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Micro-Raman depth profile investigations of beveled Al^+-ion implanted 6*H*-SiC samples

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ABSTRACT

6*H*-SiC single crystals were implanted with 450 keV Al^+-ions to a fluence of 3.4×10^{15} cm^{-2} , and in a separate experiment subjected to multiple Al^+ implantations with the four energies: 450, 240, 115 and 50 keV and different fluences to obtain rectangular-like depth distributions of Al in SiC. The implantations were performed along [0001] channeling and non-channeling ("random") directions. Subsequently, the samples were annealed for 10 min at 1650 °C in an argon atmosphere. The depth profiles of the implanted Al atoms were obtained by secondary ion mass spectrometry (SIMS). Following implantation and annealing, the samples were beveled by mechanical polishing. Confocal micro-Raman spectroscopic investigations were performed with a 532 nm wavelength laser beam of a 1 μm focus diameter. The technique was used to determine precisely the depth profiles of TO and LO phonon lines intensity in the beveled samples to a depth of about 2000 nm. Micro-Raman spectroscopy was also found to be useful in monitoring very low levels of disorder remaining in the Al^+ implanted and annealed 6*H*-SiC samples. The micro-Raman technique combined with sample beveling also made it possible the determination of optical absorption coefficient profiles in implanted subsurface layers.

1. Introduction

Silicon carbide (SiC) has been widely investigated by a variety of different methods in an attempt to better understand the properties of this potentially important material [1]. High thermal conductivity, high breakdown field, high electron saturation velocity and a large band gap make SiC a promising candidate for high temperature, high frequency and high power electronic devices. In order to exploit this potential ion implantation is the only method of selective doping of SiC, because of the low dopant diffusivities at temperatures below 1800 °C [2]. High fluence Al^+-ion implantation is the most promising procedure to fabricate low resistivity p-type regions in SiC [3] but is inevitably accompanied by radiation damage in the form of vacancies, interstitials and extended defects and even after annealing at elevated temperatures some residual lattice damage is observed [4]. Al^+-ion implantation-induced damage depth profiles were investigated by micro-Rutherford backscattering spectroscopy with channeling (micro-RBS/C) in the beveled 6*H*-SiC samples [5]. In the latter study the beveling technique allowed the signal from the uppermost layers to be eliminated in an attempt to obtain real information about radiation damage at a specific depth in the sample.

Raman scattering is a non-destructive, contactless spectroscopic method providing information on phonon modes in crystals [6]. Raman lines have been used to study implantation damage in 6*H*-SiC [7,8]. However, up to now, no reports have been found in the literature on using Raman spectroscopy for depth profiling in ion implanted and beveled SiC.

2. Experimental

N-type 6*H*-SiC from Si crystal [9] were Al^+-ion implanted at FZR Dresden-Rossendorf at room temperature with single fluence (sample Nos. 1 and 2: $D = 3.4 \times 10^{15}$ cm^{-2}, $E = 450$ keV) and with four different fluences (sample Nos. 3 and 4: energy sequence [keV]: 450, 240, 115, 50; fluences [cm^{-2}]: 3.4×10^{15}, 16.6×10^{14}, 9.6×10^{14}, 5.2×10^{14}, respectively) to achieve a nominal concentration of atoms about 10^{20} Al atoms/cm^{-3} (see Table 1). The directions of the implantations were: [0001] *c*-axis (channeling direction) for samples Nos. 1 and 3; and 10° tilt from [0001] with 10° rotation around [−1100] for samples Nos. 2 and 4 ("random" direction, i.e. the target seen by impinging ions as amorphous-like structure). Before the implantations, a standard

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Table 1
Ion implantation parameters of the investigated 6*H*-SiC samples.

Sample no.	Energy (keV)	Fluence (cm^{-2})	Orientation	Nominal concentration (cm^{-3})
1	450	3.4×10^{15}	[0001]	10^{20} (max)
2	450	3.4×10^{15}	"*random*"	10^{20} (max)
3	450	3.4×10^{15}	[0001]	10^{20} (average)
	240	16.6×10^{14}		
	115	9.6×10^{14}		
	50	5.2×10^{14}		
4	450	3.4×10^{15}	"*random*"	10^{20} (average)
	240	16.6×10^{14}		
	115	9.6×10^{14}		
	50	5.2×10^{14}		

procedure of sample orientation was performed in the implantation chamber using 600 keV He^{2+} ions, focused to a 1 mm beam in diameter next to the edge of the sample to avoid introducing additional damage into the sample. Subsequently, the ion beam was changed to Al^{+}-ions to perform the implantations. All of the above mentioned fluences and energies as well as the directions of the implantations were chosen to study the influence of the implantation directions on the generated profiles of implant and damage in 6*H*-SiC for the same nominal concentration of the dopant, and to compare the experimental results with the computer simulation utilizing the crystal-TRIM code [10]. After the implantations, the samples were cut into two pieces. One part of the samples was annealed at the temperature of 1650 °C for 10 min in an Ar atmosphere to produce the best activation of Al dopant and to reduce ion beam induced damage. The other part was used for the SIMS (Fig. 1) analysis for the as-implanted state. SIMS depth profiles were measured with a Cameca magnetic sector instrument.

Subsequently, the samples were beveled using mechanical polishing with a rotating glass plate and diamond paste consisting of 0.1 μm diameter grains. The values of the obtained bevel angles α were of the order of a few tenths of a degree. α was measured with an accuracy of 10% using an optical interference technique and a Dektak 8000 profilometer.

The beveled samples were investigated with a confocal micro-Raman spectrometer in backscattering geometry using a LabRam HR 800 Jobin Yvon spectrometer coupled with a microscope and a laser working at the 532.14 nm line. Fig. 2 shows a scheme of light collection geometry from the beveled sample. The light was focused to the 1 μm diameter spot with a 100× microscope objective and the same objective collects the scattered radiation. The Raman equipment used in the present work with highly-transparent material (unimplanted SiC) can be characterized by a confocal depth resolution of about 6 μm [8]. A computerized step-motorized moving stage enabled precise positioning of the sample and scanning across the beveling edge along the length *l* typically of about 1 mm to analyze the damaged region of 6*H*-SiC to the depth of about 2.0 μm. Values of the length *l* of all samples were measured using a precise, step-motorized moving stage and a TV digital camera coupled with a microscope. For each sample between 24 and 40 Raman spectra were recorded to probe the whole damaged subsurface layer.

3. Results and discussion

Fig. 3 shows a typical micro-Raman scattering spectrum from the unimplanted single-crystalline (0001) 6*H*-SiC. Several first-order one-phonon Raman lines are observed assigned to different acoustic and optic phonons (longitudinal and transverse) of different symmetries [11]. The sequence of micro-Raman spectra as obtained from the beveled Al-implanted and non-annealed 6*H*-SiC (sample no. 1) is displayed in Fig. 4. Post-implantation damage for this sample is so strong that Raman signal almost completely vanishes when measured on the non-beveled part of the sample,

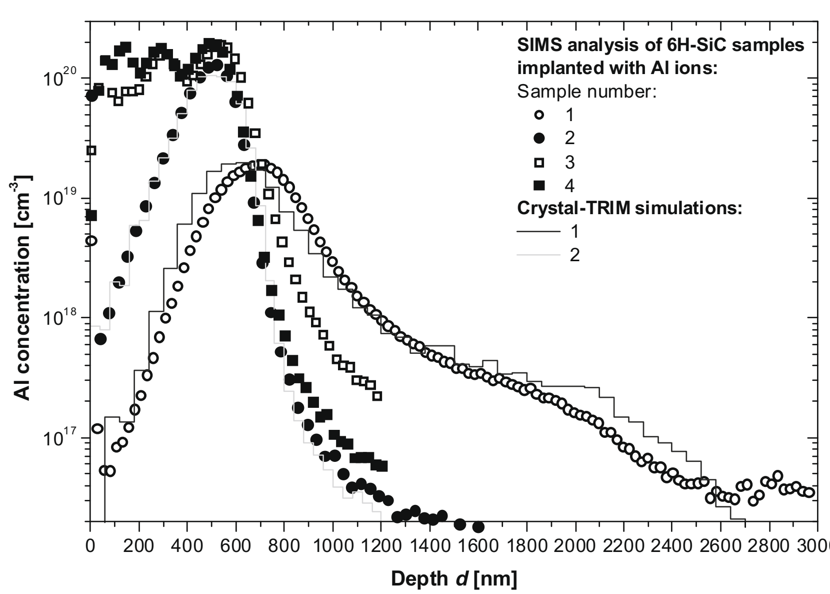

Fig. 1. Depth profiles of implanted Al atoms in 6*H*-SiC as determined by SIMS technique and compared with the results of crystal-TRIM computer simulations.