X-ray microbeam investigation of the depth dependence of ion-implantation induced defects in Si

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Introduction

The lattice defects produced during ion-implantation doping of semiconductors represent a long-standing problem for semiconductor process design, as well as for fundamental understanding of damage production and defect evolution in semiconductors. In particular, because of the forward momentum of interstitial atoms relative to their respective vacancies, interstitials have on average a small displacement toward larger depths. As a result, during annealing or high-temperature implantation, this separation of vacancies and interstitials leads to a vacancy-rich region shallower than the damage peak and the projected range of the implanted ions [1]. We have used submicron x-ray beams on the UNI-CAT beamline at the Advanced Photon Source (APS) to make the first cross-section x-ray scattering measurements [2] of the depth dependence of the relative concentration, size distribution, and vacancy/interstitial nature of clustered defects in MeV self-ion-implanted Si.

Methods and Materials

In this investigation, <001> oriented floating zone silicon crystals were irradiated with 9 x 10^{16} 10 MeV Si ions at a temperature of 300° C. The crystals were subsequently cleaved along {110} planes normal to the implanted surface and syton polished to allow cross-section diffuse scattering measurements as a function of depth along the implantation direction. As shown in Fig. 1, monochromatic x-ray microbeams with ~0.65 µm (horizontal source size limited) spatial resolution at an energy of 8.95 keV were generated on the UNI-CAT beamline at the Advanced Photon Source using a 150 µm diameter compound Fresnel zone plate with a 5.6 cm focal length, obtained in collaboration with SRI-CAT. A 25 µm tungsten wire was inserted in the incident beam to eliminate unfocused radiation from passing through a 20 µm order-sorting aperture.

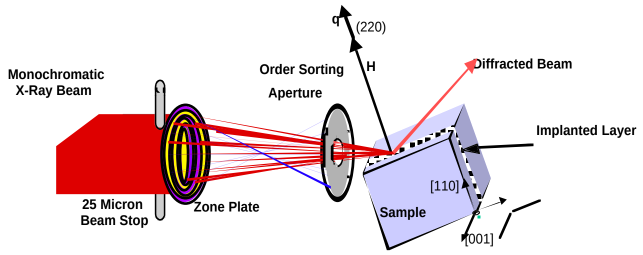

Figure 1: Microbeam cross-section diffuse scattering geometry.

Results

The inset in Fig. 2 shows a cross-section depth profile of the x-ray diffuse scattering at q = 0.04 $Å^{-1}$ at the (220) reflection. The abrupt rise at depth = 0 denotes the crystal surface, and a large peak arises at the projected range of the implanted Si ions. The figure shows the measured diffuse scattering (at the arrow positions) scaled by q^4 to emphasize the large-q "local-Bragg" scattering region. The scattering from interstitial and vacancy-type clusters is distributed to opposite sides of the (q = 0) Bragg position and is peaked at q-values inversely proportional to the size of loop-type defects [2]. The solid lines are fits of the data by scattering calculations for vacancy and interstitial dislocation loops, with concentrations for radii of 5–50 Å as parameters.

The strong intensity for positive-q at 4.25 µm indicates interstitial-type clusters corresponding to the large number of implanted ion interstitials at the projected range, while the small increase in scattering for negative-q at 1.8 µm indicates an excess of vacancy-type clusters in this region.

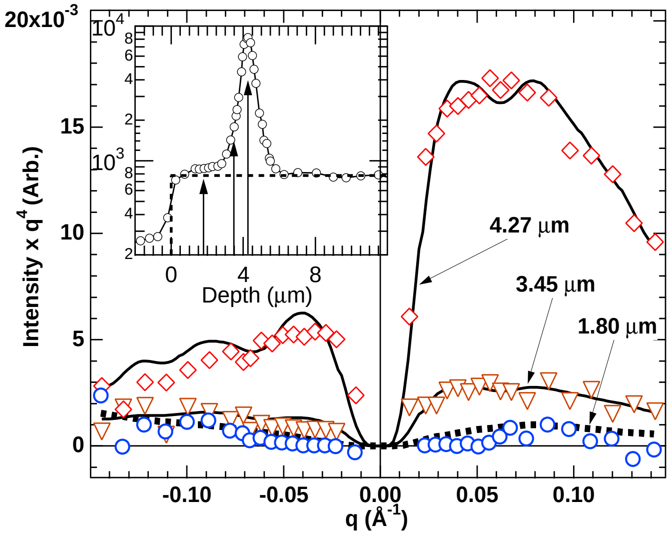

Figure 2: Depth–resolved diffuse scattering (scaled by q^4) for self-ion irradiated Si near the (220) reflection. The arrow positions in the inset denote measurement positions.

Discussion

X-ray diffuse scattering measurements such as presented here are complementary to electron microscopy measurements in that they have sensitivity to small defect clusters that are difficult to image by electron microscopy. Moreover, x-ray diffuse scattering measurements provide a direct separation of the vacancy and interstitial components, which is an exceedingly tedious task using electron microscopy, for the case of small dislocation loops. Measurements with improved spatial (depth) resolution and varying implant/annealing conditions are in progress.

Acknowledgments

Research sponsored by the U.S. Department of Energy DMS and LTR Programs under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corp. UNI-CAT beamline at the APS is supported by the UIUC-MRL, ORNL, NIST, and UOP LLC. Use of the Advanced Photon

Source was supported by the U.S. Department of Energy, Basic Energy Sciences, Office of Science, under Contract No. W-31-109-Eng-38.

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