Depth Dependence of Radiation Hardening in 10 MeV 4He+-Ion Bombarded Molybdenum

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Materials for the first wall of fusion reactors are subjected to heavy irradiation damage caused by 14 MeV neutrons and high-energetic ions. In order to assess the surface deterioration of the materials such as blistering, mechanical properties near the surface, where implanted ions and irradiation-induced lattice defect coexist and interact, must be estimated.[1] This problem has not yet been investigated, because of difficulty in measuring mechanical properties of micro region. In this paper, depth profile of micro-hardness is determined directly in $^{4}He^{+}$-ion bombarded molybdenum to simulate the problem. Molybdenum is one of candidate materials for the first wall components of JAERI Experimental Fusion Reactor.[2]

Plate specimens with 0.5 mm thickness prepared from powder-metallurgy molybdenum (P/M Mo) were annealed in vacuum for 1 h at 1500°C and their interstitial impurities were 20 wt ppm carbon, 20 wt ppm nitrogen and 19 wt ppm oxygen. These specimens, which were set on the water-cooled copper holder in the vacuum chamber, were bombarded by 10 MeV $^{4}He^{+}$-ions in AVF Cyclotron of Tohoku University. Local irradiation condition on the specimen was determined precisely. Ion fluence distribution on the specimen surface was determined by monitoring beam profile by means of micro Faraday-cup array and by measuring induced-radioactivity distribution of Cu dummy pieces, where the nuclear reaction of $^{63}Cu(\alpha,n)^{66}Ga$ and 1.039 MeV γ from ^{66}Ga were used. Temperature profile of the surface was measured by means of InSb infrared radiometer with a scanning system. The average temperature was about 300°C. The beam current was chosen so that the specimen temperature did not much exceed so-called the stage III where vacancy migration is thermally activated. After irradiation, micro Knoop hardness was measured at room temperature along the direction from the surface on the cross-sectional area with a distance resolution of about 1 μm using a 2 gf weight. These techniques of local dosemetry and micro-indentation made it possible to estimate the depth- and fluence- dependence of irradiation hardening in relatively inhomogeneous beam profile.

Figure 1 shows the depth dependence of the Knoop hardness ratio of as-irradiated condition to unirradiated one for various fluences in P/M Mo. It is noticed that the depth profile of irradiation hardening is similar to the damage energy profile. Steeply hardened layer (peak) exists near the projected range (R_p = 28 μm), while relatively flat and low hardened region (plateau) is present between the layer and surface. Irradiation hardening disappears at depth beyond 30 μm.

The fluence dependence of peak and plateau hardness in depth profile is shown in Fig. 2. The peak value depends more strongly on fluence than the plateau does. The probable degree of damage under a given fluence is represented by the integrated number of times in which each component atom may be displaced from its lattice site (displacement per atom). In this case, the range of fluence from 10^{20} to 10^{22} ion/m^2 corresponds nearly to the range of dpa from 0.1 to 10 at peak depth and that from 0.01 to 1 at plateau depth. At the same dpa level the peak value is higher than that of the plateau. Therefore, not only dpa but also implanted He atom may contribute to irradiation hardening in the former. Both curves have a incubation dose of about 10^{20} ion/m^2. In order to determine the mechanism of observed hardening, the study of anealing behavior and microstructure is in progress.

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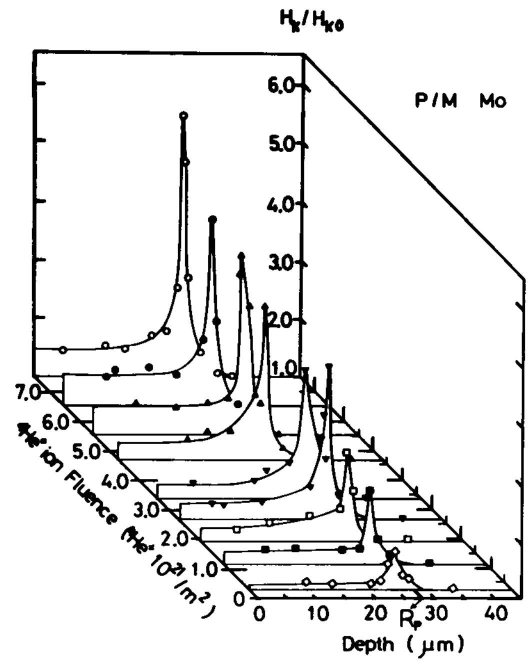

Fig. 1. Depth dependence of Knoop hardness ratio for various fluences in molybdenum.

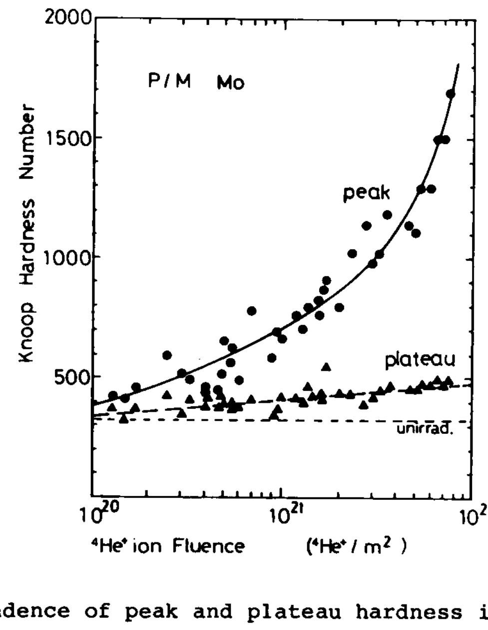

Fig. 2. Fluence dependence of peak and plateau hardness in molybdenum.