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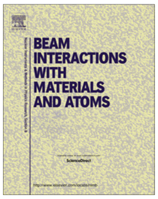

The parameter influence of ion irradiation on the distribution profile of the defect in silicon films

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ABSTRACT

As silicon is an important element in semiconductor devices, the process of defect formation under ion irradiation in it is studied well enough. Modern electronic components are made on silicon lattices (films) that are 100–300 nm thick (Chernysh et al., 1980; Shemukhin et al., 2012; Ieshkin et al., 2015). However, there are still features to be observed in the process of defect formation in silicon. In our work we investigate the effect of fluence and target temperature on the defect formation in films and bulk silicon samples.

To investigate defect formation in the silicon films and bulk silicon samples we present experimental data on Si+ implantation with an energy of 200 keV, fluences range from 5 * 1014 to 5 * 1015 ion/cm^2 for a fixed flux 1 μA/cm^2 and the substrate temperatures from 150 to 350 K The sample crystallinity was investigated by using the Rutherford backscattering technique (RBS) in channeling and random modes.

It is shown that in contrast to bulk silicon for which amorphization is observed at 5 × 1016 ion/cm^2, the silicon films on sapphire amorphize at lower critical fluences (1015 ion/cm^2). So the amorphization critical fluences depend on the target temperature. In addition it is shown that under similar implantation parameters, the disordering of silicon films under the action of the ion beam is stronger than the bulk silicon.

1. Introduction

An ion penetrating the solid body collides with atoms and transfers them part of its energy. If the energy transferred to an atom in the elastic collision exceeds the threshold displacement energy of atoms in the lattice, the atom leaves the site. Usually the energy of the recoil atoms is high; therefore, as a result of the movement these atoms form a large cascade of collisions destroying the crystalline structure.

Knocked out of the lattice sites atoms of the matter form vacancies and structural defects along ion tracks. In addition, defects occur as a result of the interstillial ion between the lattice sites. The accumulation of such defects form a dislocation, vacancy pores, etc. The process of ion implantation accumulates radiation defects [1].

Damage produced by incident ions can significantly transform various properties of solid. In this regard, we are interested in studying radiation resistance of materials and defect formation under ion irradiation. For example, defects in the silicon semiconductor matrix are capable of forming optically active centers emitting in the 1.5 μm region [2–4]. The paper [5] indicates that porous silicon has paramagnetic properties, and the number of paramagnetic centers increases by several orders of magnitude with the increasing number of defects.

The defect formation in solids by bombarding ions varies with the type of material. The paper [6] shows that during ion irradiation of metals complete destruction of the crystalline structure does not occur up to the fluence 10^{18} ion/cm^2.

Unlike metals the surface of semiconductor materials amorphizes at fluences of 10^{15}–10^{16} ion/cm^2. Total amorphization occurs when the number of ions fallen on a unit area of the surface exceeds a certain value called the critical fluence of amorphization. Low radiation resistance of semiconductors is caused by a smaller (in comparison with metals) rate of defect annealing under ion irradiation.

As silicon is an important element in semiconductor devices, the process of defect formation under ion irradiation in it is studied well enough. Modern electronic components are made on silicon lattices (films) that are 100–300 nm thick [7–9]. However, there

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are still features to be observed in the process of defect formation in silicon.

In our work we investigate the effect of fluence and target temperature on the defect formation in films and bulk silicon samples.

2. Experimental

The study was conducted on structures “silicon on sapphire” of the epitaxial silicon layer 300 nm thick [10] and on bulk samples of silicon based on the accelerator HVEE-500 at ion energies up to 500 keV [11]. The implant tract includes systems for beam scanning and focusing, a neutral particles trap and a vacuum pumping system.

The scanning system of the beam comprises two sets of deflecting plates in a cylindrical chamber located in the line of the beam after the electrostatic triplet lenses, as well as the generator and power sweep signals for electrostatic deflection of the beam as “x” and “y” with a frequency of about 1000 Hz. The system scans the target with a beam area with a uniformity of fluence in this area not less than 99%. To prevent the channeling effect of the ion beam falls on the sample surface under the angle $\alpha = 7°$ from the normal to the surface.

The trap of neutral particles is implemented by applying voltage to two additional deflecting plates, whereby the charged particle beam deflectes by seven degrees in the beam line. Axial symmetry of the beam is analysed using a beam monitoring system. The deflection voltage on the plates can be disabled with a relay on a signal from the current integrator when the necessary fluence is achieved. This causes immediate withdrawal of the beam from the target.

The residual pressure in the chamber during the experiment was less than $2 \cdot 10^{-4}$ Pa. To eliminate the influence of impurities on the defect formation silicon ions were used for irradiation. To prevent heating of the sample the current density during the experiment was maintained constant and it did not exceed 1 μa/cm^2 (0014 dpa/s). Dose ranges from $5 * 10^{14}$ to $6 * 10^{15}$ ion/cm^2 (from 1.12 to 13.5 dpa).

The test samples were attached using spring clamps on the vacuum grease on a large copper holder to provide thermal contact. Cooling was carried out either by using liquid nitrogen or Peltier element. The temperature was controlled automatically in online mode with an interval of 0.01 s. In case of a temperature change of 0.5 K the system automatically corrects settings on the power supply of Peltier element for heating/cooling of the substrate.

The control of crystallinity of the structure was carried out using the Rutherford backscattering (RBS). Measurements of the RBS spectra were obtained by using 1.7 MeV He$^+$ ions on the accelerator HVEE AN-2500. The ion beam was falling along the normal to the sample surface, the scattering angle was $\theta = 120°$. Two of the RBS spectra were recorded: the one in the channeling direction and the other in the direction containing no open channels. The maximum signal ratio of backscattered He$^+$ ions in the direction of the channeling to the signal in the direction not containing open channels characterizes the degree of the sample crystallinity: the smaller this ratio, the better is the crystal structure.

3. Results and discussion

Fig. 1 shows the RBS spectra of the sample after irradiation with Si$^+$ ions at a fluence of 10^{15} ion/cm^2 (2.25 dpa), recorded in the channeling (a) and random directions (b). The comparison of the spectra shows almost complete disordering of the crystalline structure of the silicon films that occurred after irradiation, except a thin region near the surface. On the depth scale (where the surface corresponds to 0) the maximum of vacansions distribution formed as a result of ion bombardment ($R_v = 215$ nm) is given. Calculation was carried out in the program TRIM. Curve C shows that in the initial silicon film near the interface backscattered yield from the silicon substrate has increased. This suggests that the concentration of defects near the interface is greater as compared with surface layers. These data are in agreement with data in an article [7], where via transmission electron microscopy was shown that in silicon films formed by chemical vapour deposition at a distance of 100 nm from the interface films contains silicon twins defects, dislocations, etc. At the same time, we know that bulk semiconductor materials amorphize at higher fluences of irradiation at 5×10^{16} ion/cm^2 [12,13].

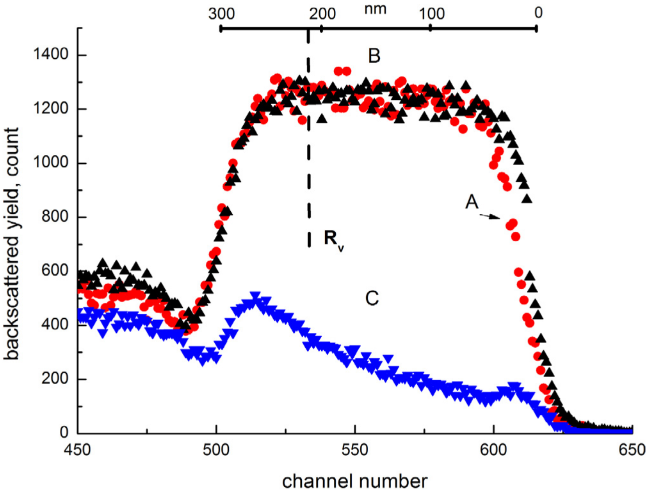

Fig. 1. Energetic spectra of backscattered He+ ions with an energy of 1.7 MeV for the scattering angle 120 degrees. A (channel) after implantation Si+ E = 200 keV and the fluence 10^{15} ion/cm^2, B – random direction, C (channel) from a virgin silicon film.

Fig. 2 presents the RBS spectra of a bulk single crystal sample of Si (100) after irradiation by Si$^+$ ions at a fluence of 3×10^{15} (6.75 dpa) and 6×10^{15} ion/cm^2 (13.5 dpa). The data indicate that a complete disordering of the silicon target does not occur. The maximum depth of a radiation damage is close to the value of the average projective range. A weakly damaged layer remains near the surface of the top silicon layer. On the depth scale (from

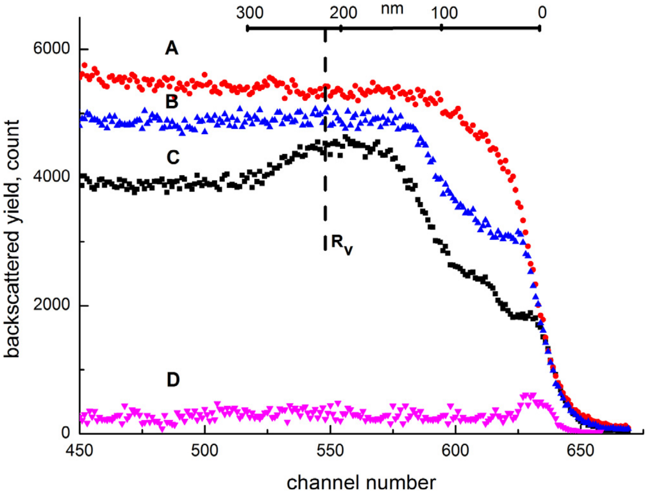

Fig. 2. Energetic spectra of backscattered He$^+$ ions with an energy of 1.7 MeV for the scattering angle 120 degrees. B (channel) after implantation Si$^+$ E = 200 keV and the fluence 6×10^{15} ion/cm^2, C (channel) after implantation Si$^+$ E = 200 keV and the fluence 3×10^{15} ion/cm^2; D (channel) – virgin silicon; A – random direction.

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