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Defects in hydrogen implanted SiC

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ABSTRACT

SiC is a widely used wide-bandgap semiconductor. Ion implantation is often employed in SiC for doping, defect engineering and transferring of SiC thin films on different substrates. To transfer SiC or to get freestanding thin SiC films by "smart-cut" [Appl. Phys. Lett. 112 (2018) 192102], a large fluence of hydrogen (proton) ion implantation will be applied. Here, we show the structure and defect properties in 6H-SiC single crystals after hydrogen implantation up to a fluence of $5 \times 10^{16}\,cm^{-2}$ at different energies of ions. We present the characterization by Rutherford Backscattering/Channeling spectrometry, Raman spectroscopy and electron spin resonance. Upon H^+ ion implantation, point defects are mainly created and cause the lattice vibration softening. Our analysis also suggests that H^+ ion implantation induces less lattice disorder than heavy ions at fluences producing the same number of displacements per atom. We also discuss the possible nature of the point defects and their influence on the electrical properties.

1. Introduction

Silicon carbide (SiC) is a wide band-gap semiconductor (6H-SiC with Eg of 3.05 eV) with unique mechanical, electrical, and thermal properties, which make the material suitable for many demanding applications in extreme conditions, such as high temperature, high power, high frequency and high radiation exposure [1]. Up to date, SiC is already commercially available at large scale and with high quality at the microelectronic grade. In addition to the bulk wafers, there is a growing demand for devices made from a thin layer of SiC on a substrate to enable lower-cost applications [2–4]. Recently, the ion-slicing technique by using hydrogen (H^+) ion implantation with a high fluence and post-annealing processes was used to transfer thin SiC films on different substrates [5–8] or free standing thin films [4]. The implanted hydrogen form a buried layer of microcavities at the H^+ ion penetration depth. Being annealed at high temperatures (generally above 600 °C), the wafer splits along this buried H-microcavity layer, leaving a thin single-crystal SiC film bonded to the substrate, the same as for Si [9]. The thin SiC films can be used as the active device layer in many applications [2,3]. Therefore, it is crucial to investigate the H implantation induced effects in the SiC layer. The surface morphology [10] and the lattice vibration [11] of SiC after H^+ implantation have been investigated by scanning microscopy and Raman scattering, respectively. Barcz et al. have studied the influence on the diffusion and impurity segregation in SiC after H^+ implantation [12]. In this paper, we present a systematic structural investigation on the H implanted SiC at high fluences. The structural analysis lays out the evolution of structure change caused by implantation damage. For H^+ implantation, point defects are found to be the dominated defects, which cause the lattice vibration softening. The analysis also suggests that H^+ implantation induces less lattice disorder than heavy ion implantation at fluences producing the same number of displacements per atom (*dpa*).

2. Experimental

Semi-insulating one-side polished 6H–SiC (0 0 0 1) single crystals from the KMT Corporation (Hefei, China) have been implanted with H ions at an energy of 30 keV and 100 keV. The samples are identified as H30 and H100, respectively. The implanted fluence for both energies is $5 \times 10^{16}\,cm^{-2}$. The distributions of radiation damage and implanted H atoms have been estimated from Monte Carlo calculations using SRIM2003 [13] with a density of 3.21 g/cm^3 and displacement energy of 21 eV for C and 35 eV for Si [14], respectively. The option "Detailed Calculation with full Damage Cascades" was selected for the calculation. The implantation induced lattice damage was characterized by micro-Raman spectroscopy (Horiba-LabRAM) at room temperature. The

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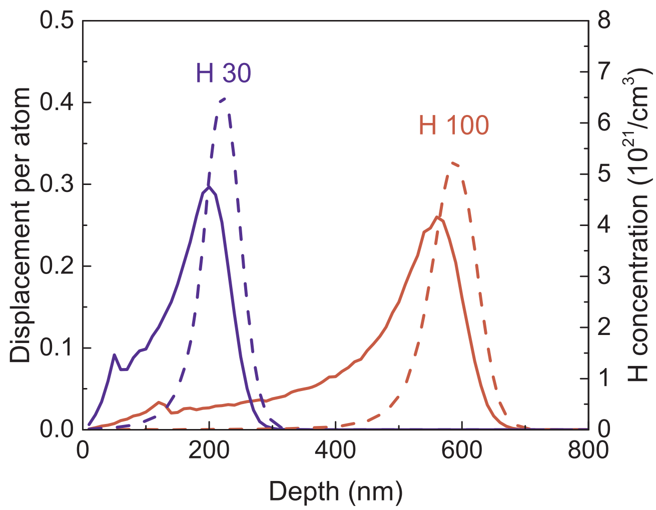

Fig. 1. SRIM simulation of displacements per atom (dpa, solid lines) and H concentration (dashed lines) in SiC for 30 keV and 100 keV H ion implantation for the fluence of 5×10^{16} cm^{-2}. The H implantation results in a similar peak damage concentration at different depths.

Raman scattering was excited using a linearly polarized continuous 532 nm Nd:YAG laser with a liquid-nitrogen cooled CCD. The electron spin resonance (ESR) was measured at 9.46 GHz by a Bruker ESR spectrometer. The Rutherford Backscattering/Channeling spectra (RBS/C spectra) were obtained on the high precision (~0.01°) three-axis goniometer in the vacuum chamber with precise controlled orientation of the sample surface relative to the collimated 1.7 MeV He$^+$ ion beam. An Au-Si surface barrier detector was placed at the backscattering angle of 170°.

3. Results and discussion

3.1. SRIM simulation

Fig. 1 shows the depth profile of radiation damage and H distribution for both samples. Ion implantation in covalent semiconductors is accompanied by the formation of intrinsic point defects due to elastic collisions between ions and lattice atoms. For high ion energies the energy loss is almost entirely to electrons in the target, while in the low-energy regime atomic collisions with vacancy cascade formation dominate. Therefore, the density of point defects in the region near the end of the ion range is thus much higher than in the rest of the ion track. As expected, H ion implantation at different energies results in a similar *dpa* at different depths. The *dpa* is calculated as: *dpa* = implantation fluence × displacements per ion and unit depth/atomic density, where the displacements were calculated by SRIM code [13]. The H distribution is also shown for comparison, which displays a slightly deeper distribution than the lattice damage. Note that the SRIM code does not take into account recombination of the primary interstitials and vacancies and thus the actual damage levels in the sample can be lower than the simulated values. The depth profiles of damage verified by RBS/C are shown below.

3.2. RBS/channeling

As a powerful tool for characterizing implantation induced damage in crystalline materials. RBS/C is used to quantitatively determine the ion-implantation-induced atomic disorder of Si sublattice in 6H-SiC. The RBS/C spectra along SiC [0 0 0 1] are shown in Fig. 2 for the virgin SiC and for the H ion implanted samples. A random spectrum is also shown for comparison, which was obtained by accumulation spectra during tilting the crystal by −4° to 4° in two directions with respect to

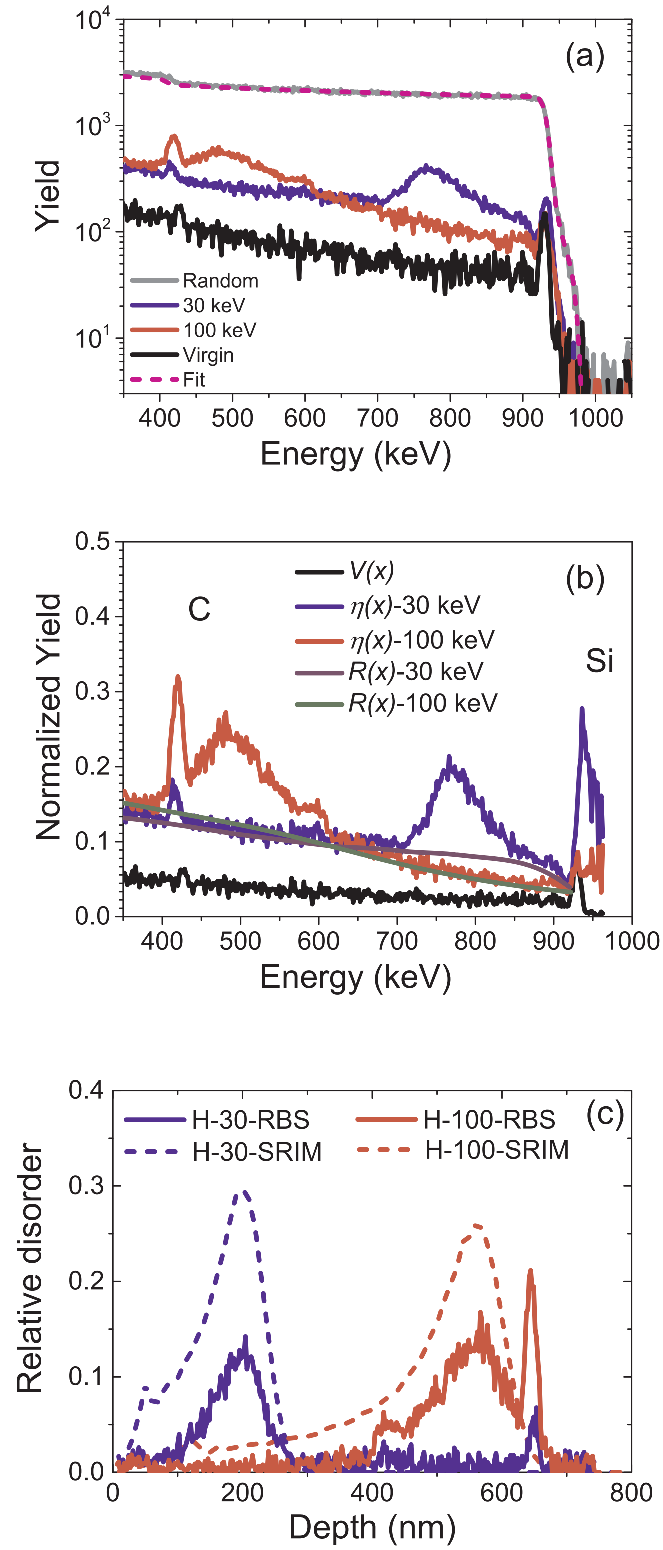

Fig. 2. (a) A sequence of 1.7 MeV He RBS/C spectra of a 6H-SiC single crystal implanted with H ions at 30 and 100 keV at room temperature. A random spectrum and a channeling spectrum from a virgin sample are also included for comparison. A curve fit of the random spectrum is shown by the short dash line. Backscattered He ions from the sample surface are marked for the Si and C sublattices, respectively. (b) The normalized virgin spectrum, V(x), the normalized channeling spectra, η(x) and the dechanneling function, R(x), is determined from the iterative procedure. (c) The depth profiles for the relative disorder of the Si sublattice along the [0001] direction obtained from the channeling RBS spectra.