doi:10.1017/S1431927614011167

Microsc. Microanal. 20 (Suppl 3), 2014

Hardening of Copper Induced by High Energy Xenon Ion Bombardment

A. S. Khalil[1]

[1.] Metallurgy and Mining Department, Tabbin Institute for Metallurgical Studies, Cairo, Egypt.

High energy neutron irradiation facilities are limited world-wide especially of the 14 MeV neutrons which is the characteristic energy of fusion neutrons produced in fusion reactors. Thus heavy ion accelerators are used to irradiate metals providing a convenient method of simulating the energetic recoils created in collisions between these fast fusion neutrons and lattice atoms of metals. It is often found that the yield stress of metals and alloys increases significantly upon irradiation. This phenomenon is called radiation hardening and is attributed to defects formed by the displacement of lattice atoms as a result of ion irradiation [1].

In this work, the change in hardness of polycrystalline pure copper irradiated by energetic heavy ions was investigated. The interest in copper stems from the fact that it may serve as a model material in irradiated face centered cubic (FCC) alloys with their potential utilization in the future fusion reactors for power generation. The fusion reactors will be characterized by harder neutron spectrum relative to the current fission reactors and their adverse effects on materials.

Samples cut from cold-rolled 99.998 wt% pure copper sheet with main impurities of iron (0.0013 wt %) and nickel (0.0004 wt %) then annealed at 350 ^{o}C for one hour in vacuum. The irradiation was carried out at room temperature on the external beam of the U-400 cyclotron of the Joint Institute for Nuclear Research, Dubna, Russia. The 130 MeV Xe ions striking the samples have a flux of ~ 10^{11} ions.cm^{-2}s^{-1}. For post-irradiation investigation JEOL 100 CX TEM was used to observe the microstructure and Vickers microhardens tester (Model PMT-3M) was utilized for hardness measurements. We used 100 gf loads to ensure that the indentation impressions depths of 6 μm lay completely within the damaged region which extends to ~ 8 μm from the surface [2], the errors in measurements were ± 5%.

The values of the change in Vickers hardness, ΔH_v defined as the value of measured hardness of un-irradiated sample subtracted from that of irradiated sample were plotted as a function of the ion fluence as shown in figure 1a. An increase of ΔH_v with increasing ion fluence indicates a hardening effect. For a better comparison, these data were re-plotted in figure. 1b as a function of Displacement per Atom (dpa) values (defined as the calculated number of times that an atom is displaced from its lattice equilibrium position for a given fluence) [2, 3] including that of 14 MeV neutron irradiation measured within the same dpa range in pure Cu (up to ~ 0.01 dpa) from Heinisch and Martinez [4]. The observed decrease of the rate of variation of ΔH_v for higher Xe ion irradiation fluences (> 2 x 10^{13} ion/cm^{2}) suggests that an equilibrium dynamic state of defects is approached. This might occur when a displacement cascade develops in the vicinity and/or overlap an already existing defect cluster causing its annihilation with the result that there is very small increase in defect cluster concentrations for higher ion fluence irradiations [5]. For the case of neutron irradiated copper it has been observed that a state of saturation is reached when the neutron fluences are greaten than 10^{20} n/cm^{2} or ~ 0.1 dpa [6]. The observed hardening effect is due to defect clusters formed by ion irradiation which appear as bright spots in dark background revealed by the dark-field TEM image as depicted in figure 2. These clusters result from displacement cascade events formed in the wake of Xe ions penetrating the Cu lattice.

A cascade arises from energetic recoil of primary knock-on (PKA) copper atom depositing its energy in a very small region within the surrounding lattice which is typically ~ 10 nm in size. This creates a high localized supersaturation of vacancies and self-interstitial atoms; subsequent reorganization of these point defects takes place within extremely short lifetimes of the order of ~ 10^{11} s [3]. The resultant recombination and rearrangements processes of these "primary" point defects finally results in formation of the observed "secondary" defect clusters which act as obstacles to dislocation movements according to the dispersed barrier hardening models of metals and alloys [1, 3].

References:

[1] H. Ullmaier, Materials Research Society Bulletin, **22** (1997), p.14.
[2] SRIM-2008 Code (http://www.srim.org).
[3] Materials Science and Technology: A Comprehensive Treatment, **Volume 10B,** ed. R. W. Cahn, P. Hansen and E. Kramer (VCH, Weinheim, Germany, 1991), p. 180.
[4] H. L. Heinisch and C. Martinez, Journal of Nuclear Materials **141-143** (1986), p.883.
[5] R. C. Britcher and H. W. Blewitt, Journal of Nuclear Materials **98** (1981), p.63.
[6] S. J. Zinkle, Oak Ridge National Laboratory Report CONF-900623-20, Nashville, TN, USA 1990.

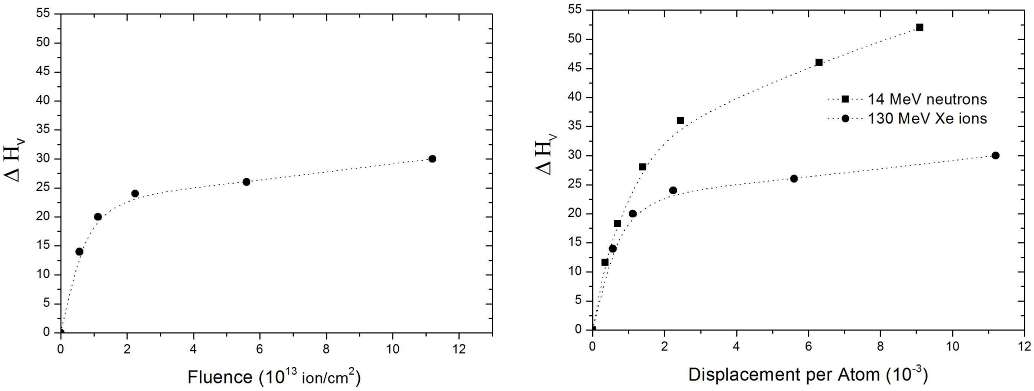

Figure 1. The changes in hardness (ΔH_V) versus Xe ion fluence in (a), and in (b) the data are plotted with that for 14 MeV neutron irradiation data [4] versus the displacement per atom (dpa) values.

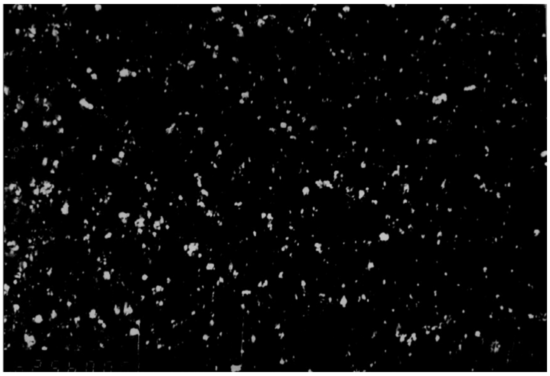

Figure 2. Dark-field TEM image at 300 kx magnification showing the strong diffracting defect clusters responsible for hardening in copper irradiated by 130 MeV Xe ions at fluence of 6 x 10^{13} ion/cm^2 .