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Properties of Metamagnetic Alloy $Fe_{48}Rh_{52}$ in High Magnetic Fields

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Abstract—A technique for differential scanning calorimetry (DSC) of materials in high magnetic fields is developed. Based on Peltier elements, a differential calorimeter is designed to work in Bitter coil magnet fields (up to 140 kOe). Calorimetric studies are conducted for $Fe_{48}Rh_{52}$ alloy with the reverse magnetocaloric effect (MCE) in the vicinity of the metamagnetic structural phase transformation (PT). It is shown that the transition latent heat falls during both forward and reverse transformation as the magnetic field grows.

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Alloys of the Fe–Rh family have become of great practical and fundamental interest in recent years. They have attracted the attention of researchers studying the magnetocaloric properties of magnetics ever since the 1980s and remain record holders in values of reverse MCE: $\Delta T = -12.9$ K in a magnetic field of 19.5 kOe [1]. Alloys with compositions close to equiatomic display abnormally high saturation magnetization in the ferromagnetic phase (up to 130 G $(g\,cm^3)^{-1}$) [2] and have a number of unique properties, e.g., giant MCE, elastocaloric [3] and barocaloric [4] effects that are revealed near the 1st order of metamagnetic structural PT. The PTs observed in Fe–Rh epitaxial polycrystalline thin films are also of interest for prospective use in thermomagnetic recording [5] or in resistive memory cells [6].

In this work, the thermomagnetic properties of rapidly quenched $Fe_{48}Rh_{52}$ alloy, as promising material for magnetic cooling, were studied by means of DSC in high magnetic fields. Both crystalline phases of $Fe_{48}Rh_{52}$ alloy have BCC structures like CsCl but with different lattice parameters, since an isotropic increase in volume of 1% takes place in reverse PT [7]. Using a SQUID magnetometer, the field dependences of magnetization were obtained for a sample of $Fe_{48}Rh_{52}$ at temperatures of 290 to 340 K (Fig. 1). We may assert judging by these curves that there were two phases in the sample; one was ferromagnetic in the investigated range of temperatures, while the second was weakly magnetic and had a magnetic-field-induced PT of the 1st order.

Typical temperatures of the metamagnetic structural PT of the investigated alloy were initially determined using a Netzsch commercial calorimeter in zero magnetic field. The scanning rate was 10 K min^{-1}. The start and finish temperatures of the direct transition were $M_s = 312.6$ K, $M_f = 305.7$ K; those of the reverse transition were $A_s = 322.1$ K, $A_f = 329.4$ K (Fig. 2). The PT latent heat was determined from the area under the DSC peak, enabling us to calibrate a novel differential

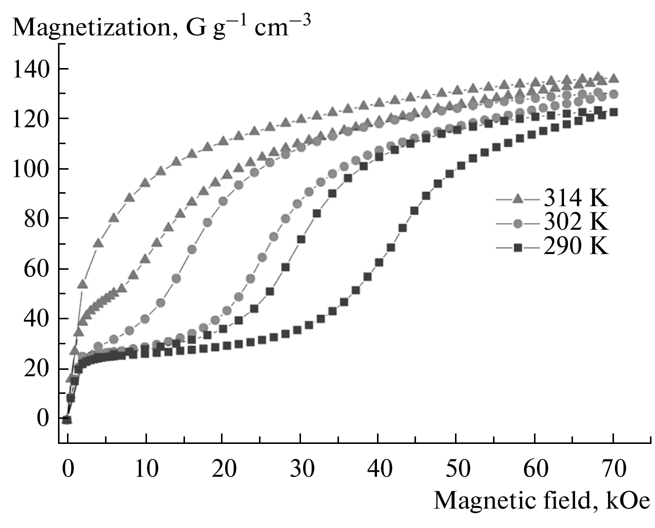

Fig. 1. Field dependence of magnetization for $Fe_{48}Rh_{52}$ alloy at different temperatures: (▲) 314 K; (●) 302 K; (■) 290 K.

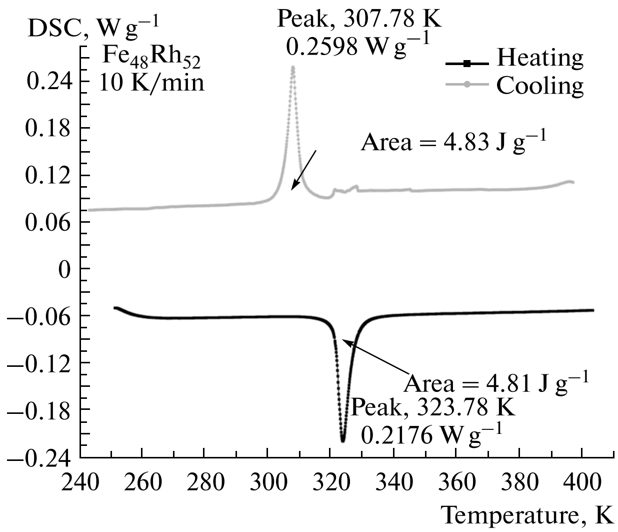

Fig. 2. DSC data for $Fe_{48}Rh_{52}$ alloy in zero magnetic field. The heating/cooling rate is 10 K min^{-1}.

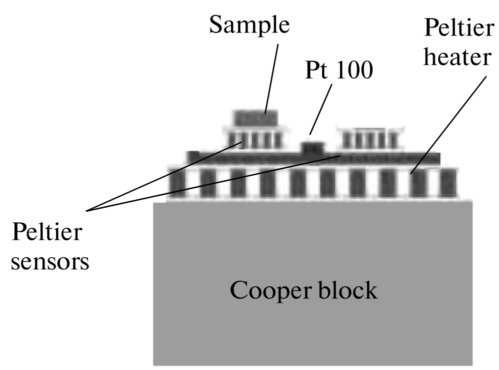

Fig. 3. Scheme of the experimental setup for the DSC of materials in a Bitter coil magnetic field (up to 140 kOe).

calorimeter based on Peltier elements for operation in high magnetic fields.

The technique proposed in [8] was used to produce a novel DSC in a magnetic field; the Peltier element can be used as a highly sensitive gauge to measure the thermal flux. Two Peltier elements on a copper substrate connected in a differential mode were used in our setup. A sample of the investigated $Fe_{48}Rh_{52}$ alloy was glued onto one of the elements. The substrate temperature was controlled with a Lake Shore unit connected to the Peltier heating element and a Pt 100 platinum thermoresistor (Fig. 3). The copper block had a good thermal contact with the walls of the vacuum chamber into which the calorimeter was placed. The described setup was placed in a Bitter coil magnet field of up to 140 kOe.

The results from DSC for our $Fe_{48}Rh_{52}$ alloy in fields up to 40 kOe are shown in Fig. 4. The rate of temperature change was 10 K min^{-1}. The graph clearly shows the unevenness of the PT temperature shift in the field and the broadening of DSC peaks. The latent heat of PT was calculated from the area under the peaks in different magnetic fields; the resulting data are presented in Fig. 5. One can see that as the magnetic field grew from 0 to 20 kOe, the latent heat of direct PT fell from 4.83 to 3.86 J g^{-1}, while that of the reverse PT dropped from 4.81 to 3.04 J g^{-1} as the magnetic field grew from 0 to 40 kOe. This is in satisfactory agreement with the results obtained in [4].

We also studied he latent heat of PT induced by the magnetic field at constant temperature $T = 280$ K. The rate of magnetic field growth was 120 kOe min^{-1}. The results for magnetic fields of 120 and 140 kOe are shown in Fig. 6. This technique allowed us to deter-

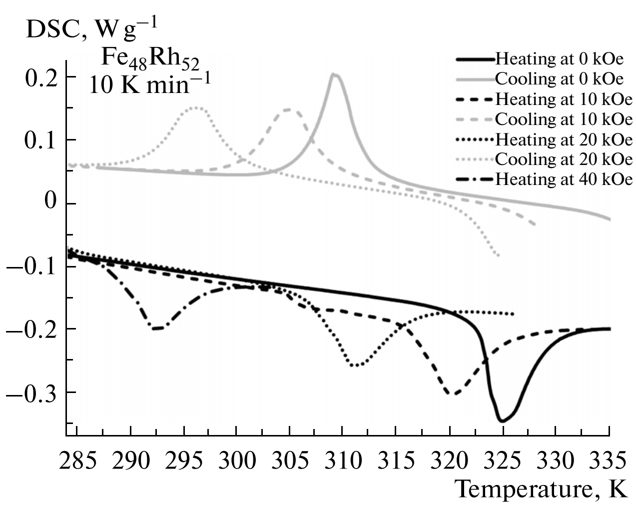

Fig. 4. DSC data for $Fe_{48}Rh_{52}$ alloy in magnetic fields of 0–40 kOe. The heating/cooling rate is 10 K min^{-1}.

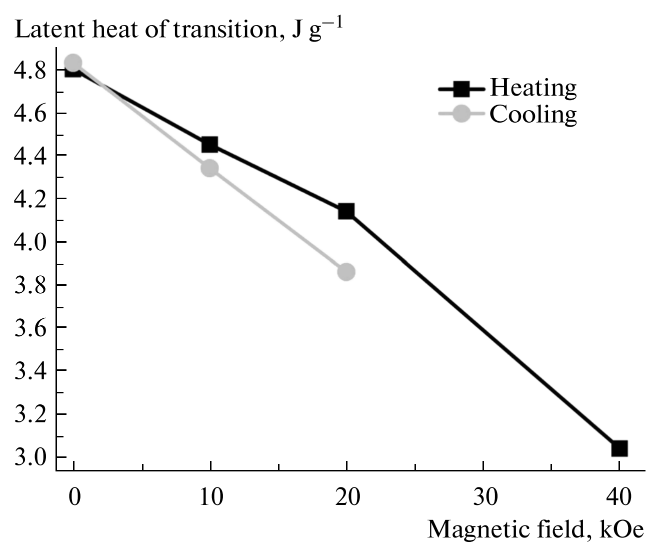

Fig. 5. Dependence of latent heat on the applied magnetic field at heating and cooling in $Fe_{48}Rh_{52}$.

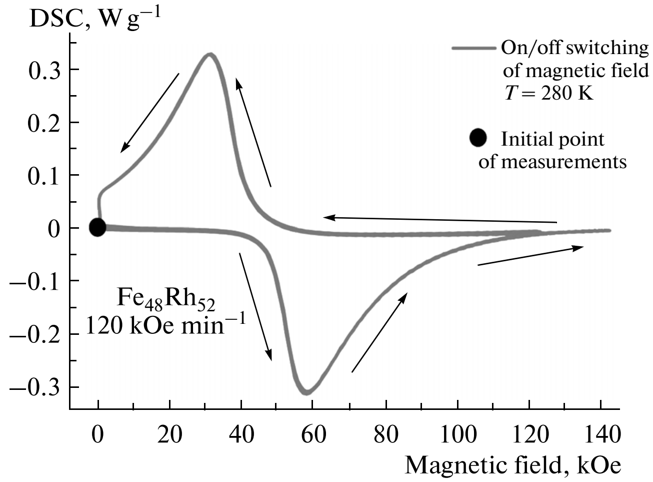

Fig. 6. Calorimetric study of the latent heat of PT during the on/off switching of a magnetic field with a rate of 120 kOe min^{-1} at a constant temperature of 280 K in $Fe_{48}Rh_{52}$ alloy.

mine the minimum magnetic field needed to produce a complete PT at constant temperature. Given the conditions for $Fe_{48}Rh_{52}$, this field is 120 kOe.

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