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Chemical behavior of energetic deuterium implanted into tungsten carbide

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Abstract

The chemical behavior of energetic deuterium implanted into tungsten carbide (WC) samples has been investigated by XPS and TDS. The TDS experiments showed that almost of all deuterium retained in WC was desorbed in the temperature region from 300 to 700 K and the residue at around 1000 K. The deuterium (D_2) desorption peak at around 1000 K was found to originate from the desorption of deuterium atom (D) trapped by carbon (C). Its retention was considerably small and was saturated at low deuterium ion (D_2^+) fluence. The area of the large D_2 desorption peaks, which corresponds to the D retention in WC, increased as D_2^+ fluence increased. The D_2 desorption in the temperature range of 300–700 K takes place in three stages, the lower two peaks were attributed to the desorption of D retained in two interstitial sites, and the highest peak corresponds to D trapped by carbon vacancies induced by chemical sputtering of C by energetic D_2^+.

From these experimental results, the D trapping and detrapping behaviors are discussed and it is concluded that the hydrogen isotope retention is governed by the amount of interstitial sites and carbon vacancies in WC. The hydrogen isotope retention could be lowered if the surface temperature of WC were above 700 K.

Keywords: Tungsten carbide; Plasma facing materials; Thermal desorption; Tritium retention

1. Introduction

According to requirements and selection criteria for plasma facing materials in the ITER design, carbon fiber composite and tungsten (W) have been selected as the divertor armor [1]. The re-deposition of sputtered substances modifies the surface layers of the materials into metal carbides under plasma irradiation at high temperature during long-term discharges. Previous calculations have indicated that a tungsten carbide (WC) layer could be formed during the bombardment of tungsten by carbon impurity ions [2]. Therefore, hydrogen

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isotope behavior should be studied not only in pure materials, such as C and W, but also WC as well.

Elucidation of hydrogen isotopes trapping and substantial thermal release from wall materials are one of key issues for determination of tritium inventory in the first wall and divertor of fusion reactors from a viewpoint of tritium safety. In the present study, to understand tritium behavior in WC, we have studied thermal desorption processes of energetic deuterium ion (D_2^+) implanted into WC, and electronic structure of WC by means of thermal desorption spectroscopy (TDS) and X-ray photoelectron spectroscopy (XPS), respectively.

2. Experiment description

Samples used in this study were polycrystalline WC provided by Allied Material Corp (Tokyo, Japan). The size of the sample was 10 mm × 10 mm × 0.5 mm and the density was 14.86 g/cm^3, which very close to that of a single crystal WC. The sample was mounted for D_2^+ implantation and analyses on a sample holder equipped with a ceramic heater. Details of the experimental set-up can be found in Ref. [3].

In order to remove residual gases, such as H_2, H_2O, O_2 and so forth, the sample was preheated at 1373 K for 10 min before D_2^+ implantation. The sample was characterized by means of X-ray diffraction (XRD) and XPS techniques. The XRD pattern of the WC sample after preheating was displayed in Fig. 1. No peaks corresponding to W, W_xC (except $x = 1$) or WO_y were detected, indicating the phase purity of the WC sample, consistent with previous reports [4–6]. It was also found that the atomic composition ratio of W and C measured by XPS was almost unity.

One kiloelectronvolt of D_2^+ ions were implanted into the WC sample with a fluence up to 1.0×10^{22} D$^+$ m^{-2} at 323 K and a flux of 1.0×10^{18} D$^+$ m^{-2} s^{-1}. To investigate the thermal desorption behavior of D_2^+ implanted into WC, TDS experiments were carried out after the implantation. The sample was heated up to 1373 K at a heating rate of 0.5 K s^{-1}. Desorbed gases were analyzed with a quadrupole mass spectrometer. A Highly Oriented Pyrolytic Graphite (HOPG: purchased from Pechiney Co.) sample was also investigated as a reference sample. As a pretreatment, the HOPG sample was heated up to ~1400 K for 10 min to remove residual gases. The experiential conditions were the same as those for WC. The XPS measurements were also performed after D_2^+ implantation.

3. Results and discussion

Fig. 2 shows the TDS spectrum of desorbed D_2 from WC after D_2^+ implantation with the ion fluence of 2.5×10^{21} D$^+$ m^{-2}. It was found that D_2 was desorbed in the temperature range of 300–700 and 900–1100 K. The TDS spectra at the lower temperature range con-

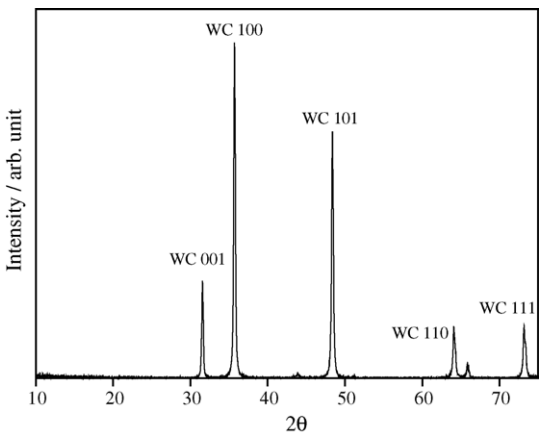

Fig. 1. XRD pattern of WC after heating treatment at 1373 K.

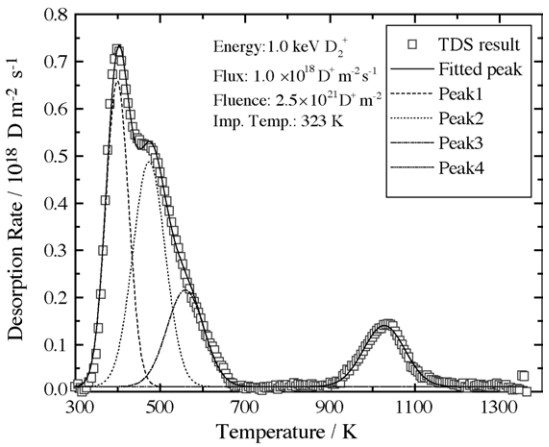

Fig. 2. TDS spectra of D_2 for D_2^+ implanted WC with fitted peaks.