Effect of H^+ ion irradiation on surface morphology of $Fe_{40}Ni_{40}B_{20}$ metallic glass

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MS received 26 June 1986

Abstract. The effect of irradiation by H^+ ions on surface modifications of metallic glass $Fe_{40}Ni_{40}B_{20}$, in the as-quenched, structurally relaxed and crystallized state, has been studied. Swollen regions develop on the surface of the as-quenched and structurally relaxed specimens, whereas blisters form on the surface of the crystallized specimen, under identical conditions of irradiation. The results are explained in terms of the distribution of hydrogen in the amorphous and crystallized conditions.

Keywords. Metallic glass; H^+ ion irradiation; surface morphology.

1. Introduction

The effect of irradiation by gaseous ions like He^+ , Ar^+ and H^+ on amorphous alloys has been reviewed by Nandedkar and Tyagi (1984) and the irradiation effect has been found to be strongly influenced by a number of factors such as the state of the material, specific composition, the implanting ion and the defects resulting from irradiation.

The present study aims at bringing out the effect of H^+ ion implantation on the surface morphology of $Fe_{40}Ni_{40}B_{20}$ metallic glass in three different states, namely, as-quenched, structurally relaxed and crystallized.

2. Experimental

Amorphous $Fe_{40}Ni_{40}B_{20}$ (Vitrovac 0040), 12 mm wide and 40 μm thick ribbon was used. Segments (20 mm long) were vacuum sealed ($\approx 10^{-3}$ torr) and annealed at 423 ± 2 K and 723 ± 2 K separately for 40 min to cause structural relaxation and crystallization respectively in the material (Toloui *et al* 1985). The complete amorphous nature of the structurally relaxed specimen was confirmed by x-ray diffraction.

The as-quenched, structurally relaxed and crystallized specimens were subjected to pre-irradiation electropolishing in an electrolyte containing acetic acid and perchloric acid in 10:1 proportion at 15 V. Irradiation was carried out with H^+ ions of 250 keV to a fluence in the range of 2×10^{18} to 4×10^{18} ions/cm² using a mass analyzed and collimated beam of 3 mm diameter from an AN-400 Vandegraff accelerator as described earlier (Yadava *et al* 1980).

The changes in surface morphology of the specimens resulting from H^+ ion irradiation were examined by using a scanning electron microscope (Philips PSEM 500).

3. Results

The scanning electron micrographs in figures 1–3 respectively show the surface features of the as-quenched, structurally-relaxed and crystallized specimens of $\text{Fe}_{40}\text{Ni}_{40}\text{B}_{20}$ metallic glass following implantation of H^+ ions to a fluence of 4×10^{18} ions/cm². A large number of swollen regions developed on the irradiated surfaces of the as-quenched and structurally relaxed specimens and consequently the irradiated surface became rough (figures 1 and 2). The average size of the swollen regions developed on the surface of the structurally relaxed specimen (figure 2a) is smaller than that developed on the surface of the as-quenched specimen (figure 1a).

The dark regions in figures 2a, b arise from excessive localized swelling of the matrix around them. The enlarged views of the irradiated surfaces of the as-quenched and structurally relaxed specimens in figures 1b and 2b respectively show that tiny globular features are associated with the swollen surface of the as-quenched specimen (figure 1b), however, no such features are seen on the swollen surface of the structurally relaxed specimen (figure 2b).

Contrary to these observations, in the case of crystallised specimen, distinct blisters are seen on the surface following H^+ ion implantation (figure 3a). The domes of the blisters (figure 3b) appear quite smooth.

4. Discussion

The implanted H^+ ions produce defects through displacement damage process before they get thermalized at short depths in the near-surface region. Vacancy like defects produced in the amorphous specimens are usually unstable and collapse into the distributed free volume. The major fraction of the implanted hydrogen remains entrapped, particularly in the thin irradiation-affected zone of the amorphous specimens due to increase in the free volume and absence of any potential trapping site and preferential path, to cause inward migration of hydrogen below the irradiation affected zone. Due to neutron irradiation the amorphous $\text{Fe}_{40}\text{Ni}_{40}\text{B}_{20}$ has been found to dissociate into small amorphous regions enriched with boron to approach $(\text{Fe}, \text{Ni})_3\text{B}$ composition and others depleted of boron (Gerling *et al* 1983; Toloui *et al* 1985). Localized stress fields with tensile and compressive stress systems have also been reported to develop simultaneously (Toloui *et al* 1985). Similar compositional fluctuations and stress fields could develop in this material on irradiation by H^+ ions. High concentration of hydrogen and its clustering at preferred sites in localized regions, with favourable chemical composition and stress system, results in formation of gas bubbles in those regions. The growth and consequent coalescence of the underlying gas bubbles, below those seen as tiny globules at the surface, result in formation of swollen regions (figure 1b).

The smaller size of the swollen regions on the surface of the structurally-relaxed specimen (figure 2a), as compared to the as-quenched one (figure 1a) may be attributed to relatively lower concentration of hydrogen in the irradiation affected zone of the structurally-relaxed specimen. It may occur due to a wider distribution of hydrogen even below the irradiation zone because of the presence of pre-irradiation chemical inhomogenities which have higher solubility for hydrogen in the structurally-relaxed condition. Also the solubility and diffusivity of hydrogen in the

Figures 1-3. Scanning electron micrographs showing surface features of amorphous $Fe_{80}Ni_{40}B_{20}$ following H^+ ion irradiation of 250 keV to a fluence of 4×10^{18} ions/cm². **1a,b.** as-quenched. **2a,b.** Structurally relaxed.

Figures 3a,b. Crystallized.

structurally-relaxed condition would be less than that in the as-quenched state as in $\text{Fe}_{40}\text{Ni}_{40}\text{P}_{14}\text{B}_6$ (Lin and Johnson 1982). The absence of globules on the swollen surface of the structurally-relaxed specimen (figure 2b) may thus be attributed to the low concentration of hydrogen in the irradiation-affected zone and hence the smaller number of gas bubbles. Swollen features have also been observed earlier in H^+ ion irradiated amorphous $\text{Ni}_{40}\text{Fe}_6\text{Co}_{20}\text{Cr}_{12}\text{Mo}_6\text{B}_{16}$ (Yadava *et al* 1981) but at a much higher fluence of $1 \times 10^{19} \text{ H}^+$ ions/ cm^2 . It may be attributed to the higher resistance of amorphous $\text{Ni}_{40}\text{Fe}_6\text{Co}_{20}\text{Cr}_{12}\text{Mo}_6\text{B}_{16}$ against irradiation-induced decomposition because of its complex chemical composition. The formation of blisters on the surface of the crystallized specimen, following H^+ ion implantation (figure 3) may be due to the crystalline nature of the material. Crystallization of amorphous $\text{Fe}_{40}\text{Ni}_{40}\text{B}_{20}$ results in the formation of different phases such as ν (Fe-Ni), $(\text{Fe}, \text{Ni})_3\text{B}$

and $(\text{Fe, Ni})_{23}\text{B}_6$ of varying sizes. Since hydrogen resides in interstitial positions in metals and alloys and diffuses by jumps between the interstitial sites, the solubility and diffusivity of hydrogen would be different in the various crystalline phases, depending upon the size, number and interconnectivity of the interstitial sites per unit cell. The distribution of implanted hydrogen would not be limited only to the irradiation-affected zone, but also below the irradiation zone because of the high solubility of hydrogen in some of the crystalline phases referred to above. The wide distribution of implanted hydrogen in the crystallized state of the material is further favoured by the interphase boundaries. Though the defect sites produced in the irradiated region would act as trap sites for hydrogen, the interaction of hydrogen with defect sites in metals is weak and hence the interphase boundaries, in particular those associated with tensile stress fields and triple junctions with triaxial stresses would be potential sites for trapping of hydrogen in the crystallized specimen.

The high concentration of hydrogen above a critical level at potential trapping sites, at a depth of several hundred Å from the surface, results in nucleation of gas bubbles. The coalescence of bubbles leads to the formation of penny-shaped cavities. The increase in cavity pressure leads to plastic bulging of the thin layer of material above the cavity to form blisters on the surface of the crystallized specimen (figure 3). Formation of blisters on the surface of the crystallized $\text{Fe}_{40}\text{Ni}_{40}\text{B}_{20}$ following H^+ ion implantation in the present investigation is in agreement with the earlier observation made in the crystallized $\text{Ni}_{40}\text{Fe}_6\text{Co}_{20}\text{Cr}_{12}\text{Mo}_6\text{B}_{16}$ (Yadava *et al* 1981).

Acknowledgements

The authors are grateful to Prof. T R Anantharaman, for his encouragement and interest in the work. Useful discussions with Prof. P Ramachandra Rao, Prof. C Suryanarayana and Prof. S Lele are gratefully acknowledged.

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