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Study of crystal damage by ion implantation using micro RBS/channeling

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Abstract

The combination of microbeam implantation and in-situ micro RBS/channeling analysis in the Rossendorf nuclear microprobe facility enables crystal damage studies with high current densities not achievable in standard ion implantation experiments. Si(100) samples were implanted with 600 keV Si^+ ions and a fluence of $1 \times 10^{16}\ cm^{-2}$. Using a beam spot of 200 μm × 200 μm current densities from 4 to 120 μA/cm^2 were obtained. The substrate temperature was varied between RT and 265 °C. The implanted regions were subsequently analysed by micro RBS/channeling with a 3 MeV He^+ beam having a spot size of 50 μm × 50 μm. Crystal damage up to amorphisation was observed in dependence on the substrate temperature. Above a critical temperature T_C no amorphisation occurs. T_C was determined for each series of samples implanted with the same ion current density j. It was found that the empirical Arrhenius relation $j \sim \exp(-E_a/kT_C)$, known from standard implantation experiments, is also valid at high current densities. The observed Arrhenius law can be derived from a model of epitaxial crystallisation stimulated by defect diffusion.

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1. Introduction

Modern commercial ion beam implantation systems aim at high throughput by using high-intensity ion beams. To avoid a damage of the electronic device by ion beam heating the industrial implantation stages are furnished with a cooling device. It is well known that current density of the beam and implantation temperature influence the crystal damage and are important for the device characteristics. Whereas crystal damage has to be avoided in the case of doping, it can be preferred as trapping centres for metal contamination. Especially Si implantation at high energy is applied to produce trapping centres for this purpose.

Experimental data of crystal damage as a result of ion implantation are important for many industrial applications. But these data are available only for the usually used ion current densities of about 10^{11} up to $10^{13}\ cm^{-2}\ s^{-1}$, e.g. in [1–4]. Experiments with high ion current densities of about $10^{15}\ cm^{-2}\ s^{-1}$, especially at high ion energies, are rare, mainly because universities and research laboratories have no access to modern industrial implantation systems. A method to enlarge the current density of a typical MeV accelerator system is to focus the ion beam. Microprobe systems are able to deliver high densities up to about $10^{15}\ cm^{-2}\ s^{-1}$ and have the advantage that the sample temperature is not affected by the implantation procedure due to the small spot size. The method allows a change of the implantation conditions at one sample whereby a fast investigation of a large parameter space is possible. The aim of this work is to study crystal damage when implanting with

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such extreme implantation values. In particular it is of interest to verify the published damage models.

2. Experimental

2.1. Sample preparation

A series of Si(1 0 0) samples was implanted with 600 keV Si ions and a fluence of 1×10^{16} cm^{-2} by the nuclear microprobe [5] at the 3 MV Tandetron accelerator of the Forschungszentrum Dresden-Rossendorf. The beam was focussed to a spot of 200 μm × 200 μm at four different current densities: 2.5×10^{13} cm^{-2} s^{-1} (4 μA/cm^2), 7.5×10^{13} cm^{-2} s^{-1} (12 μA/cm^2), 2.5×10^{14} cm^{-2} s^{-1} (40 μA/cm^2), and 7.5×10^{14} cm^{-2} s^{-1} (120 μA/cm^2). In order to avoid channeling effects at the implantation the samples were tilted by 7°. The substrate temperature during the implantation was varied between RT and 265 °C. One Si wafer contained spots implanted with a fixed current density at different substrate temperatures starting from the highest temperature to RT. Because of the small beam spot and the high thermal conductivity of Si, the heating of the sample due to microbeam implantation can be neglected [6].

2.2. The Rossendorf micro RBS/channeling setup

Until now the Rossendorf nuclear microprobe was mainly used for ion beam analysis (RBS, ERDA, NRA, PIXE) with a beam spot of typical 2–3 μm at a beam current of 100 pA–1 nA. However, because the sample manipulator is not precise enough to use it for RBS/channeling measurements a second chamber with a goniometer driven by stepper motors inside the vacuum was installed 100 cm behind the first one (Fig. 1). Due to the longer distance between the lens and the sample the minimum beam spot here is about 10 μm. A photograph of both chambers is shown in Fig. 2. The eucentric 4-axes goniometer of the RBS/channeling chamber was assembled by us and consists of two rotation stages and two translation stages. These four commercially available stages and the stepper motors are specially prepared for using in vacuum. An annular surface barrier detector with a solid angle of 35 msr is used for the detection of the backscattered ions. For PIXE measurements in channeling direction a special nozzle with a 125 μm thick Be vacuum window is mounted at an angle of 120° with respect to the beam direction. In this way it is easily possible to mount and to remove the X-ray detector without breaking the vacuum. The samples and also the beam spot on quartz or Al_2O_3 can be observed from the front side by a zoom microscope with magnifications between 130 and 300. Its object lens is located inside the chamber. The microscope view is oriented at an angle of 30° from the beam direction and the sample is illuminated mirror-symmetrically to the microscope by optical fibres from outside. By this arrangement it is easy to observe also highly reflective materials like Si wafers having only small surface defects. A CCD camera is connected to the microscope. The sample holder can be changed via a load-lock at the upper side without breaking the vacuum. The chamber is evacuated by a molecular pump connected only via a vibration damping bellow to a vacuum in the range of 10^{-8} mbar.

The samples are fixed on the backside of the holder behind an 'open window' (Fig. 3). Because the backside of the holder moves always in the focal plane of the quadrupole triplet and the tilt is eucentric, the beam spot will always be focussed onto the surface of the sample independently of

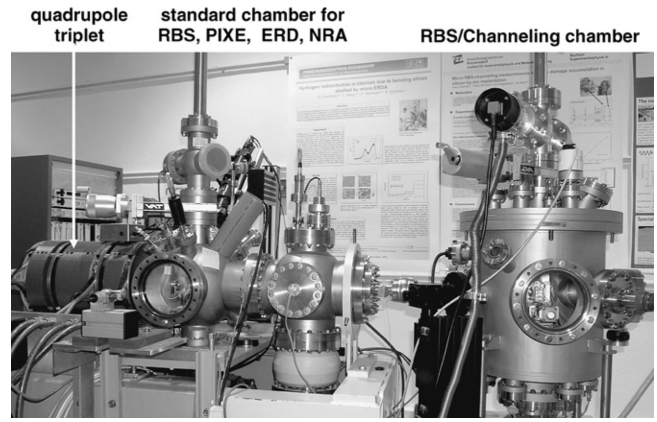

Fig. 2. Photograph of the two chambers of the nuclear microprobe.

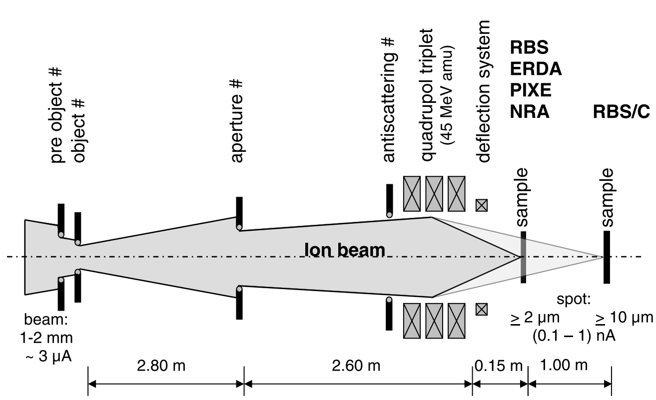

Fig. 1. Beam line scheme of the nuclear microprobe.

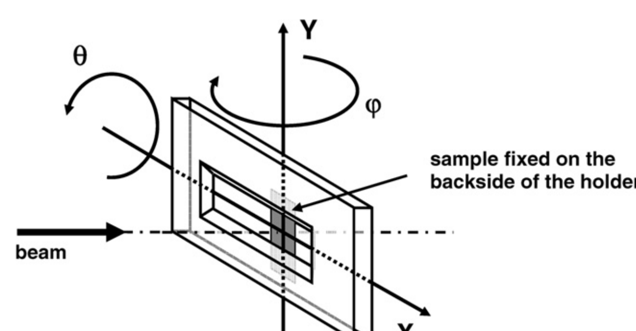

Fig. 3. Scheme of the goniometer axes and the sample holder in the RBS/channeling chamber.