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Interaction between hydrogen isotopes and damaged structures produced by He^+ implantation in SiC

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Abstract

To understand the interaction mechanism between implanted hydrogen isotopes and damaged structures in SiC, helium (He^+) ions were pre-implanted into SiC and thereafter implanted by $D_2{}^+$ ions. The chemical behavior of Si and C, and deuterium retention were evaluated by X-ray photoelectron spectroscopy (XPS) and thermal desorption spectroscopy (TDS). It was found that the decreasing rate of retention of D bound to Si was higher than that bound to C by He^+ pre-implantation, indicating that He^+ mainly interacts with the D trapping site with Si, namely carbon vacancies, and the displacement of C atoms would occur. Some He remained in the carbon vacancies and desorbed by heating. Some displaced C would migrate to the surface and aggregate on the surface by heating above 1300 K, although most of Si–C bond was recovered.

Keywords: Silicon carbide; Hydrogen isotope; Helium pre-implantation; XPS; TDS

1. Introduction

Silicon carbide (SiC) is a candidate material for fusion reactor plasma facing and structural components due to its low induced activation, good thermal conductivity, low parasitic neutron absorption, and so on [1–9]. In our previous study, hydrogen isotope trapping and detrapping mechanisms were studied [10]. It was found that the deuterium (D) desorption consisted of two stages, namely the desorption of D bound to Si at low temperature, and D bound to C at high temperature. The hydrogen isotope exchange behavior, and the retention and re-emission behaviors in SiC have been also reported [11,12]. The detrapping cross-sections of pre-implanted H and D by the $D_2{}^+$ and $H_2{}^+$ bombardments have been determined to be $3.2 \pm 0.3 \times 10^{-22}$ m^2/D$^+$ and $2.6 \pm 0.2 \times 10^{-22}$ m^2/H$^+$, respectively. The apparent rate constant of the molecular recombination reac-

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tion was determined to be 7.3×10^{-5}. The saturation concentration of D in SiC was also evaluated by the elastic recoil detection technique to be approximately 0.75 D/SiC.

Although some reports about the helium and/or neutron irradiation effects on the microstructure of SiC, and the evaluation of hydrogen retention in SiC, are also found in the literature [3–6,13–15], these works are not sufficient to elucidate the detailed mechanism for hydrogen isotopes trapping and detrapping because hydrogen isotope retention characteristics are influenced not only by the interaction with implanted hydrogen isotopes but also by the damaged structures. In the present study, damaged structures were introduced in SiC by He^+ pre-implantation and then the hydrogen isotopes retention properties and chemical behavior such as change of binding energy were investigated and compared to those results obtained for D_2^+ implantation only.

2. Experimental procedure

A polycrystalline silicon carbide wafer, named ROICERAM-HS (3C–SiC) (density: 3.1 g/cm^3) produced by the plasma CVD method purchased from Asahi Glass Co. Ltd. (Tokyo, Japan) was used as the sample. The sample disk size was Ø $10 \times 0.5\,mm^3$. Annealing prior to implantation at 1300 K was carried out in an ultra-high vacuum chamber for 10 min to remove any residual hydrogen and impurities in/on the SiC sample. After annealing, the sample was cooled to room temperature and the XPS (ESCA1600 system, ULVAC-PHI Inc., Chigasaki, Japan) measurement with a resolution of 0.1 eV using Mg Kα X-ray source (1253.6 eV) was performed to evaluate the chemical states of Si and C, and the existence of impurities [10]. It was found that there were no impurities on the surface of the SiC sample. 1.3 keV helium (He^+) ions were implanted into SiC by an ion flux of $1.3 \times 10^{18}\,He^+\,m^{-2}\,s^{-1}$ as estimated by a Faraday cup, to an ion fluence between 1.0×10^{20} and $1.0 \times 10^{22}\,He^+\,m^{-2}$ at room temperature. The chemical states of Si and C were also studied by XPS during He^+ implantation and isochronal annealing experiments. 1.0 keV deuterium (D_2^+) ions were implanted into the He^+ pre-implanted SiC at an ion flux of $1.3 \times 10^{18}\,D^+\,m^{-2}\,s^{-1}$ to an ion fluence of $1.0 \times 10^{22}\,D^+\,m^{-2}$ at room temperature. The range of D_2^+ implantation was almost the same as that of vacancies introduced by the He^+ pre-implantation estimated by TRIM code.

After He^+ pre-implantation and D_2^+ implantation, the TDS experiment was performed at the heating rate of $0.5\,K\,s^{-1}$ to a maximum temperature of 1300 K. A high resolution mass spectrometer (Microvision Plus 1-6 D, MKS Japan Inc., Tokyo, Japan) was used to discriminate between D_2 ($m/e = 4.028$) and He ($m/e = 4.003$) [16].

3. Results

Fig. 1(a) summarizes the XPS C 1s and Si 2p peak positions of as a function of He^+ fluence. The peak shifts after D_2^+ implantation are also shown in Fig. 1(b) for comparison. It was found that the peak position of Si

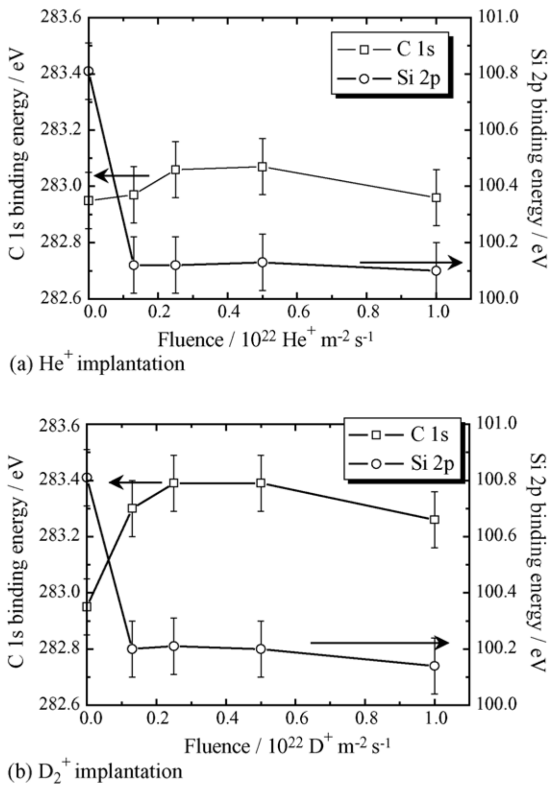

Fig. 1. XPS peak positions of C 1s and Si 2p for (a) He^+-implanted SiC and (b) D_2^+-implanted SiC as a function of ion fluence.