ANISOTROPY AND MAGNETOSTRICTION IN SINGLE CRYSTALS OF NEW SOFT MAGNETIC Fe-Ga-Si ALLOYS

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ANISOTROPY AND MAGNETOSTRICTION IN SINGLE CRYSTALS OF NEW SOFT MAGNETIC Fe-Ga-Si ALLOYS

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Abstract. – The magnetocrystalline anisotropy K_1 and magnetostriction λ_{100} and λ_{111} were measured at room temperature for disk specimens of as-grown single crystals of cubic Fe-Ga-Si ternary alloy system. Zero K_1 and zero magnetostrictive lines were obtained in the triangle diagram but they did not intersect each other.

Introduction

The soft magnetic property of cubic ferromagnetic materials depends on both the magnetocrystalline anisotropy K_1 and induced uniaxial anisotropy K_u, and arises in many cases from the magnetoelastic coupling involving magnetostriction λ and stress σ; it is favored by their smaller values. Well-known soft magnetic materials such as Mn-Zn ferrite, permalloy and sendust (Fe-Al-Si alloy) have K_1 and λ very close to zero. Recently new series of crystalline alloys with the bcc structure were found by Hayashi *et al.* [1] and Hayakawa *et al.* [2] to exhibit an excellent soft magnetism. These new alloys differ from the above materials in possessing a much higher saturation magnetic induction, nearly $4\pi M_s = 12$ to 14 kG. This property will be appropriate to a magnetic head material for high density recording by use of high magnetic coercivity media.

Another interesting feature of these new alloys is that their soft magnetic property may be related to an ordered or a disordered crystal structure as is the case in sendust alloy. Soft magnetic Fe-Ga-Si alloys involving 75 to 80 at% Fe [1] are regarded as alloying two mother alloys near Fe_3Ga and Fe_3Si. Fe_3Ga changes its crystal structure from an ordered fcc phase (Cu_3Au type) to an ordered bcc Fe_3Al phase (DO_3 type) at high temperatures above 630 °C [3, 4], and Fe_3Si from the DO_3 type to a disordered bcc FeAl phase (B2 type) at temperatures above 1120 °C. Consequently it is interesting to study K_1, magnetostriction and crystal structure in connection with soft magnetic property of the films.

This report is concerned with the growth of single crystals of Fe-Ga-Si alloys and measurement of their K_1 and magnetostriction constants λ_{100} and λ_{111}.

Experiments

Single crystals of 8 mm in diameter were grown in an alumina crucible of a pencil type in Ar atmosphere by the Bridgman method. The cooling rate of the crystal was kept to about 26 °C/hour or 45 °C/hour from the beginning of solidification, at about 1350 °C, down to 350 °C. The crystallographic directions of the crystals obtained were determined by Laue photography. Disks near 6 mm in diameter and 1 mm thick cut out from the lapped as-grown (100) slices by an ultrasonic cutter were finally etched chemically by 30 % HNO_3 solution in an ultrasonic washer to remove stress and were used to determine K_1 and magnetostriction constants. The composition of the single crystals was determined by electron probe microanalysis. The quantity K_1 was determined from torque measurements, and λ_{100} and λ_{111} were determined using strain gauges, both at room temperature.

Results and Discussion

Figures 1 and 2 show the contour lines of λ_{100} and λ_{111}, respectively, in units of 10^{-6}. It is found that in the Fe-Ga-Si ternary alloy system there exist both $\lambda_{100} = 0$ and $\lambda_{111} = 0$ lines and that λ_{100} tends to decrease with increasing Si content and decreasing Ga content, while λ_{111} decreases only with increasing Si content. Figure 3 shows the contour lines of K_1 in units of 10^3 erg/cc $\left(10^2\ \mathrm{J/m^3}\right)$. We can find that K_1 also has a zero line like λ_{100} and λ_{111}. Measurements of λ_{100}, λ_{111} and K_1 were made for several specimens annealed at 800 °C and further annealed at 1 000 °C; both 24 hours and then the samples were cooled at a rate of 300 °C/h down to 300 °C annealings lasted; however, the values were little changed. Figure 4 shows the contour lines of λ_{100}, λ_{111} and K_1, in which are also depicted the data for sputtered films [1], saturation magnetic induction B_s in kG, coercive force H_c in Oe at 10 Hz and zero magnetostriction line $\lambda_f = 0$.

Two important results are obtained from the figure. First, λ_{100}, λ_{111} and $K_1 = 0$ lines do not intersect each other. Second, an expected soft magnetic region may be close to, e.g., a composition $Fe_{74}Ga_9Si_{17}$, because in this region K_1 as well as λ_{100} and λ_{111} is very close to zero and its composition dependence is very slow as shown in figure 3, while the softest magnetic region observed in the films is a compositional area where K_1 changes rapidly and is different from the one expected from the single crystal data. A possible

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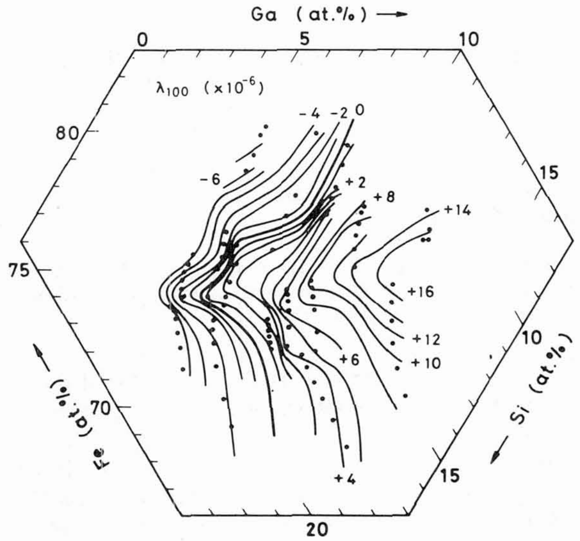

Fig. 1. – Contour lines of λ_{100} in Fe-Ga-Si ternary system at room temperature.

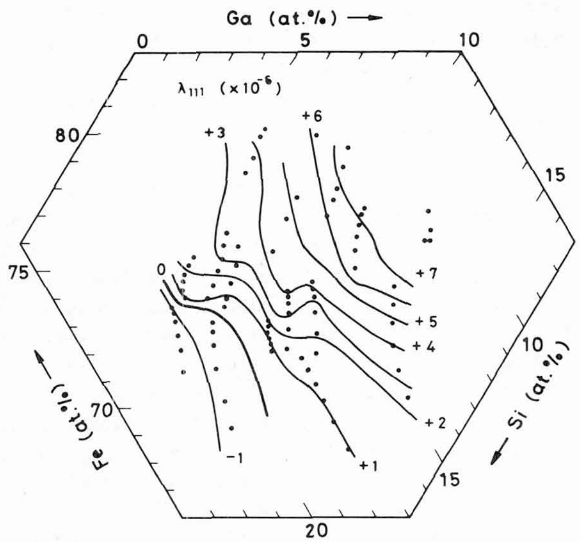

Fig. 2. – The same as figure 1, but for λ_{111}.

reason to be considered is a difference in the crystal structur between the films and crystals. Though an X-ray diffraction analysis of powdered specimens of the as-grown single crystals showed the existence of neither the B2 phase nor the DO_3 phase, a transmission electron microscopy study exhibited the existence of a certain amount of DO_3 phase.

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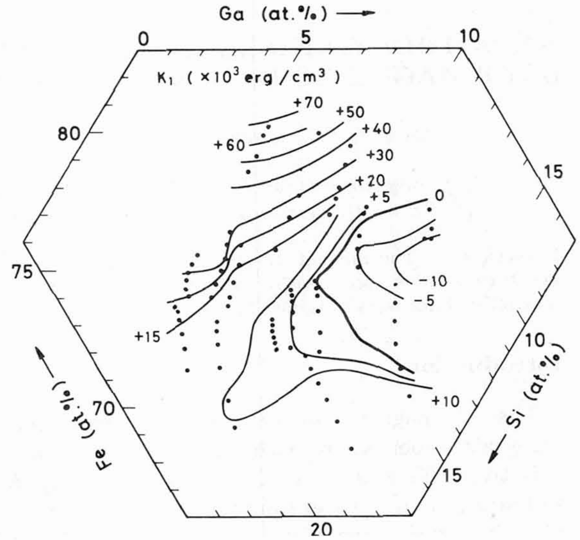

Fig. 3. – The same as figure 1, but for K_1.

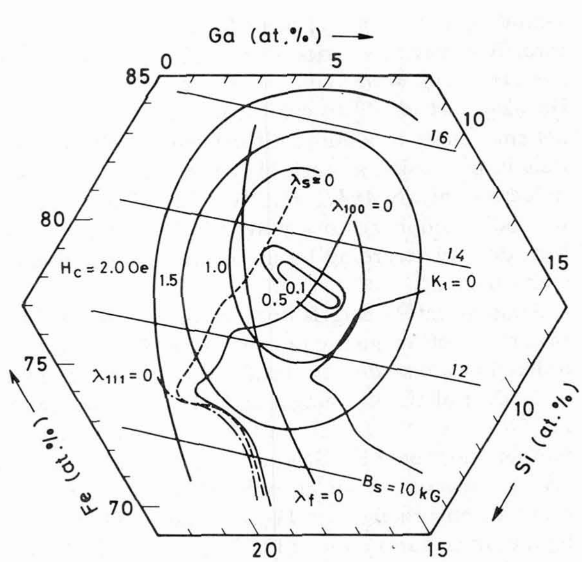

Fig. 4. – Zero contour lines of λ_{100}, λ_{111} and K_1 in Fe-Ga-Si alloys together with contour lines of B_s, H_c and $\lambda_f = 0$ for sputtered films annealed at 550 °C for 1 hour.

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