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Study of irradiation damage induced by He^{2+} ion irradiation in $Ni_{62}Ta_{38}$ metallic glass and W metal

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A B S T R A C T

Metallic glasses are considered to possess good resistant against irradiation due to their inherent structural long-range disorder and a lack of grain boundaries. The He^{2+} with an energy of 300 keV was used to irradiate $Ni_{62}Ta_{38}$ binary metallic glass to investigate its resistance against the irradiation, and the irradiated behaviour of the metallic glass was compared with that of W metal. The irradiation fluence range over 2.0×10^{17} ions/cm^2–1.6×10^{18} ions/cm^2. The TEM results show that nanocrystals of μ-NiTa phase and Ni_2Ta phase appeared in $Ni_{62}Ta_{38}$ metallic glass under the irradiation fluence of 1.6×10^{18} ions/cm^2. The SEM results show that the surfaces of $Ni_{62}Ta_{38}$ metallic glasses maintained flat and smooth, whereas a large area of blisters with peeling formed on the surface of W metal at the irradiation fluence of 1.0×10^{18} ions/cm^2. It indicates that the critical irradiation fluence of surface breakage of the $Ni_{62}Ta_{38}$ metallic glass is higher than that of W metal. After the irradiation, stress was generated in the surface layer of W metal, leading to the increase of the hardness of W metal.

1. Introduction

In recent years, the anti-irradiation performance of materials has been researched widely [1–4]. One of the applications of irradiation resistant materials is as spaceflight devices used in the space environment, and the strong irradiation in the space is one of the main reasons resulting in failure of the aircraft. Galactic cosmic rays consist of 90% protons, 9% helium nuclei, and a small amount of heavy nucleus and electrons [5], while the near-earth space irradiation mainly includes high-energy neutrons and gamma rays [6]. The effects of space irradiation will lead to the performance of spacecraft components deteriorating, thus in order to guarantee the operation of the spacecraft, selecting materials with good anti-irradiation performance is a key issue. In addition, the first mirror of optical diagnosis system in the fusion device suffers the bombardment of X-rays, gamma rays, neutrons, and Helium ions [7–9], hence the candidates of material which are used as the first mirror also need to have good anti-irradiation performance.

In a variety of irradiations, helium ions bombardment can result in the gas particles retaining in materials and forming holes which will lead to swelling, foaming, embrittlement, exfoliation and so on. The series of degradation behaviors shorten the service lifetime of the materials used in the irradiation environment, thus the effect of helium ions irradiation on the material has been widely researched. Y. Ueda et al. [10] discovered that helium ions bombardment made fuzz and helium holes form on the surface of W metal, and caused the surface embrittlement. M. Miyamoto et al. [11] investigated the changes of surface reflectivity of single-crystal Mo before and after helium ions irradiation and found out that the formation of bubbles and holes on the surface decreased the reflectivity. Liu et al. [12] presented that blistering and swelling ocurred in the CLAM steel after helium ions irradiation.

Among the candidates of anti-irradiation materials, metallic glasses are supposed to be resistant against displacive damage caused by the aforementioned irradiations due to their inherent structural characteristics of isotropy and long-range disorder. And due to a lack of crystalline structures and grain boundaries which are considered as the main cause of deterioration of anti-irradiation performance of materials, metallic glasses are thought to have a good resistant against irradiations. Recently, the irradiation behavior of metallic glasses had been widely studied, such as ZrNiCu crystalline phase precipitated [13,14] and irradiation soften ocurred [15,16] in Zr-based metallic glasses under heavy ion irradiation; nanocrystalline appeared [17,18], roughness of the surface increased [19] and the magnetic properties changed caused by magnetic moment rotation [17,20] in Fe-based metallic glasses after irradiation; the hardness of Ti-based metallic glasses decreased due to the irradiation [15,21] and so on. Therein, NiTa

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binary metallic glasses are supposed to have good resistance against irradiation [22,23] and good stability due to their high glass transition temperature, wide supercooled liquid region and ultra high strength [24].

In this paper, we used He^{2+} ions with an energy of 300 keV to irradiate $Ni_{62}Ta_{38}$ binary metallic glass to investigate its resistance against irradiation, and employed W metal which possesses high melting point and good stability [25] as a comparison to provide the reference of possibility which NiTa binary metallic glass applied in the irradiation environment.

2. Experiment methods

$Ni_{62}Ta_{38}$ metallic glass ribbons with the dimension of 2 mm × 10 mm × 40um were prepared by arc melting under a Ti-gettered argon atmosphere. The purity of W metals with the dimension of 5 mm × 5 mm × 2 mm was 99.95 wt%. The surfaces of W metals were mechanically polished to a mirror. Prior to the irradiation experiments, the samples cleaned ultrasonically for 15 min with acetone and alcohol, respectively.

Irradiation experiment was performed on the 320 kV highly charged ion research platform at Institute of Modern Physics, Chinese Academy of Sciences. The samples were irradiated with the He^{2+} ions beam of 300 keV, the beam flux was 1.2×10^{13} ions/cm^{2}s and the fluences were 2.0×10^{17} ions/cm^2, 4.0×10^{17} ions/cm^2, 1.0×10^{18} ions/cm^2 and 1.6×10^{18} ions/cm^2. During the irradiation, the ion beam was perpendicular to the surface of samples and sample holder was cooled by water.

Using SRIM program to simulate the damage in $Ni_{62}Ta_{38}$ metallic glass and W metal caused by He^{2+} irradiation. The phase structure of the unirradiated and irradiated samples was studied by X-ray diffraction (XRD) with Cu Kα radaition. And the changes on microstructure of samples were analysed by transmission electron microscope (TEM) operated at voltage of 200 kV, the samples were obtained by focus ion beam (FIB) technology. The evolution of surface morphology of samples was characterized by scanning electron microscope (SEM). The hardness of W metals before and after irradiation was measured by nanoindentor.

3. Results and discussion

Fig. 1 shows the distribution of DPA and concentration of He atoms with depth calculated by SRIM package [26]. It can be seen that the numbers of atomic displacement reached the peak

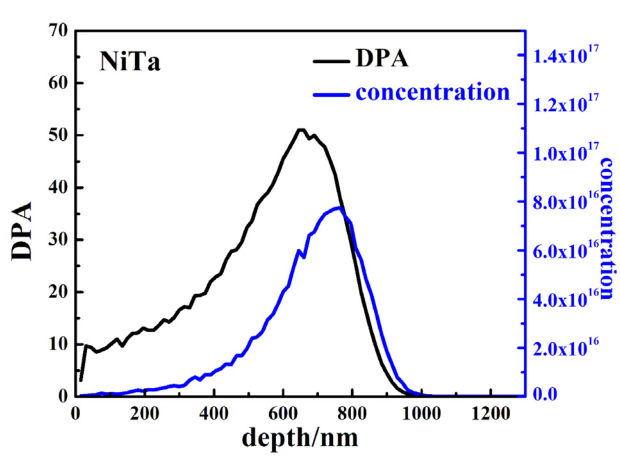

Fig. 1. The depth dependent distribution curve for DPA and concentration of He atoms in $Ni_{62}Ta_{38}$ metallic glass after He^{2+} irradiation of 300 keV with a fluence of 1.6×10^{18}/cm^2.

Table 1
Relative parameters of $Ni_{62}Ta_{38}$ metallic glass and W metal irradiated with He ions of 300 keV calculated by SRIM simulation program.

	$Ni_{62}Ta_{38}$	W
Target density(atoms/cm^2)	6.7715×10^{22}	6.3381×10^{22}
Projected range(nm)	674.4	499.8
Sputtering yield(ions)	0.0048	0.0021
Electronic energy loss(eV/Angstrom)	49.95	62.52
Nuclear energy loss(eV/Angstrom)	0.30	0.37
DPA peak value(dpa)	52	27

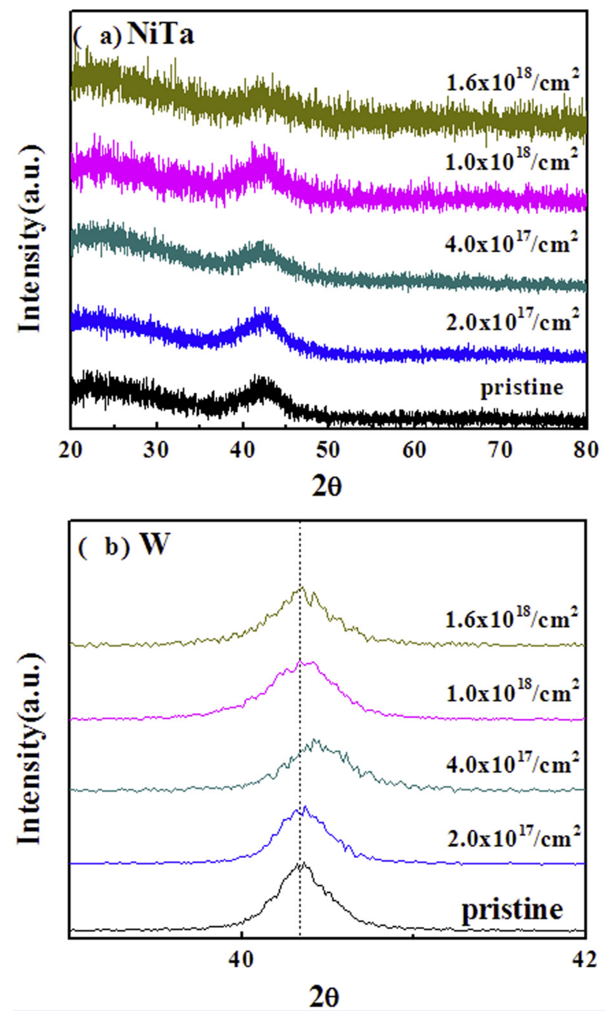

Fig. 2. The XRD pattern of (a) $Ni_{62}Ta_{38}$ metallic glasses (b) (1 1 0) plane of W metals before and after He^{2+} irradiation with different fluences.

(~52 dpa) at the depth about 670 nm which corresponds to the projected range of He ions in $Ni_{62}Ta_{38}$ metallic glass. The peak value of concentration of He atoms was about 7.8×10^{16} ions/cm^3. The detailed simulation results of $Ni_{62}Ta_{38}$ metallic glass and W metal under He ions irradiation are listed in Table 1. Due to the fact that the displacement threshold of Ni atom and Ta atom is smaller than that of W atom, the DPA value caused by He ions irradiation in $Ni_{62}Ta_{38}$ metallic glass was larger than that in W metal, the electronic energy loss and nuclear energy loss of $Ni_{62}Ta_{38}$ metallic glass was smaller than that of W metal.

Grazing incidence X-ray diffraction (GID – XRD) method was used to detect the structure of the $Ni_{62}Ta_{38}$ metallic glass and W metals before and after irradiation, the patterns are shown in Fig. 2. In Fig. 2a, the XRD pattern of pristine $Ni_{62}Ta_{38}$ metallic glass