SHORT REPORT

J. Sci. Soc. Thailand 11 (1985) 93 - 98

DOMAIN MAGNETIZATION IN AMORPHOUS $Fe_{81}B_{13.5}Si_{3.5}C_2$ ALLOYS

THAMRONG METHASIRI[a] AND I-MING TANG[b]

[a] *Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*

[b] *Department of Physics, Faculty of Science, Mahidol University, Bangkok, Thailand*

(Received 1 July 1985)

Abstract

The Mössbauer spectra of the amorphous $Fe_{81}B_{13.5}Si_{3.5}C_2$ ribbons (METGLAS 2605 SC) field annealed at 594 K and 654 K are obtained for three different orientations of the ribbons. The intensity ratios of the second (fifth) peaks to the first (sixth) peaks in the spectra of these ribbons are used to determine the fractional volumes of the domains which contain the magnetization lying along the anisotropy axis, along the ribbon axis and perpendicular to the ribbon plane. As the annealing temperature is increased, the ribbon's magnetization tends towards a single domain configuration with the magnetization in the transverse direction.*

Recently, there has been a great deal of interest shown to the amorphous $Fe_{81}B_{13.5}Si_{3.5}C_2$ alloy (METGLAS 2605 SC) because of its high magnetoelastic coupling. Modzelewski *et al.*[1] found that the maximum value of the magnetomechanical coupling constant of this ribbon exceeded 0.9 while Spano *et al.*[2] reported that the maximum value was 0.98. These high values of the coupling constants were achieved by annealing the 2605 SC ribbons in a transverse magnetic field of a few koe. Possible commercial applications of the 2605 SC ribbons based on its high coupling constant value was recently pointed out by Savage and Spano[3].

Mössbauer studies of the 2605 SC ribbons have been carried out by Saegusa and Morrish[4] and by Bhatnagar *et al.*[5] They both found that the hyperfine field and the magnetization of this amorphous alloy exhibit the $T^{3/2}$ dependence characteristic of spin wave excitations. The two studies disagreed, however, on the values of the coefficients

* METGLAS is a registered trademark of the Allied Chemical Corp. (USA).

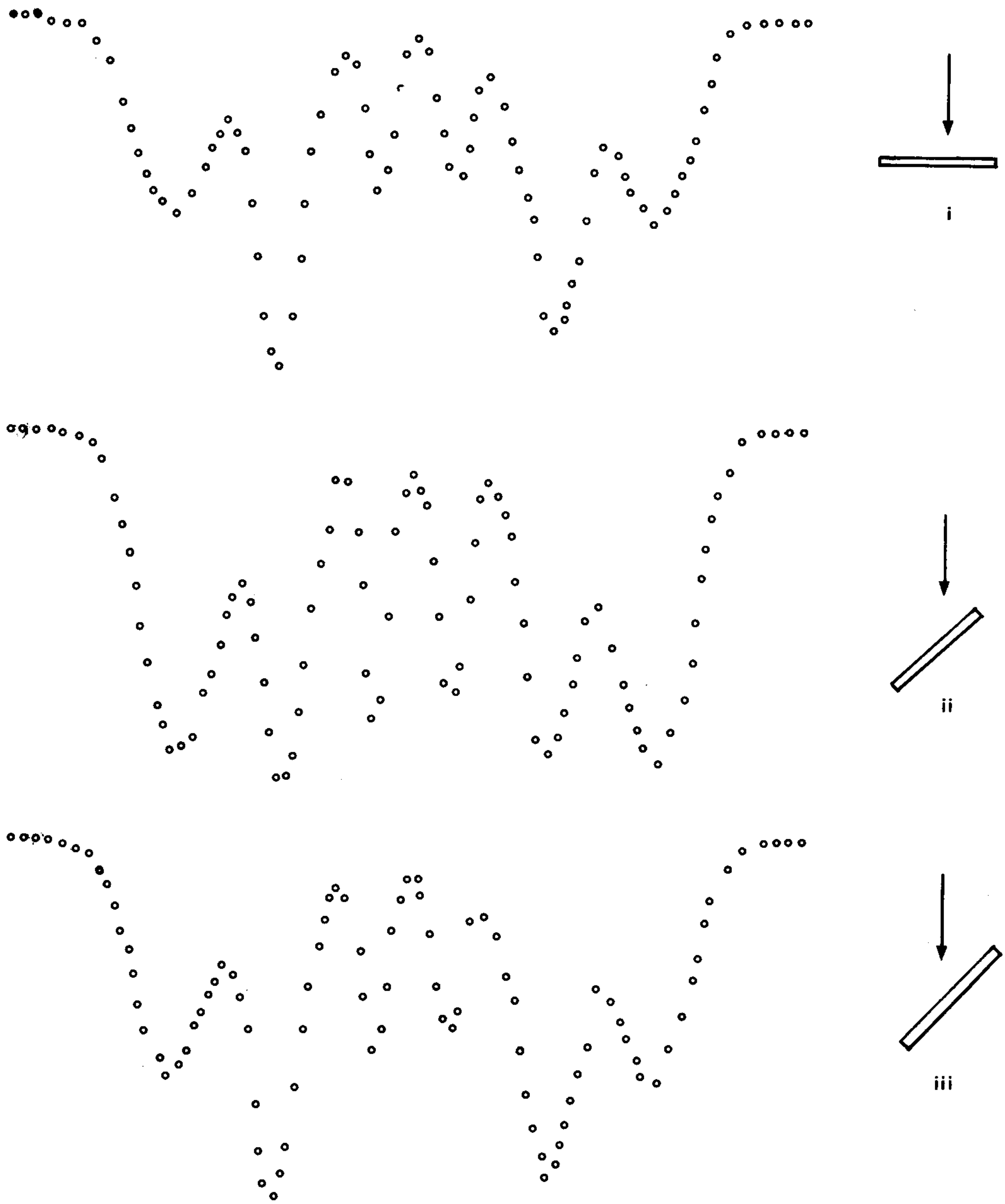

Figure 1. Mössbauer Spectra of the 594 K Annealed $Fe_{81}B_{13.5}Si_{3.5}C_2$ Ribbons. i. The spectrum at room temperature when the ribbon is oriented perpendicular to the incident γ-ray. ii. The spectrum when the ribbon is orientated so that the longitudinal axis of the ribbon is at right angle to the incident γ-ray. iii. The spectrum when the transverse axis is at right angle to the γ-ray. (Data points are of the order 10^6 counts per channel.)

of the $T^{3/2}$ dependence, the values of the Curie temperature and the crystallization temperature. The kinetics of the amorphous to crystalline transition in this alloy has also been studied. Saegusa and Morrish[6] found the transition to occur in two stages. Evidence for the two-step transition was seen in the difference in the behaviours of the out-of-plane rotation of the magnetic anisotropy[7] in two temperature regions.

The $Fe_{81}B_{13.5}Si_{3.5}C_2$ ribbons are also interesting because of their magnetic domain formations. Scanning electron microscope studies[8,9] show that the domains in an as-quenched ribbon are parallel to the long axis of the ribbon. Upon annealing in a transverse field, the domains were seen to be transverse to the major axis with no closure domains. No visible domain wall motion was observed when the annealed ribbons were subjected to fields directed along the long axis of the ribbon. Initial Mössbauer studies[10] on the 2605 SC ribbons annealed in a transverse magnetic field of 2 kOe at 680 K indicated that the magnetization was entirely in the plane of the ribbon (with about 90% of the material magnetized along the transverse axis). Hasegawa *et al.*[11], found that the ferromagnetic resonance studies on the sister alloy $Fe_{80}B_{20}$ (METGLAS 2605) indicated that the magnetization of this alloy was also in the ribbon plane.

It is the purpose of this paper to report on our study of the domain magnetization in the amorphous $Fe_{81}B_{13.5}Si_{3.5}C_2$ alloys annealed in a transverse field at 694 K and 654 K for twenty minutes in a hydrogen atmosphere. Our study is a continuation of the earlier study of Bucci *et al.*[10], and like that study, we have measured the Mössbauer absorption spectra for several different orientations of the ribbon with respect to the incident γ-ray. A description of the experimental set up is given elsewhere[12]. Figure 1 shows the spectra for the 594 K annealed specimen when the ribbon plane is perpendicular to the incident γ-ray, when the ribbon is rotated 45° about its long axis and when the 45° tilted ribbon is rotated 90° about its plane perpendicular axis. The spectra for the 654 K annealed specimen are similar to the spectra shown. Both sets of spectra are similar to the spectra recorded for the glassy ferromagnet $Fe_{40}Ni_{40}P_{14}B_6$ (METGLAS 2826) in similar geometries by Chien and Hasegawa[13].

The six peak Mössbauer spectra were fitted to the superposition of six Gaussian curves by a Mössbauer curve fitting program called HADASH. The HADASH program was constrained to produce a symmetric fit of the data points. The fitting program used by Saegusa and Morrish[4,6] had a similar constraint. Their program, however, fitted the data points to six Lorentzian line shapes. The intensities (or areas) of the six absorption peaks are provided by the HADASH program. In Table 1, we have listed the ratios of the intensities of the second (fifth) peaks to those of the first (sixth) peaks for the three orientations along with the ratios for the 680 K annealed ribbon obtained by Bucci *et al.*[10] These intensity ratios can be used to determine the direction of magnetization in the ribbon once a model for the configuration of the moments has

TABLE 1. RATIOS OF THE INTENSITIES OF THE SECOND (FIFTH) LINES TO THE INTENSITIES OF THE FIRST (SIXTH) LINES[1].

Specimen Orientation	594 K	654 K	680 K[2]
i	1.207	1.251	1.29
ii	0.633	0.596	0.45
iii	1.028	1.118	1.25

[1] Experimental uncertainities exist in the third decimal place in the values listed in the first two columns
[2] Taken from ref. 10.

TABLE 2. FRACTIONAL VOLUMES OF THE DOMAINS.

Specimen Domain	As-quenched[1]	594 K	654 K	680 K[1]	700 K[1,2]
a	0.407	0.733	0.816	0.937	0.2
b	0.582	0.265	0.199	0.023	–
c	0.069	0.064	0.08	0.037	0.8

'a' is the domain in which the magnetic moments are lying in the direction of the annealing field (the transverse direction). 'b' is the domain in which the moments are lying in the direction of the shape induced anistropy (the long axis). 'c' is the domain in which the moment is perpendicular to ribbon plane.

[1] Taken from ref. 10.
[2] Rough estimate given in ref. 10.

been decided upon. The two most commonly used models are the uniform magnetization model and the domain magnetization model[14]. In the former model, the magnetization is taken to be uniform in the ribbon, while in the latter, it is assumed that there are different types of domains in the ribbon, where the magnetization lies along different directions. Chien and Hasegawa[13] used the uniform magnetization model to determine the direction of the magnetization in METGLAS 2826 alloy. In light of the observations of domains in the 2605 SC ribbons by scanning electron microscope[8] and the analysis of Bucci *et al.,*[10] which showed that the observed variation of the intensity ratios when the tilted ribbon is rotated about its plane perpendicular axis is in agreement with the predicted variation in the domain magnetization model and is in disagreement with the variation predicted by the uniform magnetization model, we have chosen to use the domain magnetization model to analyze our data.

As is well known,[7] the intensity of the second (fifth) line in the ^{57}Fe Mössbauer spectrum goes as 4 $\sin^2\theta$ where θ is the angle between the direction of the γ-ray and the magnetic moment, while the intensity of the first (sixth) line goes as 3 $(1 + \cos^2\theta)$. In the domain magnetization model, the intensities of the lines are the sums of the contributions to the line from each domain, i.e.,

$$I_{2(5)total} = 4 \sum_{domain} P(j) \sin^2 \theta_j$$

and

$$I_{1(6)total} = 3 \sum_{domain} P(j) (1 + \cos^2 \theta_j)$$

where θ_j is the angle between the γ-ray direction and the magnetic moments lying in the j-th domain and where P(j) is the weight of the contribution of the j-th domain to the total intensity of the peak. In the model used by Bucci et al[10]., P(j) is assumed to be proportional to the number of magnetic moments in j-th domain (or more specifically, to the fractional volumes occupied by each domain). By measuring the intensity ratios for three orientations of the ribbons, the fractional volumes can be determined. The results of these determinations are listed in Table 1, along with the fractional volumes of an as-quenched ribbon and of a ribbon annealed at 700 K. The latter values were taken from ref. 10. The fact that the fractional volumes do not add up to one is due to experimental uncertainties[3] associated with determination of the intensities of the first and second absorption peaks in the Mössbauer spectra.

Looking at Table 2, we see that the fractional volume occupied by the 'a' domain increases as the annealing temperature is increased. For the 700 K annealed specimen where surface crystallization has taken place[6], the volume occupied by the 'a' domain drops drastically and most of the ribbon is occupied by the 'c' domain. This transition to a ribbon in which most of the magnetic moments lie perpendicular to the ribbon plane is due to the compressive stress arising from the difference in the densities of the alloy in the surface layer and in the bulk[15]. The positive magnetostriction of the 2605 SC ribbons leads to the magnetic anisotropy being perpendicular to the ribbon plane. Our results tend to support the use of the rotational magnetization process by Savage and coworkers[2,3] for explaining the large magneto–elastic coupling of the METGLAS 2605 SC ribbons.

Acknowledgement

The Mössbauer spectra were taken at the American University, Washington D.C., by T. Methasiri. He would like to thank Dr. E. Callen for the kind hospitality shown him and to thank Dr. J.R. Cullen for some valuable discussions.

References:

1. Modzelewski, C., Savage, H.T., Kabacoff, L.T. and Clark, A.E., (1981) *IEEE Trans. Mag.* **Mag–17,** 2837.
2. Spano, M.L., Hathaway, K.B. and Savage, H.T. (1982) *J. Appl. Phys.* **53,** 2667.
3. Savage, H.T. and Spano, M.L. (1982) paper presented at *Joint Intermag/Magn. Magn. Mat. Conf.,* Montreal, July.
4. Saegusa, N. and Morrish, A.H. (1982) *Phys. Rev. B* **26,** 19.
5. Bhatnagar, A.K., Prasad, B.B. and Jagannathan, R. (1984) *Phys. Rev. B* **29,** 4896.
6. Saegusa, N. and Morrish, A.H. (1982) *Phys. Rev. B* **26,** 6547.
7. Saegusa, N. and Morrish, A.H. (1983) *J. Magn. Magn. Mat.* **31–34,** 1555.
8. Hernando, A., Aroca, C., Madurga, V. and Savage, H.T. (1982) *J. Appl. Phys.* **53,** 2297.
9. Livingston, J.D., (1982) paper presented at *Joint Intermag/Magn. Magn. Mat. Conf.,* Montreal, July.
10. Bucci, C., Methasiri, T., Clark, A.E. and Savage, H.T. (1982) *J. Appl. Phys.* **53,** 2670.
11. Hasegawa, R., O'Handley, R.C. and Mendelsohn, L.T. (1977) *AIP Conf. Proc.* **34,** 298.
12. Methasiri, T. and Tang, I.M. (1985) *Physica,* in press.
13. Chien, C.L. and Hasegawa, R. (1977) *Phys. Rev. B* **16,** 3024.
14. Kronmuller, H. and Groger, B. (1981) *J. Physique (Paris)* **42,** 1285.
15. Ok, H.N. and Morrish, A.H. (1981) *Phys. Rev. B* **23,** 2257.

บทคัดย่อ

การศึกษาโดเมนแม่เหล็กของ (แผ่น) สารอสัณฐาน $Fe_{81}B_{13.5}Si_{3\ 5}C_2$ เรียกทางการค้าว่า METGLAS 2605 SC สารตัวอย่างนี้ได้แอนนีลที่อุณภูมิ 594 องศาเคลวิน และ 654 องศาเคลวินตามลำดับ จากการวัดสเปคตรัมมอสบาวเออร์ที่สารตัวอย่างดูดกลืน และการวิเคราะห์อัตราส่วนความเข้มของเส้นที่สอง (หรือเส้นที่ 5) กับเส้นที่ 1 (หรือเส้นที่ 6) คำนวณหาปริมาตรของโดเมนแม่เหล็กที่เรียงตัวตามระนาบแกนต่าง ๆ ของสารตัวอย่าง พบว่าที่อุณหภูมิแอนนีลสูง จะมีโดเมนแม่เหล็กอยู่แนวเดียวคือ ระนาบขวางกับแกนยาวของสาร