Magnetization anomalies of amorphous alloys in strong magnetic fields

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(Submitted 16 March 1979; resubmitted 17 April 1979)

Pis'ma Zh. Eksp. Teor. Fiz. **29**, No. 11, 676–679 (5 June 1979)

We have found that the magnetization of a ferromagnetic amorphous alloy FeNiSiB decreases with field growth at low temperatures in the region of strong magnetic fields. Possible causes of this anomaly are discussed.

PACS numbers: 75.30.Cr, 75.50.Bb

The special features of the amorphous alloys (AA)—existence in the form of single-phase solid solutions in a broad range of component concentrations and a high degree of compositional and topological disorder—make these materials highly desirable for a study of the fundamental problem of coupling between the structure of the solid state and magnetic properties. Peculiarities of the atomic structure of AA are manifested by complexity of their magnetic structure[1] and special behavior in strong magnetic fields.[2] The purpose of this article is to show that one of the special features encountered in AA is negative magnetic susceptibility in strong magnetic fields.

In the current work we studied variation in the magnetization $M(H,T)$ of AA specimen $Fe_{62.4}Ni_{15.6}Si_7B_{15}$ at temperatures $T=10$–280 K in magnetic fields H up to 50 kOe. AA specimen in the shape of strips ~ 30-μm thick and 5–15 mm wide were obtained by a rapid cooling of a liquid-alloy jet on the surface of a rotating copper disc. Their structural amorphism was confirmed by the results of structural x-ray analysis and calorimetry. The crystallization temperature was 763 K and the Curie temperature, 730 K. Specimen magnetization was measured by means of a vibrational magnetometer in the magnetic field of a superconducting solenoid. Specimen were $5\times2\times0.03$ mm and their longitudinal axes were field aligned. Specimen temperature was regulated by means of a type LPTC-T101 (Oxford Instr.) regulator. Polycrystalline nickel was used as a standard. Figure 1 shows the dependence $M(H)$ of AA specimen in relative units at different temperatures and of a nickel specimen at $T=4.2$ K. Clearly, saturation in AA at $T\leqslant 280$ K and in nickel at $T=4.2$ K is attained in relatively high fields which probably depends on a specimen geometry and, in the case of AA, possibly also on the magnetic inhomogeneity of the alloy.[2] As the temperature is lowered, value of $\chi(H,T)=\partial M/\partial H$ at $H\gtrsim 20$ kOe first decreases, while remaining positive, and subsequently its sign changes at $T\approx 180$ K while the absolute value increases up to $T=10$ K.

To study the nature of the observed anomaly, we examined the Mössbauer spectra of AA at $T=4.2$ K in a magnetic field $H=33.6$ kOe and without a field. Measurements were conducted by means of a standard type AME-31 spectrometer with a multi-channel analyzer and semiconductor detector. The source of Co^{57} gamma rays

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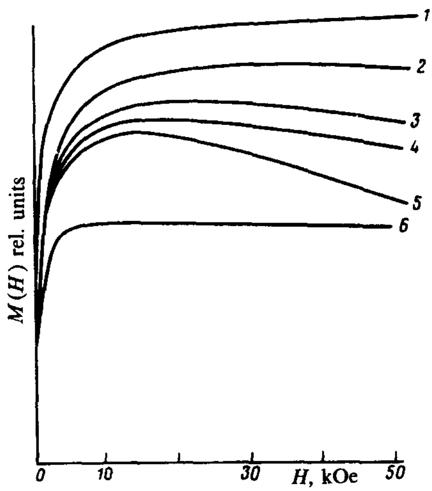

FIG. 1. Variation in magnetization with field for amorphous alloy specimen at temperatures 280 K(1), 240 K(2), 164 K(3), 107 K(4), and 49 and 10 K(5); and for nickel at temperature 4.2 K(6). $M(H)$ axis scale is arbitrary.

in chromium was kept at room temperature and the specimen with 15-mm diameter and 30-μm thickness was placed in the liquid helium at the center of a superconducting solenoid. Both the field H and gamma-ray emission were directed at right angles to the specimen plane. In the case of measurements without a magnetic field a vacuum low-temperature chamber with temperature control was used. Figure 2 shows the Mössbauer spectra of AA. At zero external field, the spectrum is characterized by six lines with Lorentzian shapes with the following half-widths: $\Gamma_{1,6} = 1.53$, $\Gamma_{2,5} = 1.2$ and $\Gamma_{3,4} = 0.55$ mm/sec and the mean effective field at the Fe^{57} nuclei $H_0 = 251.7$ kOe. When an external magnetic field $H = 33.6$ kOe was applied, the intensity of lines

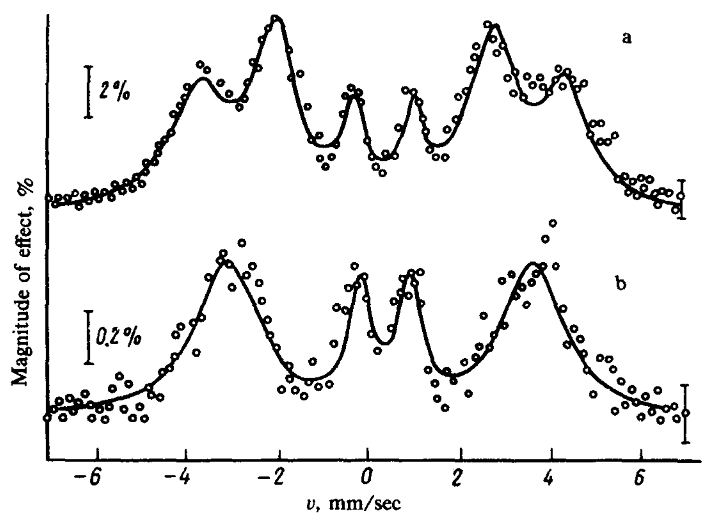

FIG. 2. Mössbauer spectra of Fe^{57} in the amorphous alloy FeNiSiB at temperature 4.2 K without a magnetic field (a) and in a field $H = 33.6$ kOe (b). Velocity zero corresponds to Fe^{57} spectrum in polycrystalline iron at room temperature. Solid lines represent curve fitting by electronic computer.

2 and 5 was negligibly small as a result of gamma-ray polarization and the value of the mean field H_0 in the absence of any changes in the specimen structure should decrease by an amount proportional to the external field H with allowance for the specimen demagnetizing field which in this case is 15 kOe. Thus, H_0 should be equal 233 kOe. Analysis of the spectrum in Fig. 2a shows that it is characterized by four lines with half-widths $\Gamma_{1,6} = 1.64$ and $\Gamma_{3,4} = 0.6$ mm/sec and $H_0 = 207.5$ kOe. Reduction of H_0 when an external field is applied is, therefore, 44.2 kOe instead of the expected 18.7 kOe. Moreover, the relative change $\Delta H_0/H_0 = (44.2 - 18.7)/233 = 10.9\%$. The H_0 field in AA is proportional to the mean magnetic moment of Fe atoms.[3]

The observed anomalous reduction in H_0 may, therefore, be considered as a decrease of the mean magnetic moment of Fe atoms in AA FeNiSiB as the external magnetic field grows. The relative reduction of a specimen magnetization $M(H)$ in a field $H = 18.7$ kOe at $T = 10$ K when compared to zero field, determined from curve $M(H)$ in Fig. 1, is $\sim 11\%$, i.e, it coincides with a relative decrease in the mean effective field H_0. It follows, therefore, that the cause of reduction of magnetization $M(H)$ studied in AA at high fields is the decrease in the mean magnetic moment of Fe atoms. An explanation for this phenomenon should be sought in the special features of the AA atomic structure. The maximum effective field at the Fe^{57} nuclei in AA $Fe_{80}P_{14}B_6$ at $T = 4.2$ K is $H_M = 380$ kOe[3]; this exceeds the value of H_M in crystalline iron at 40 kOe as a result of, it is assumed, large numbers of Fe atoms in the immediate vicinity of these atoms in AA. The bulk magnetostriction in Fe AA is positive and it exceeds the value in crystalline Fe by approximately an order of magnitude.[4] Taking these two facts into account it may be assumed that the observed decay of magnetization with the field depends on a reduction in the number of Fe atoms among the neighboring Fe atoms as the radius of the nearest neighbors increases with the field due to magnetostriction. The reversible nature of the obsered effect and its variation with the temperature both support this assumption. However, a possibility of phase transition cannot be fully excluded.[5]

The authors thank E. Dzhepbarov and A.N. Savvin for their assistance in the magnetic measurements, and V.P. Ovcharov and B.N. Kulagin for specimen preparation.

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