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ScienceDirect
Nuclear Instruments and Methods in Physics Research B 256 (2007) 669–674
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Effect of Al and Be ions pre-implantation on formation and growth of helium bubbles in SiC/SiC composites

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Received 13 July 2006; received in revised form 5 December 2006
Available online 18 January 2007

Abstract

The effect of Al and Be ions pre-implantation on microstructural change and, the formation and growth of He bubbles in SiC/SiC composite was investigated. Four kinds of ion implanted specimens were prepared with 100 appm Al, 1000 appm Al, 100 appm Be and 1000 appm Be implanted. No microstructural change was observed in the matrices and fibers of SiC/SiC composites implanted with Al or Be ions up to 1000 appm. The un-implanted and Al or Be pre-implanted SiC/SiC composites were simultaneously irradiated to 10 dpa using triple ion-beams (6.0-MeV Si^{2+}, 1.0-MeV He^{+} and 340-keV H^{+}) at 1000 °C. Helium bubbles were formed in every matrix and fiber irradiated by triple ion-beams. The size of He bubbles in the matrix was increased by implanting Al or Be ions and increased with increasing amount of implanted Al or Be ions. The size of He bubbles in the fiber was slightly increased by implanting Al or Be ions. These results suggest that Al or Be as transmutation products and impurities may accelerate the growth of He bubbles in SiC/SiC composites under fusion reactor conditions.

PACS: 61.80.−x; 68.37.Lp; 61.66.Fn

Keywords: SiC/SiC composite; Ion irradiation; Microstructural change; He bubbles; TEM; Transmutation product

1. Introduction

Silicon carbide fiber reinforced silicon carbide matrix (SiC/SiC) composites are considered for use as functional and structural materials in first wall components in fusion reactors due to their high temperature strength and low-residual radioactivity following neutron irradiation [1–4]. In the fusion environment, helium (He) and hydrogen (H) are produced as transmutation products [3,5] and He bubbles can be formed in the SiC by irradiation with 14-MeV neutrons [6]. Present authors reported that He bubbles were formed in SiC/SiC composites at higher temperature than 800 °C and the effect of He and H on microstructural change were investigated by simultaneous ion-beams irradiation with Si, He and H ions to simulate the fusion reactor condition [7]. These He bubbles may reduce the tensile strength and thermal conductivity.

Furthermore, several elements are also produced by 14-MeV neutron irradiation as transmutation products: aluminum (Al), magnesium (Mg), beryllium (Be), etc. [3]. Recently, Tyranno SA SiC fiber, which is a highly crystalline and near-stoichiometric SiC fiber, has been developed and it includes a slight amount of Al as an impurity [8,9]. Wakai et al. reported that the formation and growth of He bubbles in ferritic/martensitic steel was suppressed by pre-implantation of carbon ions [10]. It is, therefore, important to understand the effect of transmutation products and impurities on microstructural change and, the formation and growth of He bubbles in SiC/SiC composites. However, the effect of transmutation products and

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doi:10.1016/j.nimb.2007.01.078

impurities except for He and H on the formation of He bubbles and other microstructural changes in SiC/SiC composites has not been thoroughly investigated. In this study, the effect of Al and Be ions pre-implantation on microstructural changes and, the formation and growth of He bubbles in SiC/SiC composite was investigated to simulate transmutation products and impurities under fusion reactor conditions.

2. Experimental procedure

2.1. Materials

The 2D plane-weave of Tyranno SA SiC fiber fabrics were used as reinforcement in this study. The SiC/SiC composites were fabricated using the forced thermal gradient chemical vapor infiltration (F-CVI) process at Oak Ridge National Laboratory. Details of the fabrication procedure are described elsewhere [11,12]. A carbon layer was deposited on the SiC fiber as an interphase layer between the matrix and the fiber. The matrix formed by this process consists of a highly pure β-SiC with defects such as stacking faults. Such composites typically have approximately 15% porosity. However, on the scale important for the microstructural studies presented here, the matrix can be considered fully dense and stoichiometric.

2.2. Irradiation

Simultaneous ion-beam irradiation was carried out at the TIARA (Takasaki Ion Accelerators for Advanced Radiation Application) facility of the Japan Atomic Energy Agency (JAEA). Aluminum (Al) or beryllium (Be) ions were pre-implanted uniformly from 1.2 to 1.7 μm into the SiC by changing the implantation energies; 1.6–2.8 MeV Al^{2+} or 0.8–1.2 MeV Be^{+} ions. The implantation temperature was 1000° C because the operation temperature of fusion reactors is designed to be the temperature range of 800–1000 °C. Two levels of ion implanted specimens were prepared: 100 appm and 1000 appm Al or Be, which were average ion concentrations of Al or Be ions in the depth range of 1.2–1.7 μm. The displacement damage and Al or Be concentration as a function of depth from the surface in SiC were calculated using the SRIM code [13] is shown in Fig. 1. The calculated number of ions by SRIM in this study was 1000. The displacement threshold energies of Si and C were assumed to be 35 and 20 eV, respectively [14]. Then the un-implanted, Al-implanted or Be-implanted specimens were simultaneously irradiated at 1000 °C with triple ion-beams of 6.0 MeV Si^{2+} ions, 1.0 MeV He^{+} ions and 340 keV H^{+} ions as a simulation of fusion reactor conditions [3,5]. The implantation of He^{+} and H^{+} ions was conducted using an Al foil energy degrader in order to control He and H distribution in the depth range of about 1.0–1.8 μm from the specimen surface [15]. The displacement damage and, He, H and Si concentrations calculated by the SRIM code are shown as a function of depth from

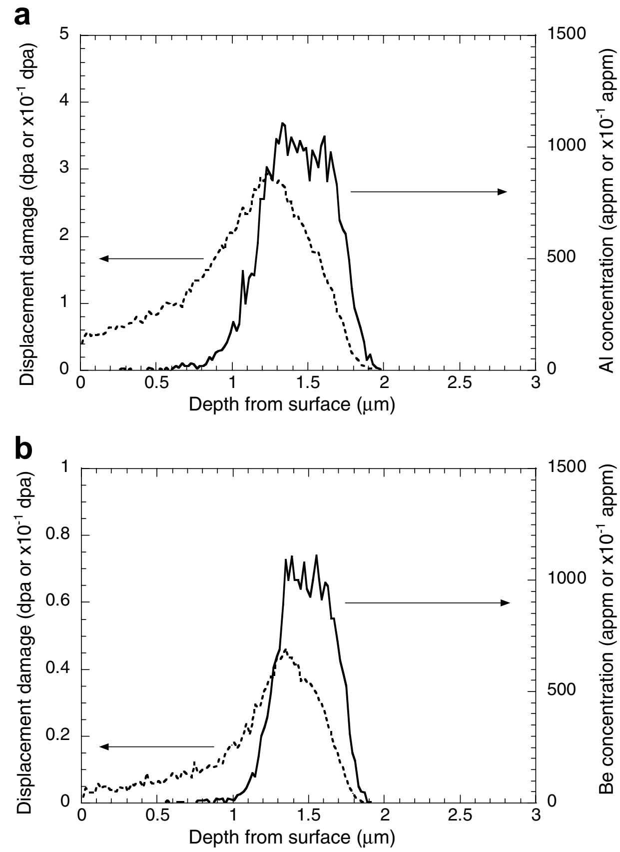

Fig. 1. Displacement damage, (a) Al concentration and (b) Be concentration as a function of depth from the surface in SiC calculated by the SRIM code.

the surface in SiC in Fig. 2. The irradiation was performed to 10 dpa for a depth of 1.4 μm as shown in Fig. 2. The resultant He/dpa and H/dpa ratio were 130 and 40 appm/dpa, which would correspond to ratios in a region of the first wall of a fusion power reactor [3,5]. In a fusion reactor, the Be/He and Al/He ratio are approximately 0.1 and 0.07, respectively [3]. The SiC/SiC composites in this study should be, therefore, implanted with approximately

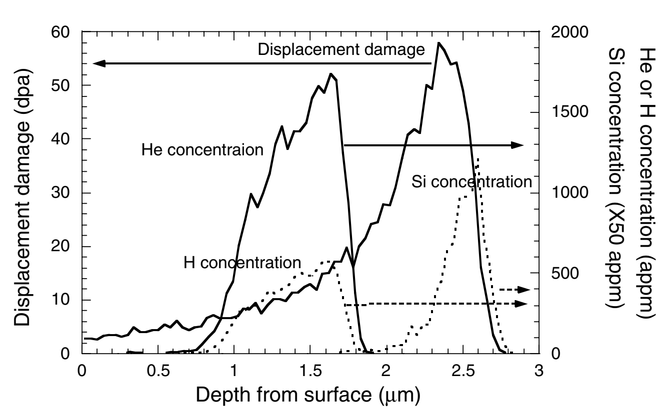

Fig. 2. Displacement damage, He, H and Si concentration as a function of depth from the surface in SiC calculated by the SRIM code.