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Distribution of Helium Bubbles in Al/B_4C MMC Irradiated with 400keV He^+ Ions

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Al/B_4C metal matrix composite (MMC) is an important neutron absorbing material used in both wet storage pools and dry storage casks of spent nuclear fuel for preventing criticality. Because of the high neutron absorption cross-section of ^{10}B, the material can effectively absorb fast and thermal neutrons, but at the same time suffers neutron irradiation damage from the nuclear spent fuel. Moreover, interactions of fast and thermal neutrons with boron lead to the production of several transmutation species such as helium, lithium and others, according to the transmutations reactions induced by neutron irradiation, including the ^{10}B (n, ^4He) ^7Li reaction and others[1]. The most abundant product of these reactions is energetic helium (~3.5MeV), which may induce further radiation damage and be precipitated out in the material as helium bubbles. The formation and distribution of the helium bubbles may affect the mechanical and chemical performance of the material in its working environment. In this experiment, helium implantation will be performed to analyze the effects of bubble formation as a result of neutron interactions with boron. Such bubble formation could have many effects in the material including reduced thermal conductivity and effects on neutron absorption behavior.

The bulk MMC sample was irradiated with 400keV He^+ to 1.5×10^{17} ions/cm^2 at room temperature. For study of depth dependent microstructure induced by the ion irradiation, TEM sample was prepared by FIB (Focus Ion Beam) lift-out method. TEM analysis and characterization were conducted with a JEOL HREM 3011 and a JEOL 2100F Scanning transmission electron microscope at the Electron Microbeam Analysis Laboratory (EMAL), University of Michigan.

B_4C particles are little difficult to be distinguished from Al grains by bright field TEM contrast, especially when the sample is thin. However, HAADF (High Angle Annular Dark Field) STEM image can clearly distinguish the two based on the huge difference in Z between the two phases (Fig.1). When helium ions are implanted in the material, ions stop in a limited range with a near Gaussian distribution. The results of SRIM (Stopping and Range of Ions in Matter) code simulation (Fig.2(a)) indicate that the peak ranges of implanted He and damage production are in different depths from the surface for Al and B_4C, respectively. Fig.2(b) exhibits a He bubble-band in the Al matrix. At a higher magnification, a bubble-band in boron carbide particle can also be observed as shown in Fig.2(c). Helium bubbles in Al are much larger and the largest ones usually appear along the Al grain boundaries and the interfaces between Al matrix and B_4C particle. In contrast, bubbles in B_4C are only about 1-2nm in diameter. Maruyama[2] indicated that precipitation of small helium bubbles having a network structure was only observed after a high ion fluence (1.16×10^{16} ions/cm^2) at high temperatures (irradiating or annealing above 760°C). It is considered that the room temperature is too low to form a network structure. However, in our study the concentration of He is high enough so that the helium bubble-band appears even after implantation at the room temperature. It is also interesting to note the partial amorphization of B_4C in this study, as indicated by white circles in the HREM image of Fig.2(d), and the amorphous hole in the diffraction pattern, as in Fig.2(e). The exact reason for the fine dispersion of He bubbles and the temperature dependence of bubbles in B_4C is under investigation[3].

Reference

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[2] Tadashi Maruyama et al, Effects of radiation on materials: 21st International Symposium, ASTM International, 2004.
[3] This work has been supported by the US DOE NEUP Program under the contract No. 00102642.

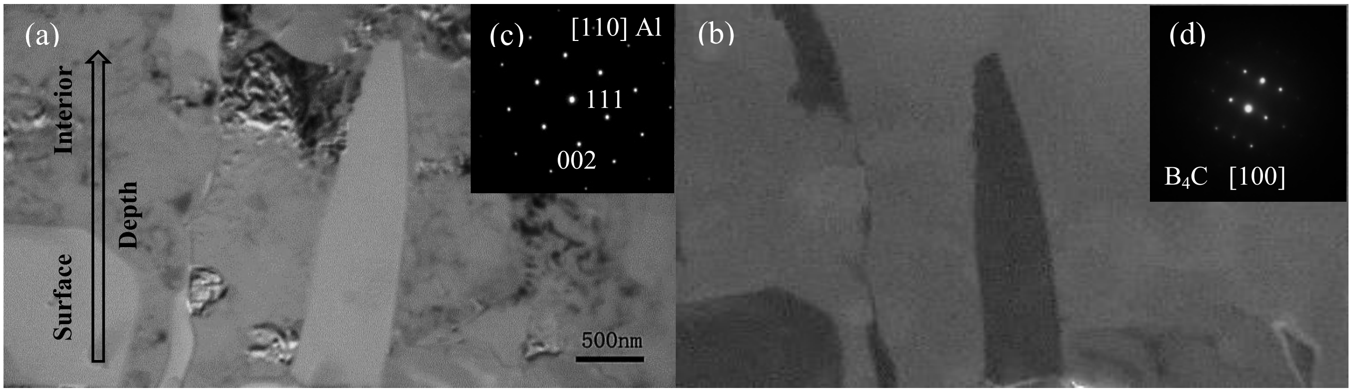

Figure 1: (a) BF image of a He ion irradiation area including boron carbide and aluminum grains; (b) HAADF STEM image of the irradiated area including boron carbide (black area) and aluminum (gray area).

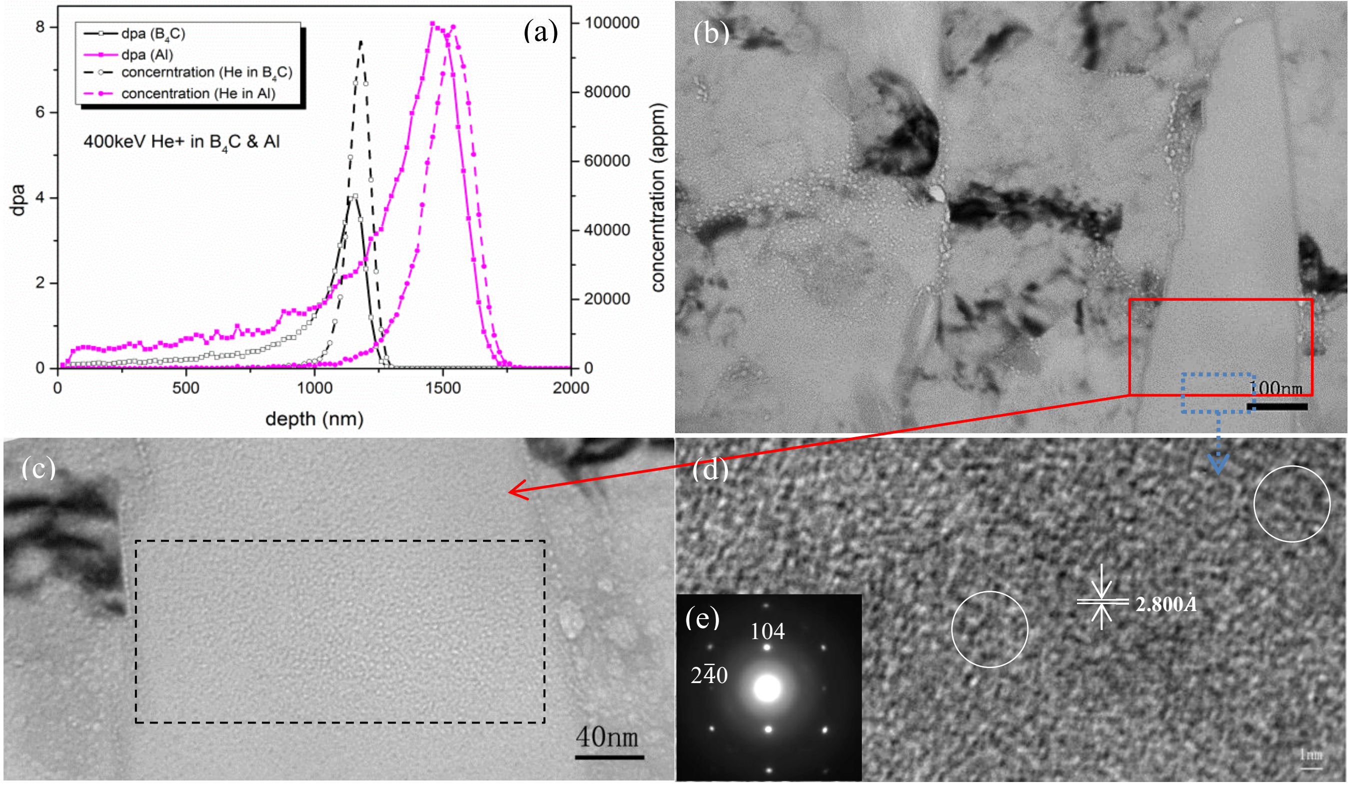

Figure 2: (a) SRIM result of damage production and He concentration profiles in Al and B_4C irradiated by 400keV He+; (b) BF image from an area in the peak He ion range with relatively larger He bubbles clearly visible in Al matrix and on grain and phase boundaries; (c) BF image of high magnification showing well dispersed much smaller He bubbles in B_4C; (d) and (e) HREM image and SAD pattern from an irradiated B_4C grain showing partial amorphization of the particle.