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Ion implantation-induced damage depth profile determination in SiC by means of RBS/C and bevelling technique

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Abstract

Ion implantation-induced damage depth profiles of 450 keV Al^+ ion-implanted 6H-SiC were studied using RBS/C technique for implantations along channeling direction and non-channeling direction with fluence of 3.4×10^{15} cm^{-2}. Bevelling method of sample preparation was used to get access to the deeper situated layers over the whole damaged region and below. To determine damage degree at the specific depth of the bevelled sample, RBS/C technique combined with a 3 MeV Li^{2+} ion beam of size of about 30 μm × 30 μm was utilized (micro-RBS/C). The micro-RBS/C method combined with the bevelling technique gave us a possibility to probe deeper reaching damage regions than in the case of conventional RBS/C investigations. It also utilizes a near-surface part of backscattered spectra, which is slightly influenced by damage created by probing ions and a random fraction of probing beam. Additionally, there is no need to perform energy calibration of detector for backscattered particles. Due to much smaller sample area hit by probing ions of micro-beam, the required fluence, comparable to that at conventional RBS/C measurements is obtained at much lower charge. Negligibly small effect of bevelling-induced mechanical damage has been observed in this study. The obtained results by micro-RBS/C method validate the results of computer simulations (Crystal-TRIM software).

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1. Introduction

Due to its excellent mechanical, thermal and electronic properties, crystalline silicon carbide has attracted a great attention lately as a material for integrated circuits and opto-electronic devices [1]. Dopant introduction into SiC is practically limited to ion implantation technique. Thermal diffusion doping is useless because of very low thermal diffusion coefficients of most impurities in crystalline silicon carbide and high thermal erosion of SiC surface.

One of the undesired effects of ion implantation is radiation damage, consisting of vacancies, interstitials and extended defects, incompletely recovered by post-implantation annealing [2]. Therefore it is necessary to know damage depth profiles of the implanted wafers, because even after annealing at elevated temperatures some residual lattice distortion can be observed [3,4]. One of the most frequently used methods of radiation defect investigations in

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semiconductors is Rutherford Backscattering Spectroscopy in combination with channeling effect (RBS/C), typically employing protons or alpha particles [5–7]. However SiC can be amorphized even with light ions – critical energy density for amorphization of crystalline SiC amounts to 23 eV/atom [8]. Fukarek et al. [9] observed the formation of defects and swelling of the 6H-SiC samples just due to RBS/C analysis for the doses of He^+ ions typically used to obtain RBS/C spectra of required statistics [5]. The probing ion beam (usually He^+ ions of a few MeV energy) penetrates the whole implanted and damaged layer, significantly influencing the investigated volume of the sample. The best way to get real information about radiation damage at a specific depth of the sample is to get rid of the signal from the upper lying layers in the channeling spectra and to suppress the influence of swelling of the target on the registered signal by a layer removal technique. Bevelling is the most useful method, based on mechanical polishing, which allows us to probe deeper reaching regions of the implanted layers [10].

The first attempt to quantitatively determine defects concentration was made by Bøgh [11] in the framework of the two-beam approximation model (TBA). The yield $\chi_D(x)$ of the probing beam traversing crystal with disorder can be written as follows [12]:

$$\chi_D(x) = \chi_R(x) + [1 - \chi_R(x)]\frac{fN_d(x)}{N}, \tag{1}$$

where $\chi_R(x)$ is the dechanneled part of the beam, i.e. random fraction of the total ion beam, $1 - \chi_R(x)$ represents the channeled part of the beam, f is the defect scattering factor, $N_d(x)$ and N are the defect and atomic densities of the material, respectively. The above two components of the beam represent: an integral of the total number of damage from the surface up to the depth x and a differential measure of damage at the depth x, respectively [12]. The experimental RBS/C spectrum is a superposition of the integral and differential part of disorder, so that there is no direct connection between the height of the spectrum and damage concentration. A proper separation of the two components needs special iterative procedures [12,13]. For heavily damaged crystals, even completely amorphized, the values of the $\chi_R(x)$ are at the level of $\chi_V(x)$ (the aligned yield from virgin crystal) at the depth close to the surface [12,13], what makes the calculation easier.

The scattering factor f takes into consideration the contribution of different kinds of defects to direct scattering. For dislocation loops $f \approx 0$, but for point defects (randomly displaced atoms) $f = 1$. The calculation model of defects distribution requires to recognize the nature of the disorder (point or extended defects), which involves another methods (e.g. TEM or XTEM technique) to study defects morphology.

Dechanneled fraction $\chi_R(x)$ of the beam is usually approximated by the formula [14]:

$$\chi_R(x) = \chi_V(x) + [1 - \chi_V(x)]P(x, \widetilde{\Theta}_C), \tag{2}$$

where $P(x, \widetilde{\Theta}_C)$ is the probability that a channeled particle becomes dechanneled due to scattering by defects at the angle $\widetilde{\Theta}_C$. In the case of analysis of sub-surface and damaged layers the traversed path x is very short and the above probability almost equals to zero. That is why in this case, the random fraction $\chi_R(x)$ may be approximated by the value $\chi_V(x)$ at the surface, which is simply determined in the RBS/C experiment.

Combination of bevelling and micro-beam techniques (micro-RBS/C), affords post-implantation investigations in a large depth region of the target. First of all, it allows utilizing the mentioned above approximations to determine damage concentration depth profiles without complicated iterative procedure. Up to now, no reports have been found on such depth profiling experiments concerning ion-implantation induced damage in SiC.

2. Experiment

N-type 6H-SiC Lely platelets from SiCrystal [15] were Al^+ ion implanted with the FZR-Rossendorf ion implanters system [16] at room temperature with fluence $D = 3.4 \times 10^{15}\ cm^{-2}$, energy $E = 450$ keV (Table 1) to get concentrations of Al atoms which are utilized to produce low-resistivity layers based on this material [3]. The directions of the implantations were: [0001] *c*-axis (channeling direction) for the sample no. 1 and 10° tilt from [0001] with 10° rotation around [−1100] for sample no. 2 ("random" direction, i.e. the target is seen by impinging ions as amorphous-like structure, without channels). Before the implantations, a standard procedure of sample orientation was performed (similar to RBS/C alignment) in the implantation chamber using 600 keV He^{2+} ions, focused to 1 mm diameter beam 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. The mentioned above fluence and

Table 1
Parameters of the investigated 6H-SiC samples

Al^+ ion implantations into 6H-SiC	Sample number (direction of implantation)	Post-implantation treatment	Bevel angle α [deg] ±10%	Scanning length l (Fig. 3) [μm] ±0.2 μm
$E = 450$ keV	1 (parallel to **c**)	Non-annealed	0.234	873
$D = 3.4 \times 10^{15}\ cm^{-2}$	2 ("random")	Non-annealed	0.263	798
	1 (parallel to **c**)	Annealed	0.305	684
	2 ("random")	Annealed	0.171	976