Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 27
ISSUE 2
April
2008

Influence of heat treatment on changes on structure and magnetic properties of CoSiB alloy

R. Nowosielski [a], A. Zajdel [a,*], S. Lesz [a], B. Kostrubiec [b], Z. Stokłosa [b]
[a] Division of Nanocrystalline and Functional Materials and Sustainable Pro-ecological Technologies, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] Institute of Materials Science, Silesian University, ul. Bankowa 12, 40-007 Katowice, Poland
* Corresponding author: E-mail address: aleksandra.zajdel@polsl.pl

Received 29.01.2008; published in revised form 01.04.2008

Properties

ABSTRACT

Purpose: This paper describes influence of heat treatment on changes on structure and magnetic properties of the amorphous $Co_{77}Si_{11.5}B_{11.5}$ alloy.
Design/methodology/approach: The following experimental techniques were used: X-ray diffraction (XRD), static and dynamic measurements of magnetic properties (magnetic balance, fluxmeter, Maxwell-Wien bridge).
Findings: The crystallization process involved by heat treatment leads to significant changes of structure and magnetic properties of amorphous $Co_{77}Si_{11.5}B_{11.5}$ alloy.
Research limitations/implications:
Practical implications: The attractive properties of Co-Si-B alloy are of special interest for basic research on the materials as well as for their potential applications, like magnetic sensors. According to the results presented in this paper the examined $Co_{77}Si_{11.5}B_{11.5}$ alloy as a soft magnetic material may be used in noise filters, saturable reactors, miniature inductance elements for abating spike noise, zero-phase current transformers, and magnetic heads etc., i.e. devices which are expected to exhibit high levels of permeability at high frequencies.
Originality/value: It has been shown that thermal annealing at temperature close to the crystallization temperature leads to a significant increase of the initial magnetic permeability.
Keywords: Amorphous materials; Electrical properties and magnetic properties; Heat treatment annealing; X-ray diffraction method

1. Introduction

Amorphous metallic alloys represent an important class of materials with both scientifically and technologically unique material properties [1-3].

Since their discovery, their properties have been extensively studied due to a great deal of interest for fundamental reasons and their enormous potential in practical applications [4]. Magnetic metallic glasses are twice as hard as steel and have excellent magnetic properties. Moreover, it was found that some characteristic of glassy alloys important for modern devices of microelectronics, depend strongly on their magnetic properties and micromagnetic structures [4]. Specially, the transition metal – metalloid amorphous magnetic alloys typically exhibit excellent soft magnetic properties with low coercivities and hysteresis loss and high permeability's which render the alloys to be an outstanding candidate for host of applications [5÷7].

It is generally know that good soft magnetic properties of melt – spun amorphous alloys are lost by annealing – induced crystallization [5-7].

The crystallization process of amorphous alloys is the complex phenomenon, depending on chemical composition of alloy and conditions of heat treatment process [8-11]. The heat treatment process can be realized by conventional or impulse method [8, 12]. The method most often used is isothermal heating in constant time, for example 0.5, 1.0, 1.5, 8.0 hour [8, 11, 12]. It is know the result of heat treatment process of amorphous alloys below the crystallization temperatures relaxes the residual internal stresses induced during the preparation process, improving the magnetic response of the material. The crystallization process of amorphous alloys is interesting because it is connected with the changes involved in chemical and physical (e.g. magnetic) properties, which determine most applications [8, 14-17].

The main of the present paper is to study the influence of heat treatment parameters of changes of structure and magnetic properties of the amorphous $Co_{77}Si_{11.5}B_{11.5}$ involved by heat treatment.

2. Experiments

Experiments were carried out on $Co_{77}Si_{11.5}B_{11.5}$ amorphous alloy obtained in a form of strips (thickness of about 0.020 mm and width of 10.0 mm) by applying melt – spinning technique. In order to study the structural changes taking place during structural relaxation and crystallization X-ray diffraction analysis (XRD7 SEIFERT – FPM) using cobalt K_α radiation have been used (Table 1).

Table 1.
The diffractometer's parameters used in XRD method for samples of $Co_{77}Si_{11.5}B_{11.5}$ alloy

Diffractometer's parameters	Diffractometer XRD 7, SEIFERT - FPM firm	
	a	b
Current intensity of X – ray tube	40 mA	40 mA
Voltage of X – ray tube	35 kV	35 kV
The time of counting in one measurement's point	7s	20s
Step between measurement's points	0.05°Θ	0.01°Θ

Section of ribbon, were annealed in electric chamber furnace THERMOLYNE type F6020C with protective argon atmosphere in the temperature range from 373÷873 K with step of 50 K. The annealing time was constant and to 30 min., 45 min. and 1 hour.

Magnetic properties were determined by making use of static and dynamic measurements of samples in as quenched state and after annealing in temperature range T_a = 373-873 K. The magnetic permeability μ_r were measured with the use Maxwell -Wien bridge at frequency about 1 kHz and magnetic field 0.5 A/m; open coil, demagnetization factor was numerically and experimentally determined. The primary magnetization curve for the ribbons in as quenched state was examined by system equipped with fluxmeter. From this curve the maximum permeability μ_{max} for amorphous $Co_{77}Si_{11.5}B_{11.5}$ alloy in as quenched state was achieved. The saturation magnetic polarization $J=\mu_0 M$ was measured by magnetic balance. Measurements of saturation magnetic polarization $J=\mu_0 M$ were performed for the samples in as quenched state however initial relative magnetic permeability μ_r was performed for samples in as quenched state as well as after annealing.

3. Results and discussion

The examinations of structure performed by X-ray diffraction (XRD) technique show that in as quenched state the $Co_{77}Si_{11.5}B_{11.5}$ alloy has amorphous structure (Fig. 1).
The investigated $Co_{77}Si_{11.5}B_{11.5}$ alloy in as quenched state has a following magnetic properties: saturation magnetic polarization J=1.15 T (Fig. 3) and maximum permeability μ_{max}= 4500 (Fig. 4). The obtained physical properties: J, μ_r (Fig.2) and μ_{max} allow to classify the $Co_{77}Si_{11.5}B_{11.5}$ alloy in as quenched state as a soft magnetic material [12].

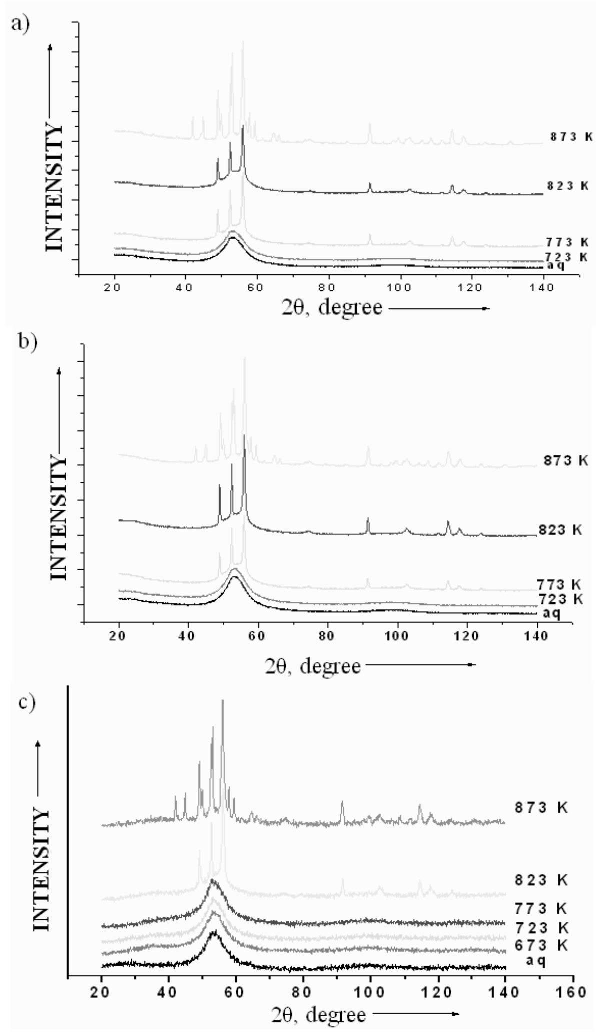

Fig. 1 X-ray diffraction pattern of the $Co_{77}Si_{11.5}B_{11.5}$ alloy in as quenched state and after annealing in temperature range T_a= 723÷873 K for 30 min.(a), 45 min.(b) and 1 hour (c). The diffractometer's parameters – see Table 1(a).

The XRD analysis shows that the first stage of crystallization is above 773 K for the $Co_{77}Si_{11.5}B_{11.5}$ alloy heat – treated for 1 hour and 823 K for the $Co_{77}Si_{11.5}B_{11.5}$ alloy heat – treated for 30 min. and 45 min (see Fig. 1).

Increase of the annealing temperature leads to changes of structure of the investigation alloy (Fig. 1).

The phases formed in different heat treatment conditions were identified using XRD, as in Fig. 1. Increase of the annealing temperature above 773 K leads to changes of structure of the investigated alloy (Fig.1). As can be seen from Fig. 1 at 823 K the crystallization of the amorphous alloy proceeds trough nucleation of the hexagonal (h.c.p.) α – Co phase in the amorphous matrix. Further increase of the annealing temperature leads to changes in X – ray diffraction pattern (Fig. 1) and at annealing temperature 873 K the existence Co_2B, Co_3B and Co_2Si phases were observed (Fig.1) besides to the α-Co phase.

Fig. 2 shows initial relative magnetic permeability μ_r measured at room temperature plotted versus 30 min. annealing (Fig.2a), 45 min. annealing (Fig. 2b) and 1 hour annealing (Fig.2c). The changes of magnetic properties have been observed with increasing the temperature annealing of investigated alloy. From Fig. 2, it can be recognized that μ_r passes by a distinct maximum (at annealing temperature 723 K) related to formation of nanocrystalline phase α –Co, or annealing out of free volumes (microvoids) formed into during fabrication is observed [16,17]. The last stage of annealing, in the temperature range from 730 K up to 850 K, is characterized by decrease of magnetic permeability (Fig. 2) of investigated alloy. Existence of borides Co_2B and Co_3B observed leads to decrease of magnetic permeability (Fig. 2). This phenomenon (at temperature above 730 K) can be explained by formation of the equilibrium phases as well as the grain coarsening. It can be recognized that the highest value is observed after 30 min. annealing – 1220. After 1 hour annealing initial relative magnetic permeability μ_r is 1140 and after 45 min. annealing - 1020. Investigated alloy after annealing in 30 and 45 min. from as quenched state to temperature 823 K have the same value (Table 2). After annealing 1 hour initial relative magnetic permeability μ_r is different compare with annealing in 30 and 45 min (Fig. 2 and Table 2).

Table 2.
The parameters of heat treatment (temperature and time) and initial relative magnetic permeability μ_r of the $Co_{77}Si_{11.5}B_{11.5}$ alloy

Annealing temerature T_a, K	The initial relative magnetic permeability μ_r of the $Co_{77}Si_{11.5}B_{11.5}$ alloy		
	30 min. annealing	45min. annealing	1h annealing
aq	620	640	620
373	700	660	1000
423	600	600	780
473	600	560	800
523	320	440	480
573	320	360	640
623	420	560	780
673	500	680	840
723	1220	1020	1140
823	10	10	80

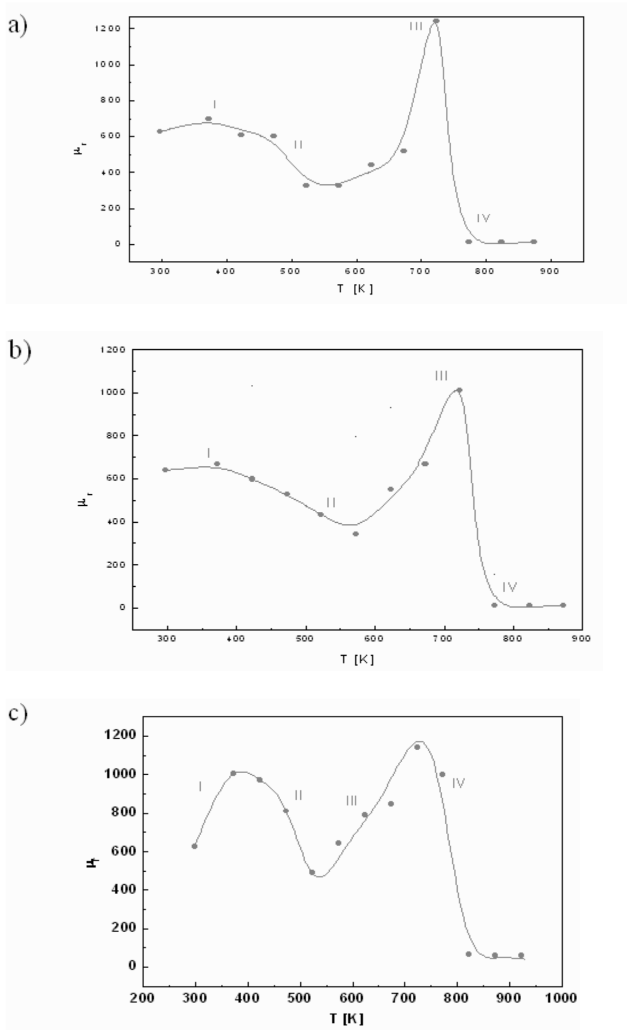

Fig. 2. Initial relative magnetic permeability μ_r for $Co_{77}Si_{11.5}B_{11.5}$ alloy after 30 min. annealing (a), 45 min. annealing (b) and 1 hour annealing (c).

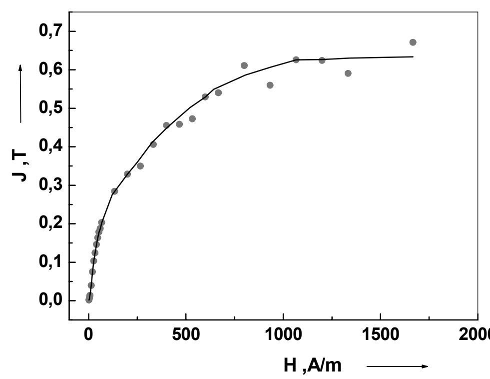

Fig. 3. Magnetization J versus magnetic field H for $Co_{77}Si_{11.5}B_{11.5}$ alloy obtained by fluxmeter

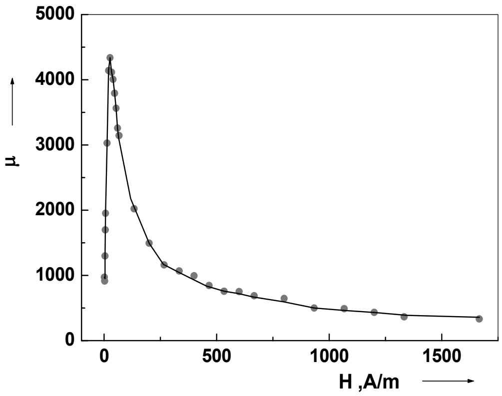

Fig. 4. The maximum permeability μ_{max} achieved from the primary curves of magnetization for $Co_{77}Si_{11.5}B_{11.5}$ alloy in as quenched state

4. Conclusions

The main conclusions of the present paper can be summarized as follows:

- the research results showed that $Co_{77}Si_{11.5}B_{11.5}$ alloy in as quenched state has an amorphous structure and physical properties like: maximum permeability μ_{max} = 4500, saturation magnetic polarization J = 1.15 T and initial relative magnetic permeability μ_r = 1220 (for 30 min. annealing)
- thermal annealing of amorphous $Co_{77}Si_{11.5}B_{11.5}$ alloy within the temperature range 373–873 K leads to crystallization process and changes of magnetic properties
- the crystallization process leads to increase initial relative magnetic permeability and maximum value have for alloy after annealing in temperature 723 K – 1220
- in the temperature T=873 K appearance of boride Co_2B, Co_3B and silicide phase Co_2Si was state. The existence of boride phases was confirmed by a decrease of initial magnetic permeability after annealing.

References

[1] R. Hasegawa, Applications of amorphous magnetic alloys, Materials Science and Engineering A 375-377 (2004) 90-97.

[2] P. Kwapuliński, J. Rasek, Z. Stokłosa, G. Haneczok, Magnetic properties of amorphous and nanocrystalline alloys based on iron, Journal of Materials Technology 157-158 (2004) 735-742.

[3] P. Kwapuliński, A. Chrobak, Z. Stokłosa, G. Haneczok, J. Rasek, J. Lelątko, Optymization of soft magnetic properties in nanoperm type alloys, Materials Science and Engineering C23 (2003) 71-75.

[4] N. Sulitanu, F. Brinza, F.M. Tufescu, Effect of Co substitution for Ni on the microstructure and magnetic properties of (Fe, Ni)-based amorphous alloys produced by melt spinning, Journal of Non-Crystalline Solids 351 (2005) 418-425.

[5] Z.Z. Yuan, X.D. Chen, B.X. Wang, Z.J. Chen, Crystallization kinetics of melt spun $Co_{43}Fe_{20}Ta_{5.5}B_{31.5}$ amorphous alloy, Journal of Alloys an Compounds 399 (2005) 166-172.

[6] H. Chiriac, A-E. Moga, M. Urse, F. Necula, C. Hison, On the amorphization and magnetic properties of Co-Fe-Si-B powders, Journal of Non-Crystalline Solids 250-252 (1999) 766-770.

[7] L.A. Dobrzański, R. Nowosielski, J. Konieczny, A. Przybył, Soft magnetic nanocomposite with powdered metallic ribbon based on cobalt and polimer matrix, Journal of Materials Processing Technology 162-163 (2005) 20-26.

[8] S. Lesz, R. Nowosielski, A. Zajdel, B. Kostrubiec, Z. Stokłosa, Structure and magnetic properties of the amorphous $Co_{80}Si_9B_{11}$ alloy, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 155-159.

[9] D. Szewieczek, J. Tyrlik-Held, S. Lesz, Influence of crystallization of amorphous $Fe_{84}Nb_7B_9$ alloy on the structure, mechanical properties and fracture morphology after decohesion, Proceedings of the 8th International Scientific Conference “Achievements in Mechanical and Materials Engineering”, AMME’99, Gliwice – Rydzyna – Pawłowice – Rokosowo, 1999, 575-580.

[10] D. Szewieczek, J. Tyrlik-Held, S. Lesz, Changes of mechanical properties and fracture morphology of amorphous tapes involved by heat treatment, Journal of Materials Processing Technology 109 (2001) 190-195.

[11] D. Szewieczek, J. Tyrlik-Held, S. Lesz, Changes of mechanical properties and fracture morphology of amorphous tapes involved by crystallization process, Proceedings of the Scientific Conference „Materials, Mechanical and Manufacturing Engineering” M^{3}E’2000, Gliwice, 2000, 267-272.

[12] H. Chiriac C. Hison, influence of laser irradiationon magnetic properties of Co-Fe-Si-B amorphous ribbons, Materials Science and Engineering A 304-306 (2001) 1066-1068.

[13] S. Lesz, R. Szewczyk, D. Szewieczek, A. Bieńkowski, The structure and magnetoelastic properties of Fe-based amorphous alloy with Hf addition, Proceedings of the 11th International Scientific Conference “Achievements in Mechanical and Materials Engineering”, AMME’2002, Gliwice – Zakopane, 2002, 311-318.

[14] D. Dróżdż, T. Kulik, The effect of preannealing conditions on the crystallization behaviour of amorphous $Co_{78}Si_{11}B_{11}$, Materials Engineering 4 (2001) 283-285.

[15] S. Lesz, R. Nowosielski, Z. Stokłosa, B. Kostrubiec, Magnetic properties of a Co-based amorphous alloy, Proceedings of the 11th International Scientific Conference “Contemporary Achievements in Mechanics, Manufacturing and Materials Engineering”, CAM^{3}S’2005, Gliwice – Zakopane, 2005 (CD-ROM).

[16] R. Nowosielski, A. Zajdel, S.Lesz, B. Kostrubiec, Z. Stokłosa, Crystallization kinetics of an amorphous $Co_{77}Si_{11.5}B_{11.5}$ alloy, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 121-125.

[17] R. Nowosielski, A. Zajdel, S.Lesz, B. Kostrubiec, Z. Stokłosa, Crystallization of amorphous $Co_{77}Si_{11.5}B_{11.5}$ alloy, Archives of Materials Science and Engineering 28/3 (2007) 141-148.