MÖSSBAUER STUDIES OF MAGNETIC ANISOTROPY OF AMORPHOUS Fe–(Co, Cr)–Zr ALLOYS

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ABSTRACT

Magnetic anisotropies and hyperfine fields of amorphous a-Fe-(Co, Cr)-Zr alloys, their temperature and thermal stress effects were studied by using a Mössbauer spectroscopy. The results are in the following: A tensile stress field is easily created during the material production process, having the plane anisotropy to be increased for the alloys containing strong ferromagnetic coupling such as Fe-Co and Fe-Ni; a pressure stress field is easily produced, making the perpendicular anisotropy increase for the alloys containing antiferromagnetic coupling such as Fe-Cr and Fe-Mn. Introducing the new idea of attractive and repulsive forces, the fact was explained well that the dependence of anisotropies on the average outer electron concentration of 3d transition metal is similar to that of the average hyperfine field.

Keywords: Mössbauer spectroscopy Magnetic anisotropy Hyperfine field

1 INTRODUCTION

Recently, studies of a-TM-Zr (TM = Fe, Co and Ni) alloys have exhibited a lot of interesting physical properties, *e.g.*, Invar effect, micromagnetism, bimodal hyperfine field distributions $P(B_{hf})$ and so on[1-6], having become an important part of studies in the field of amorphous magnetism. The domain structure and anisotropy of a-TM-M(metalloid) alloys have been studied by many authors[7-12], but there are few reports in the field of a-TM-Zr alloys. In this paper, the anisotropies of a-Fe-(Co, Cr)-Zr alloys were studied by a Mössbauer spectrum method. Two relations between the anisotropy and magnetic interaction, stress field and attractive, and repulsive forces were discussed.

2 EXPERIMENTAL

a-Fe-(Co, Cr)-Zr alloys were supplied by Institute of Physics Academia Sinica. The amorphous ribbons about 1.2 mm wide and 20–30μ m thick were prepared by a melt-spinning technique in argon atmosphere. X-ray diffraction confirmed the amorphous state of the ribbons[13]. Mössbauer spectra were recorded in a conventional Mössbauer spectrometer in transmission geometry and fitted by an IBM PC/XT microcomputer with the improved Hesse method. In order to study the effect of thermal stress on the domain structure, for a-$Fe_{70}Co_{20}Zr_{10}$ and $Fe_{80}Co_{10}Zr_{10}$, we prepared specially two kinds of samples: one is several ribbons parallel to each other glued by few transparent adhesive tapes and the other is ones whose double surfaces were glued fully.

3 RESULT AND DISCUSSION

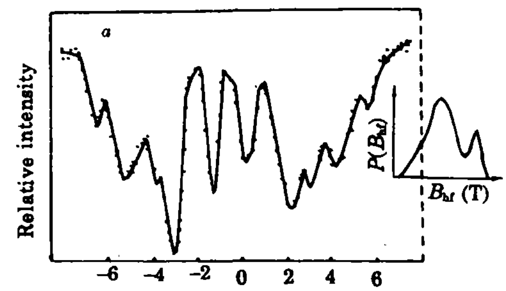
According to the method of the degree of perferential orientation of the moments introduced by Xu[14], we have discussed in detail the descriptive way of the magnetic texture of amorphous alloys, obtaining the distribution possibilities of the magnetization along the parallel and perpendicular to the ribbon plane[9]:

$$P_{\perp} = (4-A)/(4+A) \quad (1)$$

$$P_{\parallel} = 2A/(4+A) \quad (2)$$

where A is the angular factor of Mossbauer spectra with six lines (the intensity ratio of second to third line). Thus, $P_{\perp}$ and $P_{\parallel}$ mean the area ratios of the maze domain and plane domain to the total one, showing the magnitudes of the perpendicular and plane anisotropies respectively.

Fig.1 shows the Mössbauer spectra of a–$Fe_{70}Co_{20}Zr_{10}$ at 292K, 77K and thermal stress state (77K). From Fig.1, there are two groups six line spectra in a–$Fe_{70}Co_{20}Zr_{10}$, which means that two types of magnetic states exist in it[6].



As T drops from 292K to 77K, the

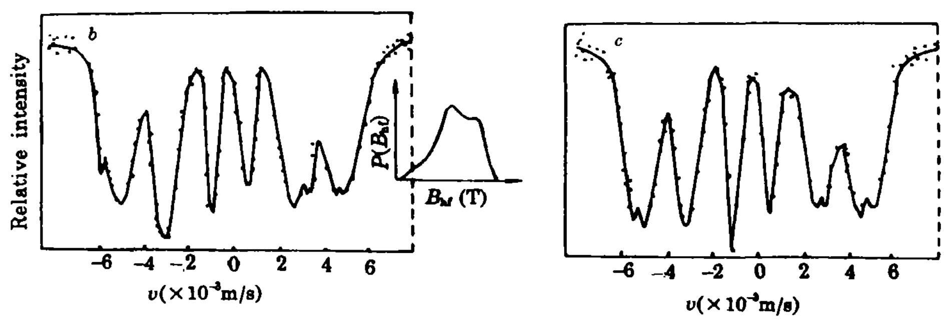


Fig.1 Mössbauer spectra of a–$Fe_{70}Co_{20}Zr_{10}$ (*a*) at 292K, (*b*) at 77K, (*c*) at thermal stress state (77K)

intensities of the second and fifth peaks decrease (A falls from 2.92 to 2.48). This is similar to the results obtained in a–$Fe_{40}Ni_{40}P_{14}B_6$ and $Fe_{80}P_{16}B_1C_3$ by Chien[11,15]. At the thermal stress state, A drops further from 2.48 to 1.79, which can be explained as follows: because the glue materials in the adhesive tape solidify and contract more strongly than the ribbon alloys possessing a positive magnetostriction λ_s[1]. Upon cooling the sample, the ribbon is compressed in its plane and a perpendicular

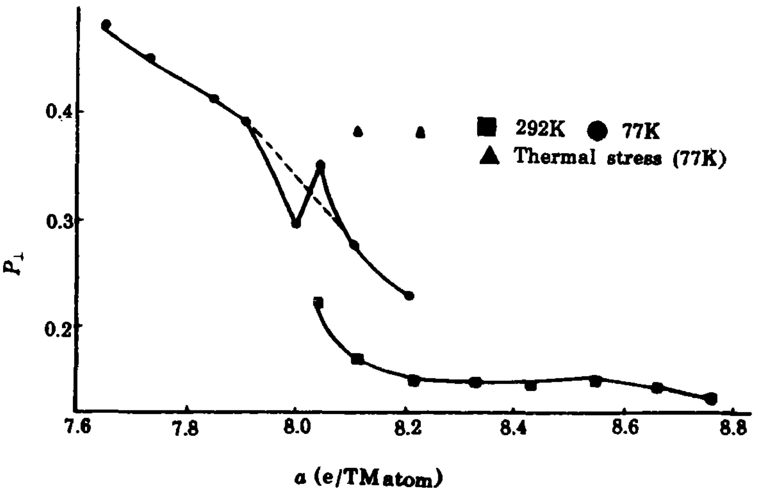


Fig.2 The a dependence of the perpendicular anisotropy of a–Fe–(Co,Cr)–Zr alloys

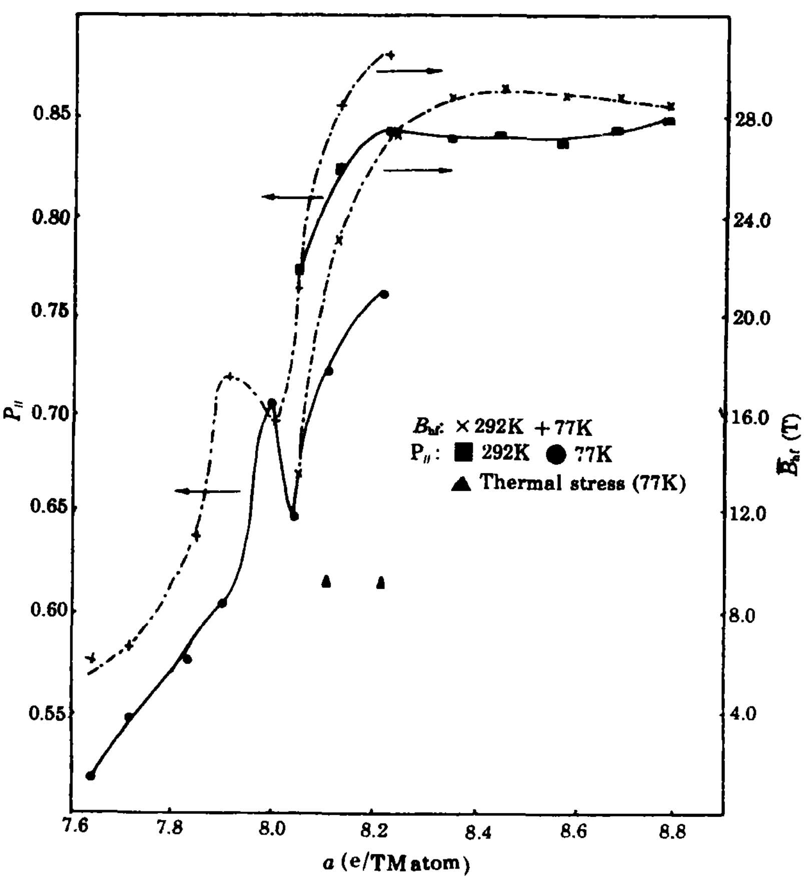


Fig.3 The a dependence of the plane anisotropy and average hyperfine field of a–Fe–(Co,Cr)–Zr alloys

anisotropy may then be induced. This is similar to the results in Ref.[12].

Fig.2 and 3 show values of $P_\perp$ and P_t for a–Fe–Co–Zr alloys at 292K, 77K and thermal stress state (77K) as a function of the average outer electron concentration of 3d transition metal atoms a. From Fig.3, the dependence of the P_t and B_{hf} on a are similar, showing an anomalous phenomenon in the vicinity of a–$Fe_{90}Zr_{10}$ associated with the Invar effect in this region. The linear increase of $P_\perp$ with increasing Cr content accompanies appearance of maze domains. The value of $P_\perp$ drops rapidly with the increase of Co content for the Co–poor a–Fe–Co–Zr and does not change significantly for Co content$>$30. When the temperature drops from 292K to 77K, the $P_\perp$ value of a–$Fe_{90-x}Co_xZr_{10}$($z=10$, 20) increases. At the thermal stress state, the $P_\perp$ value increases further, which means that the thermal stress causes an increase of the number of maze domains. The similar trend has been found in a–TM–M(metalloid) alloys[9,10]. It has been obtained that the increase of P_t with increasing Co content in a–$(Fe_{1-x}Co_x)_{78}Si_{9.5}B_{12.5}$ is similar to that of hyperfine field. Ni and Cr substitutions on the a–$Fe_{81}Si_{3.5}B_{13.5}C_2$ have different influence on the domain structure and magnetic properties. Ni(Cr) substitution will make P_t and B_{hf} increase (decrease).

In order to explain the cause of the anisotropies in amorphous alloys, Lin *et al.* have made theoretical and experimental investigations[8], thinking that the anisotropies of amorphous alloys result from geometrical microstructures (including density fluctuation, crudity of the shape and stress fields) and chemical microstructures (including non–uniformity of the composition, and atomic configurations). They suggested that the stress field caused during the melt–spinning process is a major contributor of the anisotropy in the rapidly quenched amorphous alloys. However, up to now the nature of the stress field has not been clear. In the former paragraph, we have shown that the dependence of P_t on a or Co, Ni, Cr content is similar to B_{hf} in the a–TM–Zr and TM–M made under the same conditions. O'Handley *et al.*[16] also have shown the temperature and a or Co content dependences of the reduced magnetostriction and magnetization exhibit a similar tendency. Recently Xu *et al.* have studied the anisotropies of annealed amorphous alloys[17,18]. The results indicated that, at low annealing temperatures, the angular factor A exhibits only few changes; at high ones, A changes abruptly, which is attributed to the variation of amorphous structure caused by the structural relaxation and pressure stress of the crystallizing layer or the oxide film to the body of amorphous alloys. Accordingly, it is concluded that the anisotropy of the rapidly quenched amorphous alloy is predominantly concerned with the structure and magnetic interaction.

Recently, Jansen has shown that the magnetic shape anisotropy results from a dipole–dipole interaction due to the Breit modification of the relativistic two–electron energy[19]. It was also indicated that the classical magnetic dipolar interactions can make significant contributions to magnetic anisotropy in amorphous ferrimagnetic alloys (*e.g.* Gd–Co base films) with slight structural anisotropies on either atomic or microstructural scales[20]. As the antiferromagnetic couplings exist in a-Fe-Cr-Zr and Co-poor a-Fe-Co-Zr alloys[6], being similar to the magnetic structure in Gd-Co base films, we may explain the observed results with the pair-ordering[21] (magnetic dipolar interaction). Because the magnetic dipole moment in 3d TM atom is approximately in proportion to its spin S_i, we can use S_i, instead of the dipole moment of i atom to discuss the dipole interaction. For the atom pairs such as Fe-Co an Fe-Ni, because the strong ferromagnetic interaction exists between S_i, and S_j, the spin orientations of S_i is almost parallel to S_j and a repulsive force tends to exist between the i and j atoms for the dipole interaction. Supposing i atom couples originally with j atom at the equilibrium site r_o by an elastic body, then the repulsive force between S_i, and S_j will give a rise to the tension stress between i and j atoms, which can result in two effects as follows: (1) the elongated direction of tension stress will become the preferential that of atom arrangement, which gives rise to the atomic-bond-orientational anisotropy[22]: (2) the effect of magnetostriction will make the magnetization in the local domain following the direction of the tension stress (if $\lambda_s > 0$). For amorphous film, the tension stress will make the magnetization orientate preferentialy in the film plane. The stronger the magnetism of S_i and S_j, and the better the collinear of S_i and S_j, and the more the atom pairs such as Fe-Co and Fe-Ni are, the more widly the distribution of the tension stress is extended and the more the number of plane domains are, which can be used to explain well the facts that $P_\parallel$ in a-Fe-Co-M and Fe-Co-Zr alloys increase with the increasing Co content. On the other hand, for the atom pairs of antiferromagnetic interactions such as Fe-Cr and Fe-Mn, the orientation of S_i and S_j are opposite and a attractive force tends to exist between the i and j atoms and a pressure will be given rise to. Because the effect of magnetostriction may make the magnetization in the local domain to be perpendicular to the direction of the pressure. With the increasing of Cr or Mn content such as in a-Fe-Cr-Zr, the distribution of the pressure stress will be extended gradually and $P_\perp$ will increase step by step, which can be used to explain the results in Fig.2. Because the repulsive force, magnetization and B_{hf} are all closely related to the distance, orientation and the size of spins at the different sites i and j in a magnetic material, it is comprehended that the temperature and a dependence of the $P_\parallel$, λ_s, B_{hf} and so on are similar. However, their mechanisms are different.

The temperature effect of a-$Fe_{90-x}Co_xZr_{10}$ ($x=10$, 20) and other a-TM-M alloys can be explained as follows: on cooling the ribbons, on the one hand, the magnetic coupling interaction between S_i and S_j becomes stronger and the repulsive force and tensile stress increase; on the other hand, the contraction with cold makes the reducing of the distance between i and j atoms, which gives rise to the pressure stress. Comparing these cases, if the latter is more advantageous than the former, the pressure stress will be induced and $P_\perp$ will decrease, which can be used to explain the fall of $P_{\parallel}$ in a–$Fe_{90-x}Co_xZr_{10}$ on cooling them; if the former is in advantage.$P_{\parallel}$ will increase. In the different temperature region, because of the nonlinearity of the λ_s, σ and contraction with cold, the latter is in advantage when $T_c > T > T_o$ (T_o is 77K such as in a–$Fe_{40}Ni_{40}$–$P_{14}B_6$[15], but the former is in advantage when $T < T_o$, which is the cause of the return of the easy axis to the plane observed by Chien *et al.*[15].

The anomalous behaviour of $P_{\perp}$ and $P_{\parallel}$ in the vicinity of a–$Fe_{90}Zr_{10}$ can be thought to be the cause of the atom cluster gathering (because the existence of composition fluctuation in a–Fe–Mn or a–Fe–Cr base alloys, the Mn(Cr)–rich cluster containing antiferromagnetic coupling may be formed and the ferromagnetic couplings such as Fe–Fe are gatering in its surroundings, which means cluster gathering) and the region of the cluster gathering is one of "frustration spin" as suggested in Ref.[6]. The mechanism is similar to one of the cluster gathering influencing the magnetic anisotropy in a–$F_{37.5}Mn_{37.5}P_{16}B_6Al_3$ suggested by Sherwood *et al.*[8,23]

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