Pulsed plasma ion source to modify semiconductor surface

A. Lorusso [1] [2] G. De Pascali[1] [2], V. Nassisi[1] [2], L. Velardi [3]

[1]Department of Physics, University of Salento, Lecce, Italy

[2]Istituto Nazionale di Fisica Nucleare sez. di Lecce,

[3]Department of Physics, University of Bari, and INFN, Via Amendola, 70126 Bari Italy

In this work we developed an ion beam utilised to modify the surface of semiconductor wafer. It was compound of a pulsed KrF excimer laser of irradiance of about $10^8 W/cm^2$ focused on a Si(100) solid target to induce the plasma. Low accelerating voltage values were applied in order to extract ions from the plasma plume and to implant substrates at a few nm under the surface. X-ray diffraction spectra indicate the presence of silicon crystalline phases. The average Si nanocrystal size was estimated to be about 40 nm by using the Debye-Scherrer formula. Microscopy images showed the presence of nanoparticles of different size. Their distribution exhibits a maximum concentration again at 40 nm and a fraction of 14% at 15 nm.

Pulsed laser deposition (PLD) is one of the most promising techniques for the growth of thin films and nanostructured materials [1]; it is a cold-wall processing which generates a hot dense plasma by focusing a laser beam on a solid target, and making possible the realization of thin films with high chemical purity and controlled stoichiometry. By the PLD technique, one can control size distribution of Si-nc by varying the parameters such as target to substrate distance, laser fluence, ambient gas pressure, etc. [2].

Silicon is the most important semiconductor in microelectronic industry. The most important property is the intense photoluminescence (PL) in the light visible region, which can be observed even at room temperature [3]. For this reason, Si-nc are potential candidates for Si-based optoelectronic devices. Several different techniques are used to produce Si-nc, such as plasma enhanced chemical vapour deposition (PECVD), sputtering deposition, laser ablation, ion implantation of Si+ [4], etc.

Recently, we attempted to synthesize Si-nc by using an innovative LIS (Laser Ion Source) device equipped by an useful arrangement to apply different extracting voltages [±300 V]

The experimental apparatus is schematically shown in Fig. 1. It consists of a pulsed KrF excimer laser 248 nm, 23 ns and a vacuum chamber. The pulsed laser beam was focused onto a

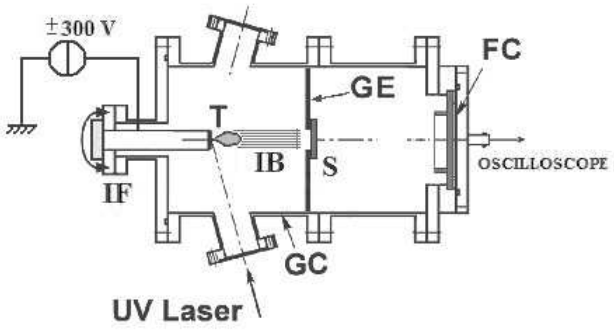

Figure 1. Experimental apparatus. GC: Generation Chamber; T: Target; S: Substrate; GE: Grounded electrode; FC: Faraday Cup.

n-type Si (100) target. The laser power density was 2.25 $10^8 W/cm^2$ and the repetition rate was 3 Hz for a total of 1000 pulses. The target-substrate distance was fixed at 3 cm.

The target support was a steam mounted on a insulating flange (IF) and it was kept in three different configurations: without any bias voltage (a configuration), +300 V (b configuration) and -300 V (c configuration) in DC mode; b and c configurations were used in order to accelerate and decelerate ions, respectively.

The laser ablation of the Si target induces the formation of Si plasma plume which propagates and expands toward the substrate which was a 512 nm thick thermally grown SiO_2 films on p-type Si (100). Substrates were placed behind a pierced aluminium disc. The structural properties of the samples were investigated by means of an glancing incidence X-ray diffraction (GIXRD). Instead, the surface morphology of the samples was analyzed by an scanning electron microscopy (SEM) and an atomic force microscope (AFM).

All the diffraction GIXRD analysis patterns are showed in Fig. 2. They exhibited two interesting peaks absence before the deposition; at $2\theta = 28.45°$ and at $2\theta = 47.3°$. The founded values correspond to (111) and (220) orientation. In particular, GIXRD (111) peaks of a, b and c are characterized by the same FWHM but with dif-

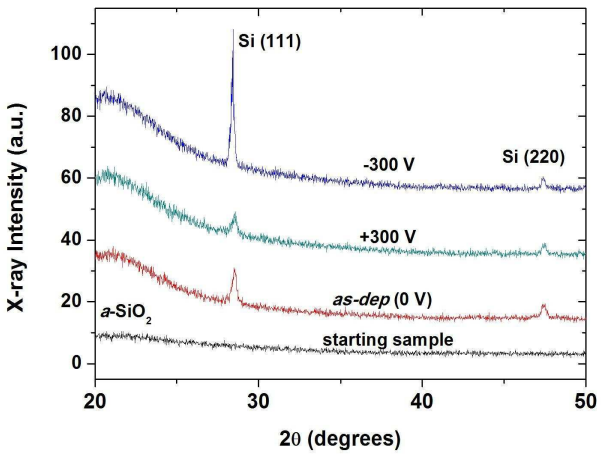

Figure 2. GIXRD pattern of a SiO_2/Si samples, before and after deposition.

ferent intensity. This behavior could be justified taking into account that the plasma plume consists of highly concentrated neutral particles as well as electrons and ions. These last are characterized by kinetic energy which induces an ion penetration depth into the substrates in addition to the deposition due to the neutral particles. The size (d) of crystals is determined by the Debye-Scherrer formula [5]:

$$d = 0.94\frac{\lambda}{\Delta(2\theta)cos\theta_B} \quad (1)$$

where λ is the X-ray wavelength (0.1541 nm) of Cu cathode, θ_B is the Bragg angle corresponding to examined peak, and $\Delta(2\theta)$ is the FWHM of the peak.

Their average diameter is estimated of about 40-50 nm. The surface morphology of the three samples was also observed by AFM where a much more dense distribution of nanoparticles was evident respect to the relative FEG-SEM images, with the presence of both big and small particles. The maximum frequency diameter obtained by the Γ-distribution function [6] is $D_{max} = 49$ nm, while the 14% of the total particles has got a 15 nm on the diameter size.

ACKNOWLEDGMENTS: Authors thank INFN Commission V and the prof. N. Lovergine and the dr. P Prete.

REFERENCES

1. D. Riabinina, C. Durand, M. Chaker, and F. Rosei, Appl. Phys. Lett. 88, 073105,2006
2. J. R. Rani, V. P. Mahadevan Pillai, R. S. Ajimsha, M. K. Jayaraj, and R. S. Jayasree, J. Appl. Phys. 100, 014302 (2006)
3. L. Pavesi, C. Mazzoleni, A. Tredicucci and V. Pellegrini, Appl. Phys. Lett. 67 (1995) 3280
4. L. Velardi, A. Lorusso, V. Nassisi, G. Congedo, Rad. Eff. Def. Solids 163 (2008) 491
5. F. Belloni, D. Doria, A. Lorusso, V. Nassisi, Nucl. Instrum. Meth. B 240, 40-43 (2005)
6. B. D. Cullity, Elements of X-ray Diffraction (Addison-Wesley, Reading, MA, 1978)