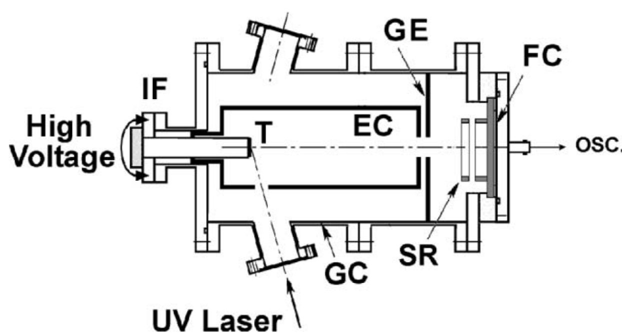

Figure 1: Experimental apparatus. GC: Generating Chamber; EC: Expansion Chamber; T: Target; IF: Insulting Flange; GE: Ground Electrode; FC: Faraday Cup; SR: Suppression Ring; OSC.: Oscilloscope.

This apparatus is fairly versatile and it can be arranged in different configurations. It consists of a generating chamber (GC) 26.5 cm long and an expanding chamber (EC) 18.5 cm long, 9 cm in diameter, which has the double task of expansion of the plasma plume, to reduce the probability of arcs during the acceleration, and of extraction elettrode put at high voltage, 40 kV. The EC was connected mechanically and electrically to the target support, which was a stem of 2 cm in diameter insulated from the whole system by an insulating flange (IF). Both the GC and EC were provided of a window of quartz as inlet port and the entrance angle of the laser was of 70° with respect to the normal to the target surface (T).

The accelerating gap was formed by a pierced aluminum disc, named ground electrode (GE), placed in front of the EC and in axis with all the accelerating system. The accelerating gap was 1,3 cm large and the irradiating area was 0.78 cm^2.

To stabilize the accelerating voltage a set of four buffer capacitors of 1 nF each was connected between the EC and GE. So, the accelerating voltage was maintained quite constant during the ion extraction.

The system was pumped by two independent turbomolecular pumps with a base vacuum of 10^{-6} Torr.

By these expedients we were able to get implantation of Si wafers placing them on the GE hole, beyond the accelerating gap.

To estimate implanting ions produced per laser pulse and unit surface a Faraday cup (FC) with a suppression ring (SR) was placed beyond the accelerating gap. The implanted samples were examinated by different thecniques such as RBS, EDX, XPS and LA-ICP-MS (Laser Ablation combined to Inductively Coupled Plasma Mass Spectrometry) analysis.

RESULTS AND DISCUSSION

Several Si substrates were implanted one at a time with Al, Cu and Ge, separately. The acceleration voltage was of 40 kV [4-6] and were applied a number of laser shots of 400, 200 and 500 for Al, Cu and Ge ions, respectively. Considering that the maximum appreciable charge state was measured to be +4, we realized a multi-energy ion implantation with ions of energy supposedly up to 160 keV. We estimated the order of magnitude of the implanted dose per laser shot, at 40 kV, measuring with the FC the plasma ion charge and considering the whole charge due to practically to the ions with charge +1, obtaining a value of 10^{10} ions/cm^2 (see Fig. 2).

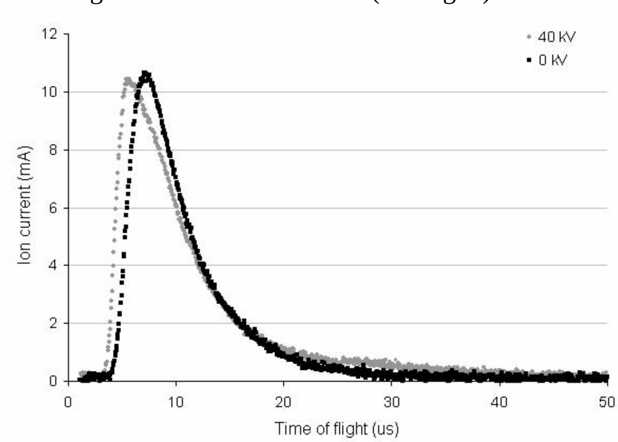

Figure 2: Current signal of Cu ions collected by FC for free expansion and with 40kV of acceleration voltage.

Some evaluations about expected depth profile were also done utilizing the well-known Monte Carlo simulation code, SRIM [7]. By these simulations and taking into account that our plasma is constituted mostly of neutral atoms (84%) and ions (16%) of charge +1 and +2 [8], we estimated that the implantation depth had to be of the order of tens nm for all three implanted elements, see Fig. 3 and Fig. 4.

We performed the RBS analysis only on Al implanted sample, but nothing significant was seen due to the low mass resolution between Si and Al. Even EDX analysis did not reveal any implanted ions owing to the large penetration depth of the probe beam.

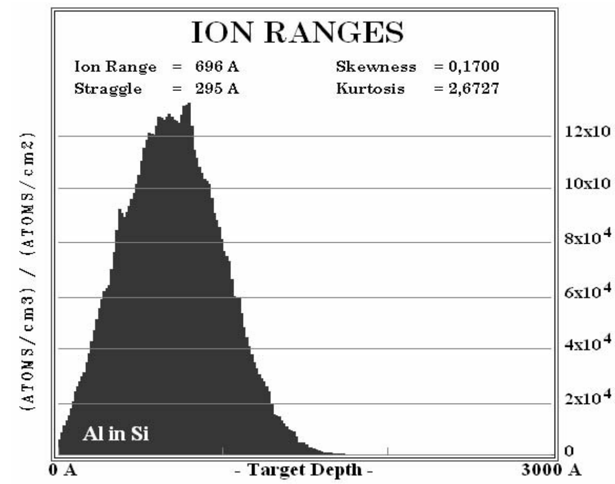

Figure 3: SRIM simulation for Al ions of 40keV implanted into Si substrate.

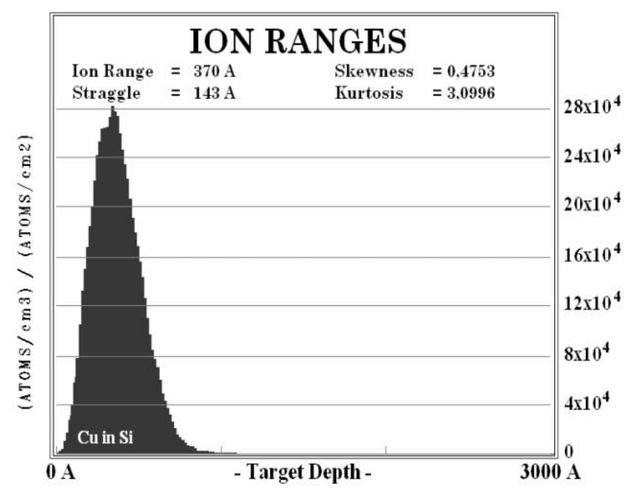

Figure 4: SRIM simulation for Cu ions of 40keV implanted into Si substrate.

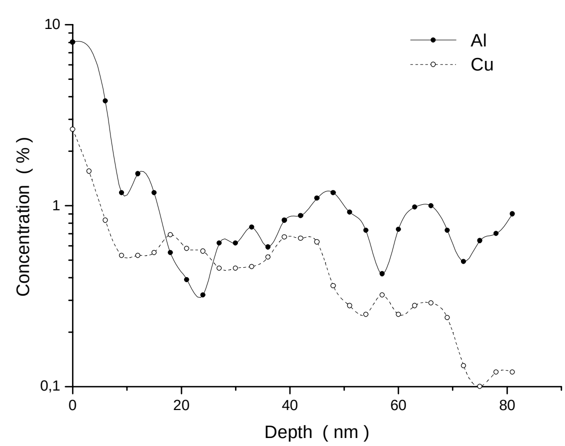

Figure 5: XPS signal on Al and Cu samples.

Differently, XPS analysis, with a 3 nm of resolution in depth step, was performed on Al and Cu implanted samples obtaining interesting results, see Fig. 5.

From this figure, one can see a decreasing trend of the concentration for both the implanted elements near the surface. This result should be ascribed to the neutral particles which, having a kinetic energy up to a few keV, are able to penetrate into the first Si layers.

Inside, it is possible to observe some structures almost uniformly distributed on a range of a few tens nm due to the large energy spread of the accelerated particles. Anyway, it is consistent with the simulated penetration depths of Al and Cu in Si, that Al ions can be seen over 80 nm (see Fig. 3) and Cu ions are practically present only below 80 nm (see Fig. 4). By XPS spectra the estimated dose was approximately of the order of 10^{12} ions/cm^2, as guessed above.

LA-ICP-MS analyses were performed on Al, Cu and Ge implanted samples. The basic principles of this technique consists on the laser irradiation of a target material, the ionization of the plasma plume by an inductively coupled plasma (ICP) device, the extraction of ions from the plasma, and finally the analysis by a quadrupole mass spectrometer (PE/Sciex Elan 6000) operating under standard conditions [9]. Such a technique allowed to estimate the implanted ion density with respect to the bulk, but unfortunately, as what regard to the implantation depth. It was able to get only the upper limit value, due to the big ablation depth per pulse.

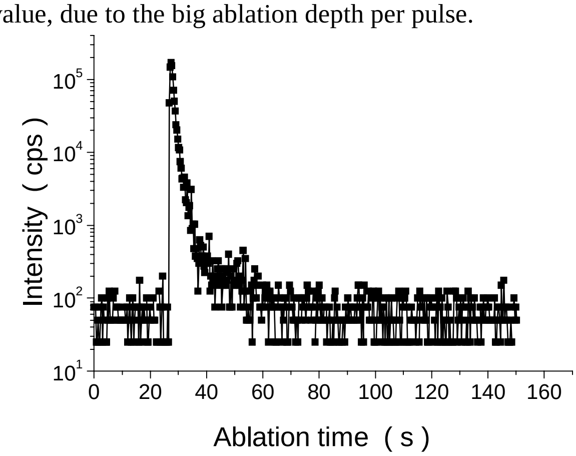

Figure 6: LA-ICP-MS signal on Ge sample.

The result of the Ge implanted sample is reported in Fig. 6 as a function of the ablation time.

Moreover, the signal in Fig. 5 was obtained owing to a laser pulse rate of 10 Hz, while as it can be noted the plasma lifetime is of about 3 seconds, so a superposition of ablated dose per laser pulse is present.

Thus, a deconvolution algorithm was applied to the experimental data to avoid the signal pile-up effect. In this way we estimated the implanted depth upper limit which resulted of a few hundreds nm for all three samples. For finer analyses it is necessary to set the laser ablation depth per pulse at values of tens nm at least.

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