such as the microhardness, wear-resistance, crack-resistance and surface microrelief.

The observed effect is produced by the following: in the dose gaining process there are alternating stresses occurring in the glass. These stresses penetrate inward the sample along the ion beam direction in the form of shock waves, which reach the back side of the sample, reflect from it many times, thus leading to the accumulation of the structural damages in glass and producing the local tightening in it. The long-range effect intensity decreases with time. It is caused by a slow relaxation of the structural damages, which were produced by the ion bombardment.

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STRUCTURE CHANGES IN SILICON IRRADIATED BY HIGH ENERGY IONS OF HYDROGEN, DEUTERIUM AND HELIUM

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Structural and optical properties of silicon irradiated by ions of 6.8 MeV hydrogen (p^+ or H^+), 13.6 MeV deuterium (heavy hydrogen $^2H^+$ or D^+) and 27.2 MeV helium (α-particles or He^{2+}) with fluences $\Phi \geq 5 \cdot 10^{16}$ cm^{-2} were studied using the complex of methods: selective etching and metallographic, ellipsometry and profilometry. The irradiated crystals were cut along the direction of irradiation, allowing to study the properties of silicon in the region of the ions' path, braking and behind it. The projection lengths of the path of the ions of a given energy are about 360 microns for p^+ and He^{2+} and about 780 μm for D^+.

The main structural defects are observed in the braking region, where concentration of radiation defects is the largest. The widths of etched lines along ion stopping change in the direction from the sample edge (where temperature was lower due to the sample cooling during irradiation) to the center of irradiation and depend of the ion type.

After proton irradiation silicon structure in the path region does not sufficiently change. Structure of the path region of helium irradiated Si changes essentially from the crystal form to the highly destroyed (perhaps, polycrystalline). At currents about 0.25 - 0.45 μA and fluences $\Phi \geq 10^{16}$ cm^{-2} the defect "walls" parallel to the stopping line appeared both in the path region, and behind stopping line at the distance equal to double projection length of the path. The number of the "walls" depended on the ion beam intensity.

We consider that the soliton mechanism is responsible for the ordered structure creation in the region behind the stopping line. Periodic structures in the path region might appear due to the moving of the recrystallization front of the highly disordered layers, possible, amorphous, in the process of the highly energetic long-lasting ion irradiation.

Introduction

Modern radiation doping of semiconductors by ion beams is characterized by the creation of layers with different from matrix properties due to controlled input of impurities and defects. The method makes it possible receiving of hidden layers with other conductivity type, forming of p-n-junctions, passivation of tensions and defects and getting of new electrical and photovoltaic characteristics.

Currently the behavior of nonequilibrum system of defects under long-lasting energetic irradiation has not been established jet and the influence of ions with about tens MeV energy range on silicon properties is the least studied. We present the data of structural changes of Si, irradiated by 6.8 MeV hydrogen (protons), 13.6 MeV deuterium (deuterons), and 27.2 MeV helium (α-particles) ions with fluences $\geq 5 \cdot 10^{16}$ см$^{-2}$ and show the perspective to use such ion beams for radiation doping technology.

Experiment

Structural and optical properties of ion irradiated silicon crystals were studied by the complex of methods: selective etching and metallographic, ellipsometry and profilometry. Silicon crystals, grown by the Czochralski and floating-zone methods, with dislocations ($N_D \approx 10^4$ cm^{-2}) and without them were used. Samples were grinded, polished, etched and irradiated by light ions (6.8 MeV protons, 13.6 MeV deuterons, and 27.2 MeV α-particles) by fluences $\geq 5 \cdot 10^{16}$ cm^{-2} in cyclotron U-120 of Institute for Nuclear Research of NAS of Ukraine. The irradiation temperature was ≤ 100 °C, as during irradiation the samples were cooled by water. The projection length of the ions' path of given energies are about 360 μm for p^+ and He^{2+} and about 780 μm for D^+. The irradiated crystals were cut along the direction of irradiation, allowing to study the properties of silicon in the region of the ions' path, braking and behind it.

Selective etching shows the difference in oxidation during chemical etching in the defective and defect-free regions of silicon. Pictures of Si structures in the ion path, stopping and behind path regions for different irradiations are given in Fig. 1, where we can see also the dark stopping line *s.*

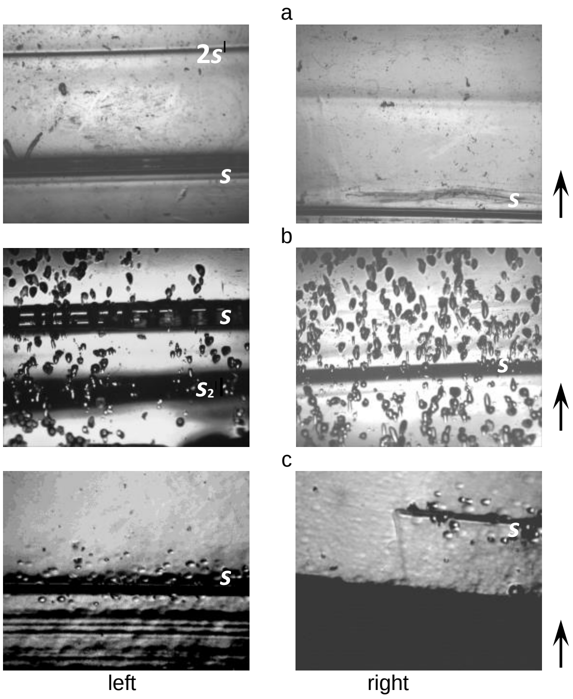

Fig. 1. The picture of selective etching (× 150) of silicon irradiated by various ions: a – 6.8 MeV hydrogen; b – 13.6 MeV deuterium; c – 27.2 MeV helium. Left side of the picture is in the center and right side is in the edge of the irradiated area. An arrows show the direction of irradiation

The highest changes were observed in the braking region, where concentration of defects was the largest. The widths of etched lines along the ion stopping region are 30 - 80 μm (p^+); 30 - 130 μm (D^+) and 140 - 200 μm (He^{2+}), in the direction from the edge to the center of irradiation. The minimal values of etched lines' width in the path region for all kind of ions were identified in the edge of irradiated part of Si, where temperature was lower due to the sample cooling. The structure of the stopping region for the deuterium ion irradiation was more complicate d in comparison with protons, and two etched lines were observed: first line *s* is in the stopping region and the additional second line s_2 is closer to the surface of irradiated sample (Fig. 1, b, left side).

After proton irradiation silicon structure in the path region does not change. Structure of the path region of helium irradiated Si changes from the crystal form to the highly destroyed (perhaps, polycrystalline). At currents about 0.25 - 0.45 μA and fluences $\Phi \geq 10^{16}$ cm^{-2} the defect "walls" parallel to the stopping line appeared in the path region (Fig. 1, c, left side), as well as behind stopping line at the distance equal to double projection length of the path. The number of the "walls" depended on the ion beam intensity [1].

Ellipsometry and profilometry studies indicated also on complex defect structure in the ion path region of the irradiated Si, depending on ion's mass, energy and time of irradiation. Absorbing and reflection constants in near surface region changed sharply at high fluences (10^{17} cm^{-2}) for hydrogen and helium ions, and profilometry measurements fixed the difference in the profile of the irradiated and non-irradiated parts of Si [2].

We assume that the soliton mechanism is responsible for the ordered structure creation in the region behind the stopping line of ions. Periodic structures in the path region, on our opinion, appear due to the moving of the recrystallization front of the highly disordered layers, possible, amorphous, in the process of the highly energetic long-lasting ion irradiation.

Conclusion

Studies of the optical and structural properties of silicon irradiated by the highly energetic light ions (6.8 MeV hydrogen, 13.6 MeV deuterium and 27.2 MeV helium) with fluences $\Phi \geq 5 \cdot 10^{16}$ cm^{-2} have revealed the complex character of the defect creation: number and width of the etched lines of tension depended on ion's mass, energy and time of irradiation. Radiative doping (the controlled introduction of structural defects) makes it possible receiving in the depth of silicon ≤ 780 μm the thin layers (30 - 200 μm) with properties various from the initial matrix.

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