Zn ION IMPLANTED Si MODIFICATION BY SWIFT Xe ION IRRADIATION

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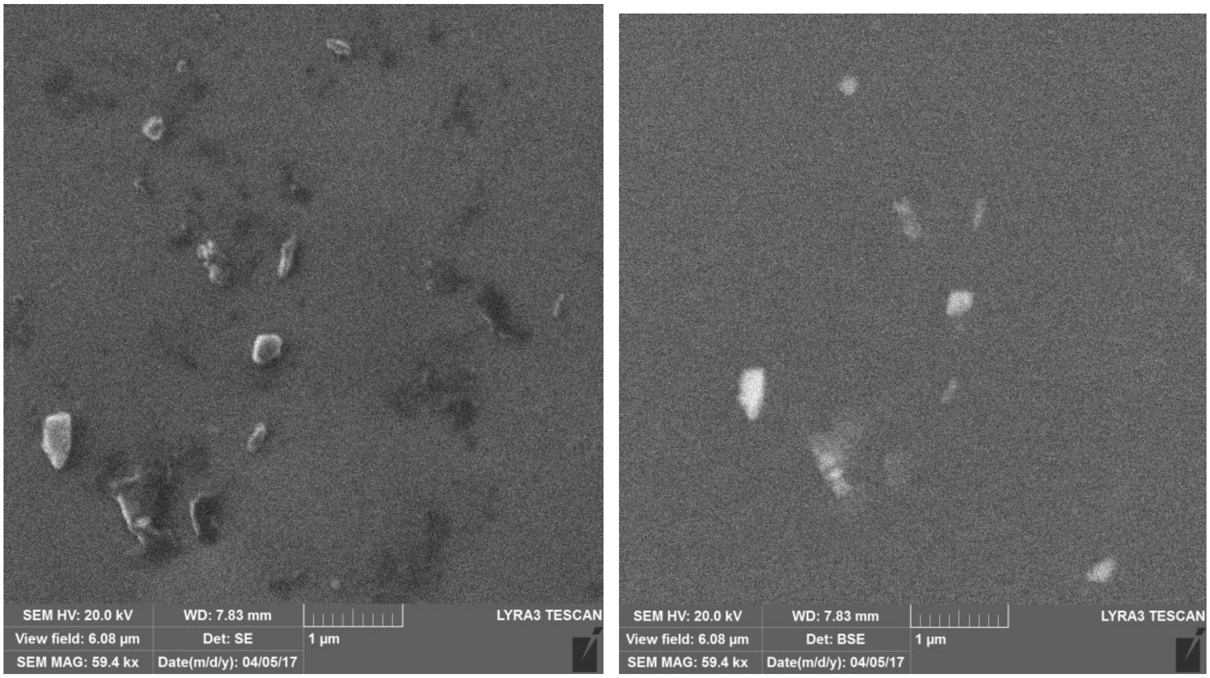
The properties of metal nanoparticles (NPs) are comprehensively investigated because of its possible application in modern opto/microelectronic devices. Metal zinc NPs can be use in UV photo-detectors based on surface plasmon resonance phenomena [1]. There are a number of publications attempted to the formation of metal NPs by supersaturation of silicon with these metals. Among them there are works connected with formation of Zn NPs in Si ion implantation [2-4]. In recent years, there were much attention has been paid to the problems of creating combined microelectronics and photonics systems on silicon substrate. So silicon is non-direct semiconductor, it is not a convenient material for these purposes. The important task is the search for ways to synthesize NPs with a narrow size distribution. Swift heavy ion irradiation (SHI) beams allows selectivity to control the dimensions of formed NPs [5]. As known SHI irradiation lead to formation of so-called latent tracks (nanometer-sized disordered regions around ion trajectory) in many oxide crystals and corresponding track-associated radiation damage may induce the change of NP form from spherical to ellipsoidal. This effect is most noticeable for multiple (about 100 times) SHI impacts [6]. In this work the Zn nanoparticles were synthesized in Si by high-dose and low-energy Zn ion implantation. Then there was carried out the modification of implanted samples by high-energy Xe ion irradiation.

The single crystal n-Si(100) substrates were implanted by $^{64}Zn^{+}$ ions with a dose of $5\times10^{16}cm^{-2}$ and energy of 50keV. In this case, according to SRIM soft [7] calculation the Zn ion projective range in Si was R_p=40nm. To avoid the substrate significant heating effect compared to room temperature the ion beam current density was less than 0.5μA/cm^2. After Zn ion implantation in amorphous Si substrate layer the amorphous Zn metal NPs with average radius of

4 nm were existed [8]. After implantation the substrates were subjected to irradiation at room temperature by $^{132}Xe^{26+}$ ions with energy of 167MeV to fluencies ranged from 1×10^{12} up to $5\times10^{14}cm^{-2}$ at 45^o incident angle to surface normal.

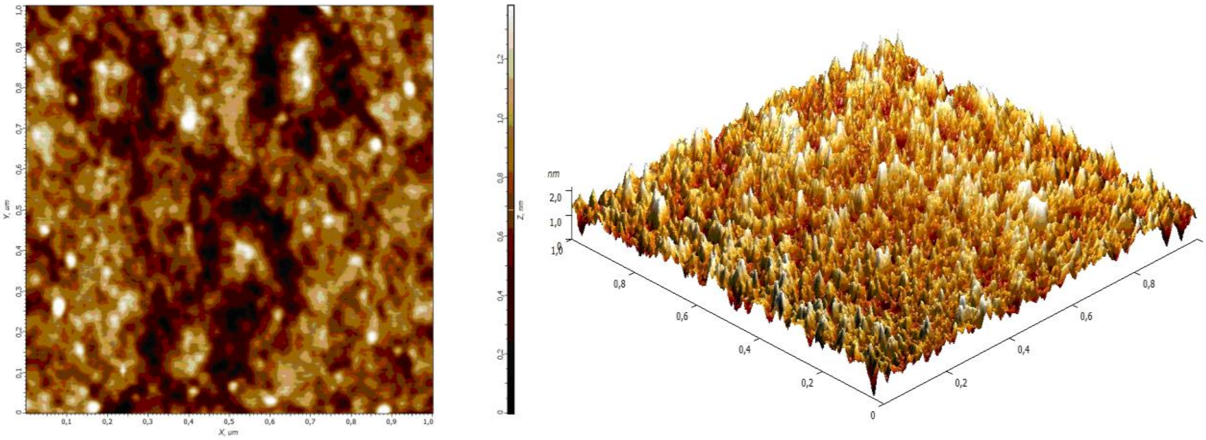
Structural changes in pre-implanted, Zn implanted and Xe irradiated samples were examined by scanning electron microscopy (SEM) LYRA3 (TESCAN) in a second emission (SE) and back scattering (BSE) modes. The last mode can us to obtained so-called Z-contrast. Using the energy-dispersive spectroscopy (EDS) microanalysis, added to this unit, it is possible to determine the element composition of the subsurface layer and obtain the element mapping. The topology of the sample surface was studied using atomic force microscope (AFM) NTEGRA (NT-MDT) in a tapping mode. The photoluminescence (PL) spectra were carried out in a spectral range of 350-800nm with photo excitation using He-Cd laser with wavelength of 325nm at temperature range 10-300K.



a) b)

Fig. 1. SEM-SE (a) and BSE (b) images of Zn implanted and Xe ($1\times10^{14}/cm^2$) irradiated Si substrate.

On Fig.1 there are presented the SEM SE (a) and BSE (b) images of the surface for the sample implanted and irradiated. In this image we can see a bright spot, and numerous dark spots. Their size is order 100nm. Bright spot is at the sample surface, and the dark spots are small surface pores with shallow depth. In Fig. 1b one can see that in the BSE mode (Z-contrast) the bright spot are left and dark spots are gone. Those, the bright spot have a mass greater than the element mass of the Si substrate matrix, i.e., it certainly Zn-contained NP. Dark spots in this image are not, i.e., they belong to the sublayer matrix. Our conclusions are confirmed by EDS microanalysis. From such a spectrum follows that except for the main elements of the substrate, namely, silicon Si-K line 71.45 at% and oxygen O-K line 1.9 at%, there are Zn impurities Zn-K line 0.44 at% and carbon contaminations C-K line 26.2 at%. From these data, it follows that observed NPs consist of metallic Zn or its chemical compound type of Zn·ZnO as zinc has a higher atomic weight than silicon.



a) b)

Fig. 2. 2D- mage of as Zn implanted surface (a) and 3D image after Xe irradiation with fluence of $1\times10^{14}/cm^2$ (b).

Fig. 2a presents a 2D image in AFM mode of the surface topology for the as implanted sample. From this it can be seen that the sample surface is quite smooth, as evidenced by the given numerical data corresponding to this image: Average Surface Inhomogeneity S = 0,872 nm, Average Roughness S_a = 0,205 nm and Root Mean Square of Roughness S_q = 0,259 nm. Such a surface smoothing of a target during implantation is a common phenomenon associated with the sputtering of target upper surface of implanted layer. On a Fig. 2b there are presents a 3D-image of the sample surface after Xe irradiation with fluence of 1E14/cm^2. One can see on this figure that the surface nonuniformity increased. It follows from the above numerical data relating to this figure: Average Surface Inhomogeneity S = 1,26 nm, Average Roughness, Sa = 0,218 nm and Root Mean Square of Roughness, Sq = 280 nm. Such a change after irradiation in the topology structure is attributed to the formation radiation effects in subsurface Si layer as compared with as implanted sample. It should be noted that by the AFM method we investigated sensibly uniform surface without any artifacts shown in Fig.1.

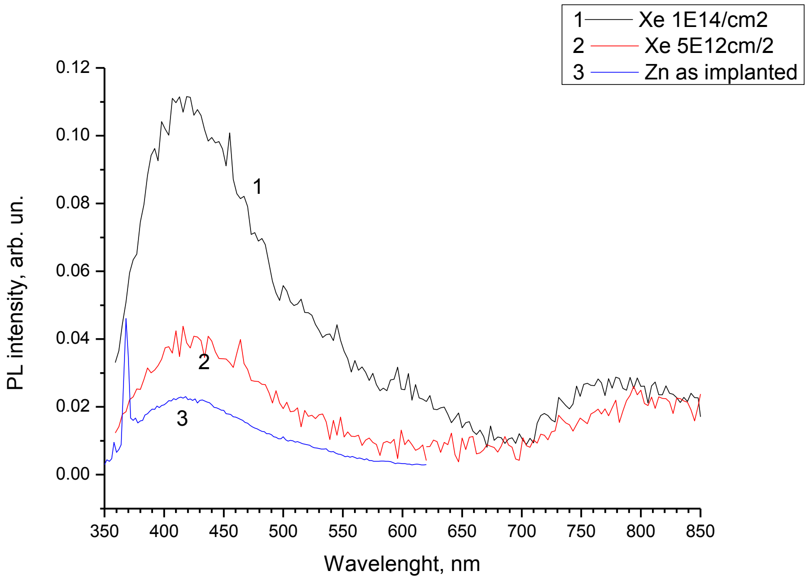


Fig. 3. PL spectra at 10K of Zn as implanted (3) and after irradiation samples with Xe fluences, cm^{-2}: 1 - 1×10^{14}, 2 - 5× 10^{12}/cm^{2}.

On Fig. 3 there are presented the PL spectra of Zn as implanted and Xe irradiated samples. On Fig. 3 (curve3) one can see that for as Zn implanted sample the PL narrow peak at a wavelength of 370nm is observed. This peak is due to ZnO phase germination and connected with exiton recombination. Also we can observe the broadened peak at a wavelength of 425 nm. This peak is due to radiation-induced point defects and their clusters. After irradiation by swift Xe ions the PL peak at a wavelength of 370nm disappeared. This indicates that the phase of ZnO is lost. During Xe irradiation PL peak at 425nm increases with increasing of Xe fluence. Also one can see the broadened PL peak at a wavelength of 800nm, which is also apparently associated with radiation effects and track formation after Xe irradiation.

1. U. Kreibig, M. Vollmer. Optical Properties of Metal Clucters. Springer, Berlin, 1995.
2. Amekura, Y. Takeda, and N. Kishimoto. Mater. Lett. 2011 (222) 96.
3. Y.Y. Shen, X.D. Zhang, D.C. Zhang, Y.H. Xue, L.H. Zhang, C.L. Liu. Mater. Lett. 2011 (65) 2966.
4. V.V. Privezentsev, V. S. Kulikauskas, E. Steinman, A. Tereshchenko, A. Bazhenov, N. Tabachkova, A. Batrakov, phys. stat. sol. (c) 2015 (12) 1170.
5. C. D'Orleans, J. Stoquert, C. Estourne's, C. Cerruti, J. Grob, J. Guille, F. Haas, D. Muller, M. Richard-Plouet, Phys. Rev. B 2003 (67) 220101R.
6. F.F. Komarov, O.A. Milchanin, V.A. Skuratov, M.A. Mokhovikov, A. Janse Van Vuuren, J.N. Neethling, E. Wendler, L.A. Vlasukova, I.N. Parkhomenko, B.N. Yuvchenko. Bull. Russ. Acad. Sci.: Phys. 2016 (80) 160.
7. J.F. Ziegler, J.P. Biersack. SRIM 2013 (http://www. srim.org).
8. V.V. Privezentsev, N.Yu. Tabachkova, K.B. Eidelmanb, S.V. Ksenich. Bull. Russ. Acad. Sci.: Phys. 2016 (80) 1421.