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Defect Formation in Silicon Implanted with ~1 MeV/Nucleon Ions

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Abstract—Defect formation processes in silicon implanted with ~1 MeV/nucleon boron, oxygen, and argon ions have been studied using microhardness and Hall effect measurements. The results indicate that ion implantation increases the surface strength of silicon single crystals owing to the formation of electrically inactive interstitials through the diffusion of self-interstitials from the implantation-damaged layer to the silicon surface. The radiation-induced surface hardening depends significantly on the nature of the ion, its energy, and the implant dose. In the case of low-*Z* (boron) ion implantation, the effect had a maximum at an implant dose of $\sim 5 \times 10^{14}$ cm^{-2}, whereas that for O^+ and Ar^+ ions showed no saturation even at the highest dose reached, 1×10^{16} cm^{-2}. When the ion energy was increased to ~3 MeV/nucleon (210-MeV Kr^+ ion implantation), we observed an opposite effect, surface strength loss, due to the predominant generation of vacancy-type defects.

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INTRODUCTION

High-energy ion implantation is of practical interest because ion doping at accelerating voltages above 1 MV in the fabrication of semiconductor devices opens up great possibilities for producing conductive dopant layers at depths of tens of microns, enables a reduction in the number of photolithographic steps, and allows one to dispense with expensive epitaxial structures.

At different steps of the fabrication of semiconductor devices (oxidation, diffusion, mounting, and others), silicon wafers are exposed to various thermal and mechanical influences, which may give rise to buckling and microcracking. These processes reduce the yield of devices to specification and are in many respects determined by the strength of the implanted wafers. Their strength is an intricate function of the mechanical properties of the material: elastic (Young's modulus), plastic (hardness), and brittle (fracture toughness) [1]. These mechanical properties are commonly evaluated by various techniques in a stress state that is far from contact loading in abrasive processing.

The only method that allows modeling of the contact interaction between abrasive particles and the material being processed is microindentation. The conditions in the indented zone are in many respects similar to those in several cases of contact interaction of practical importance, e.g., dry friction and abrasive

on the physical properties and strength of single-crystal silicon.

EXPERIMENTAL

Polished (100) KEF-4.5 (phosphorus-doped) silicon wafers 460 ± 20 μm in thickness were implanted with ~1 MeV/nucleon B^+, Ar^+, and O^+ ions at room temperature to doses (Φ) from 1×10^{13} to 1×10^{16} cm^{-2} on an ITs-9 pulsed cyclotron. The ion current density was varied from 0.3 to 2.5 μA/cm^2. The projected ion range R_p was ~15 μm. We also performed 210-MeV krypton ion implantations with doses from 5×10^{12} to 6×10^{13} cm^{-2}.

Microhardness *H* was measured in the [100] direction by a standard technique using a PMT-3 tester. The indenter load was varied from 0.3 to 3 N. In each experiment, at least 50 indents were placed on the wafer surface. The measurement results were analyzed using statistical methods. The uncertainty in our microhardness measurements was less than 3% (at a 95% confidence level).

In addition, the samples were characterized by Hall effect measurements, IR spectroscopy, and electron paramagnetic resonance (EPR) in combination with depth profiling.