Trapping of Deuterons Implanted into SiC and TiC Crystals

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Hydrogen isotopes implanted into the first walls of fusion plasma devices affect both the material involved and the plasma itself through hydrogen recycling. Current problems are understanding of hydrogen trapping and recycling at first wall surfaces, and minimization of contamination of the plasma from impurities emitted from surfaces, such as limiters. Because the potentially large radiation losses, caused by the contamination of plasma, strongly depend on the atomic number, low-Z refractory materials with good thermal shock resistance are desirable for limiters or other first wall elements. Because of the above requirements, carbon-containing compounds are receiving much attention as candidates for the first wall materials.

In the present work, the retention properties of D implanted into SiC and TiC single crystals are studied as function of annealing temperature by means of the elastic recoil detection (ERD) analysis technique with 2.8 MeV ^{4}He ions. These studies are important for tritium inventory considerations in the tokamak fusion environment.

a) SiC Crystal

The samples used were α-SiC single crystals. Deuterons of 10 keV energy from the electron isotope separator[1)] of Cyclotron and Radioisotope Center were implanted into SiC crystals with a fluence of $2\times10^{16}/cm^2$ at room temperature, and the depth profiles of implanted deuterons were studied by means of ERD analysis technique with a 2.8 MeV ^{4}He beam. The deuteron depth distribution obtained by the ERD analysis is shown in Fig. 1 in comparison with a range profile calculated by the TRIM Monte Carlo particle transport code.[2)] The simulated range profile agrees well with the measurement, if the experimental resolution is taken into account. The result indicates that the diffusion rate of the implanted deuterons is very low.

In order to examine the correlation between the retained deuteron distribution and the damage distribution created during the implantation, a channeling experiment with a 1.5 MeV $^4He^+$ beam was performed on the same crystal. Fig. 2 shows the distribution of displaced Si atoms determined by axial channeling along the [0001] direction together with a damage distribution simulated by TRIM code. The damage distribution has a tail to the surface and is limited to more shallow depth in comparison with the range profile shown in Fig. 1. It is worthwhile to note that the total number of displaced Si atoms, $4\times10^{17}/cm^2$, which is estimated from integration of the obtained curve, is twenty times larger than the number of implanted deuterons. This shows that SiC is very accessible to introduction of radiation-induced damage.

In order to measure the temperature at which the deuterium implanted with 10 keV is released from SiC, the samples were annealed isochronically for 10 min with increasing temperatures up to 1200°C. The D distributions near surface were measured by the ERD analysis at room temperature between each annealing period. Up to 700°C annealing, all the deuterium atoms implanted are retained; no change is detected in the ERD spectra. Above 700°C, the D distribution curves diminish gradually with increasing annealing temperature, as shown in Fig. 3.

The D retention is plotted as a function of annealing temperature in Fig. 4. The result indicates that the deuterium atoms are completely released at 1200°C. Assuming first-order kinetics for the release process3), the binding energy of D trapped in SiC is estimated to be 4.0±0.2 eV from the temperature dependence of the D concentration. The dissociation energy of the H-C bond (3.5 eV)4) and the H-Si bond (3.2 eV)5) are close to this value. It seems reasonable, therefore, that the deuterium atoms are trapped in SiC by forming covalent bonds with C and Si, and are released by bond-breaking. In the implanted SiC, the dangling bonds are probably created by the ion bombardment and behave as strong traps for deuterium.

Channeling experiments were also carried out on crystals annealed at 1200 C at which D was released almost completely. The results show that an appreciable amount of defects still remain in the crystal, indicating the independence between the D release process and the defect annihilation.

b) TiC Crystal

Depth profiles for 15 keV and 44 keV deuterons implanted into the $TiC_{0.96}$ samples at room temperature were examined by ERD analysis technique. In the case of $TiC_{0.96}$, it is found that a considerable amount of deuterium is lost from the near surface region before the measurement because of the fast diffusion rate. On the other hand, deuterons implanted into predamaged TiC are retained near its projected range; the deuterons are trapped by defects induced by prebombardment with C^+ beam of 350 keV energy.

Deuterons trapped by the radiation-induced defects are not released by aging at room temperature. In order to evaluate the binding energy of deuterium with defects in TiC, the D retention in predamaged TiC is measured after isochronal annealing for 10 min at temperatures from 30° to 800°C by the ERD analysis with 2.8 MeV ^4He. The deuterium content decreases dramatically at about 600°C, and deuterons are released completely at 800°C, as seen in Fig. 5.

From the temperature dependence of the fraction of D retained shown in Fig. 5, the binding energy was evaluated as 2.8±0.5 eV. The result of Fig. 5

cannot be fitted by a single binding energy but the averaged value is within the deviation ±0.5 eV.

References

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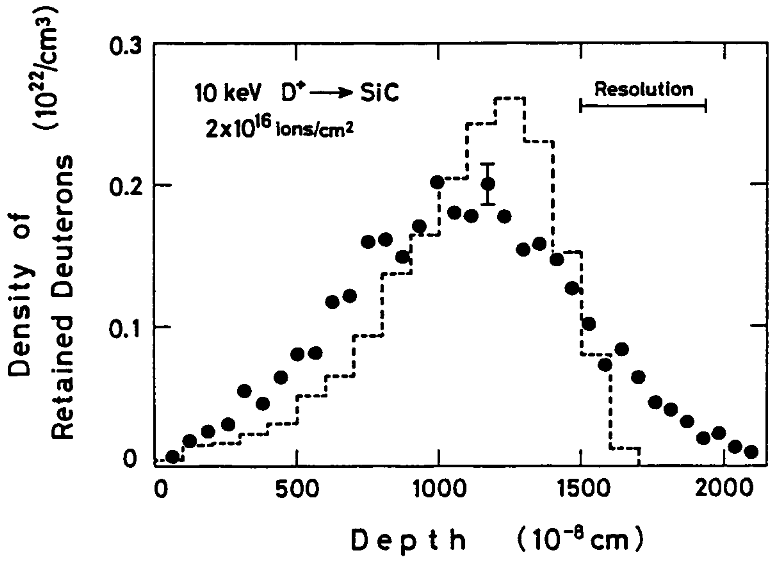

Fig. 1. Depth profile for 10 keV D^+ implanted into SiC crystal obtained by the ERD analysis. Dotted lines indicate a range profile simulated by TRIM code.

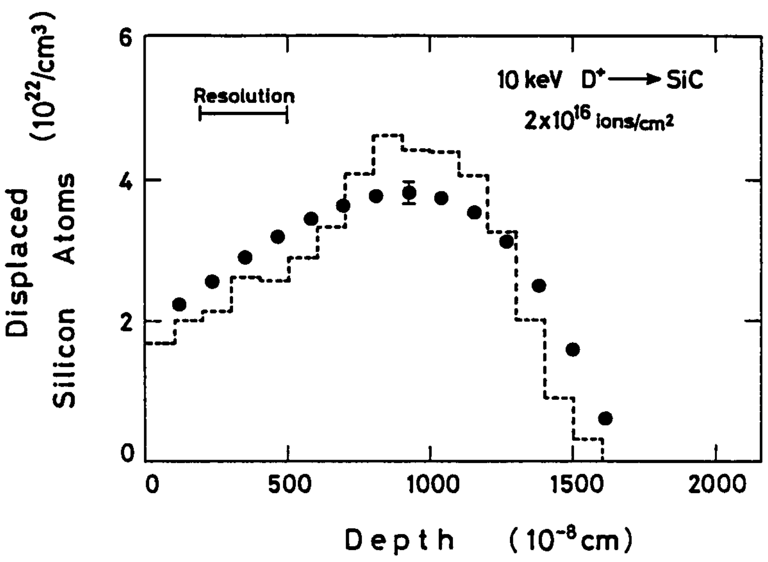

Fig. 2. Silicon damage profile for the crystal as shown in Fig. 1 obtained from channeling of 1.5 MeV $^4He^+$. Dotted lines indicate a displaced Si atom distribution simulated by the TRIM code.

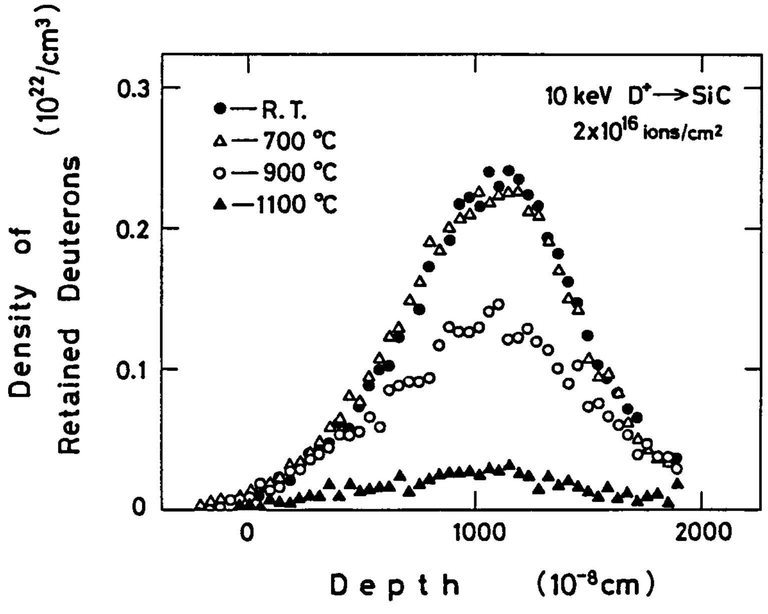

Fig. 3. Change of deuterium depth profile for D^+ implanted into SiC with isochronal annealing for 10 min at 700, 900 and 1100°C.

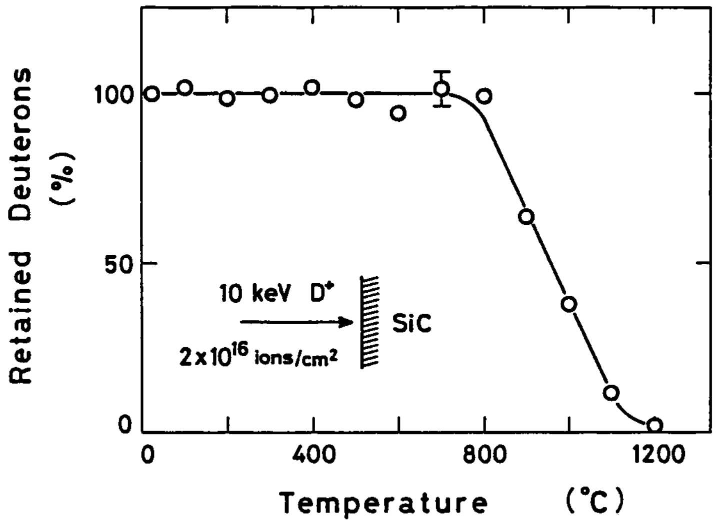

Fig. 4. D retention plotted as a function of annealing temperature.

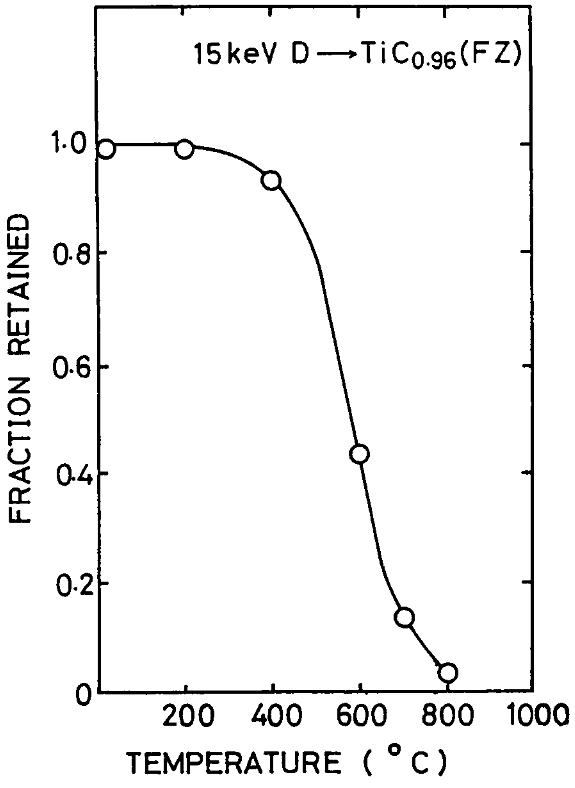

Fig. 5. Retained D fraction versus annealing temperature for damaged $TiC_{0.96}$ implanted with 15 keV D of $2\times10^{16}/cm^2$.