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Corrosion resistance and magnetostrictive properties of $(Tb_{0.3}Dy_{0.7})Fe_2$ alloy modified by nitrogen ion implantation

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Abstract: The corrosion resistance and magnetostriction of $(Tb_{0.3}Dy_{0.7})Fe_2$ alloy were investigated for different nitrogen doses of 5×10^{15}, 5×10^{16}, 5×10^{17}, 1×10^{18} ions/cm^2 and average ion energy of 140 kV. The phase and elements concentration in the implanted layer were examined by X-ray diffraction and auger electron spectroscopy, respectively. The aqueous corrosion studies were carried out in 3.5% NaCl solutions. It was found that corrosion resistance had improved substantially with respect to the untreated substrates. The corrosion resistance was maximum at a dose of 5×10^{17} ions/cm^2, and saturation in corrosion improvement was noticed at a higher dose, 10×10^{17} ions/cm^2. In contrast, the results of magnetostriction tests before and after ion implantation showed that the influence of nitrogen ion implantation on the magnetostrictive properties turned out to be small. Finally, a model was applied to interpret the influence of nitrogen implantation on the magnetostriction in the light of the information provided by the experimental results in this study.

Keywords: magnetostriction; ion implantation; corrosion; concentration distribution; rare earths

The magnetostrictive materials composed of terbium, dysprosium and iron present the unique feature to couple mechanical variables with magnetic variables. They can store high energy densities and convert mechanical energy into electric one or viceversa[1–7]. For these and other reasons, they have experienced a growing technological interest in the last decades and they have been proposed as key element in innovative sensors and actuators for bulk devices[8,9]. However, the weak anti-corrosion properties limit extensive use of such materials in engineering applications. Ion implantation is an established technique for modifying the surface properties of a wide range of materials, and capable to create a diffused layer of desired elements into a metal surface that are dissimilar to coating techniques[10–13]. The formation of the modified layer can improve mechanical, chemical or physical properties of metal surfaces. In our previous work[14–17], some experimental studies were undertaken to investigate the anti-corrosion of such materials. Our previous studies have shown that the ion implantation can improve some surface performances such as better wear and corrosion resistance. However, surface modification will lead to changes in the structure of the materials, including the creation of defects, phase transformations and the formation of intermetallics, and had an effect on the magnetostriction. At present, it is not clarified how ion implantation affects the magnetostriction. In this study, nitrogen ion implantation was used to modify the surface of $(Tb_{0.3}Dy_{0.7})Fe_2$ alloy, the changes in the microstructure of ion implanted specimens of different treating conditions were compared, and the magnetostriction of ion implanted specimens was investigated.

1 Experimental

A commercially available magnetostrictive rod with the composition of $(Tb_{0.3}Dy_{0.7})Fe_{1.95}$ was used and cut into the samples with the dimension of 7 mm×7 mm×25 mm, which were ground and polished using standard metallographic methods. Their surfaces were then implanted with nitrogen ions at different doses of 0.05×10^{17}, 0.5×10^{17}, 5×10^{17}, 10×10^{17} ions/cm^2. The ions energy was 140 kV. The implantation process was carried out in a BNU-400 type implanter.

The resistance to corrosion was examined in non-deaerated 3.5% NaCl solution at a temperature of 25 ºC using the potentiodynamic method to determine the polarization curves in the CorrTest-cs330 electrochemical workstation. The samples were polarized in the anodic direction beginning from a potential of –1.5 V up to a potential of 1.5 V. The potential variation rate was 25 mV/s. The reference electrode was a saturated calomel

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electrode. X-ray diffraction analysis was carried out using a Bruker AXS D8 X-ray diffraction (XRD) apparatus. Standard ASTM data were applied for phase identification. Because the X-rays were attenuated in the materials, resulting data were representative of a surface layer of limited depth. Measurements of the concentration profiles of nitrogen implanted samples were performed by auger electron spectroscopy (AES). The magnetostrictions of samples were measured by a multi-functional magnetic parameters testing platform developed by ourselves.

2 Results and discussion

The XRD patterns of the samples before and after ion implantation of nitrogen ions with the different doses are shown in Fig. 1. It is found that there are a few microstructure and phase changes in the implanted specimens as compared with the unimplanted specimen. For the samples implanted at doses of 0.05×10^{17}, 0.5×10^{17} ions/cm^2, the (112) diffraction peaks exhibit obvious broadening, and the intensities of the peaks become weaker, suggesting that nitrogen atoms had entered into the interstitial sites, the crystal lattices were distorted, and eventually the crystal structure on the surface was destroyed with an increase of ion implantation concentration. With a further increase of the dose to 5×10^{17} ions/cm^2 the phase Fe_8N appears, as shown in Fig. 1, which can be deduced that the phase $(Tb_{0.3}Dy_{0.7})Fe_2$ in the substrate subsurface was partially decomposed. Fe atoms trapped the N-ions, so the nitride formed. Form Fig. 1, it is also found that there are few phase changes in the sample implanted at a dose of 10×10^{17} ions/cm^2 as compared with the sample implanted at a dose of 5×10^{17} ions/cm^2 , which can be deduced that the phase remains unchanged in excess of 5×10^{17} ions/cm^2.

Concentration distributions in near-surface layers of implanted N specimens measured by AES with different doses are shown in Figs. 2(a–d). For the samples implanted at doses of 0.05×10^{17}, 0.5×10^{17} ions/cm^2, the depth profiles are approximate to a Gaussian distribution. The calculated penetration depth of N interstitial atoms is individually about 300 and 500 nm. The peak position is about 200 and 250 nm. The nitrogen concentration increases rapidly with an increase in implanted doses. From XRD patterns as shown in Fig. 1, it can be deduced that implanted nitrogen atoms are in interstitial positions.

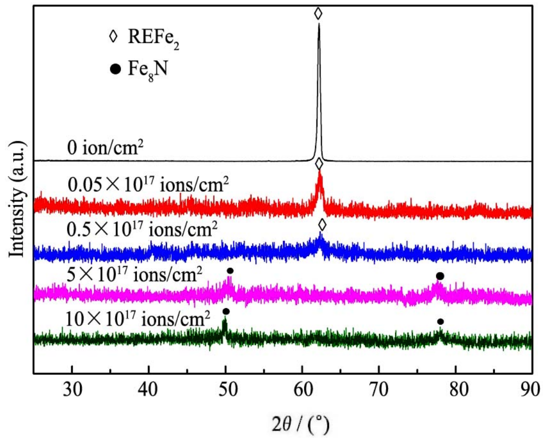

Fig. 1 XRD patterns of the samples before and after ion implantation of nitrogen ions with different doses

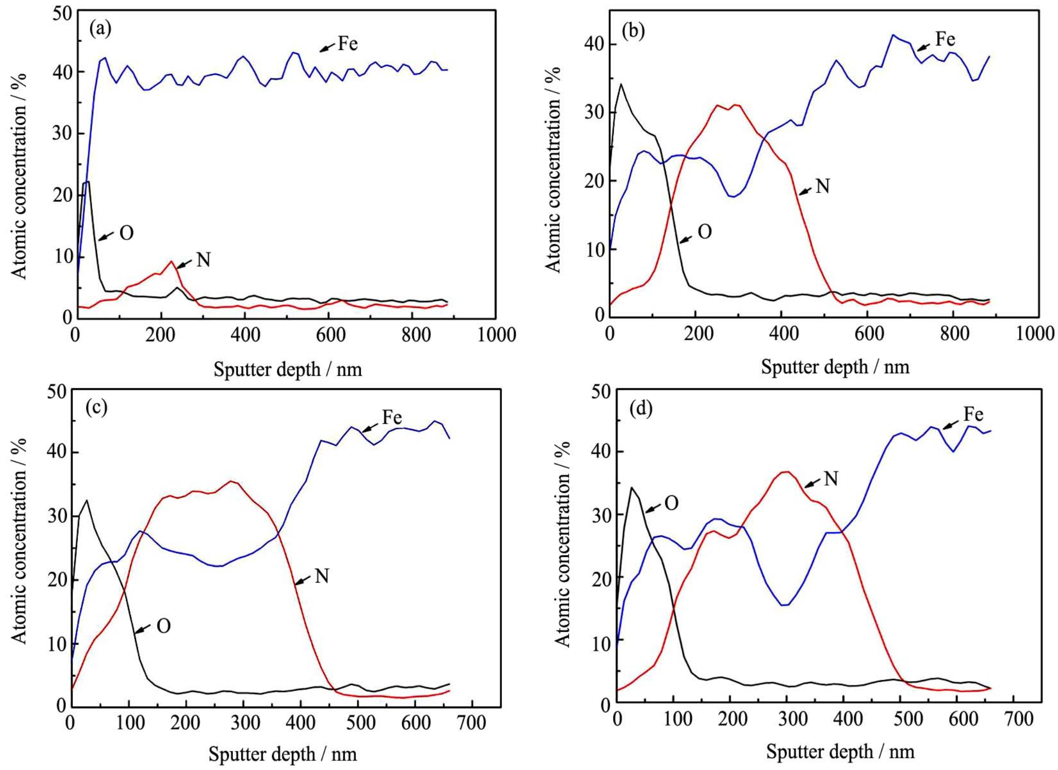

Fig. 2 AES concentration depth profiles for nitrogen ion implantation with different doses
(a) 0.05×10^{17} ions/cm^2; (b) 0.5×10^{17} ions/cm^2; (c) 5×10^{17} ions/cm^2; (d) 10×10^{17} ions/cm^2