Magnetostriction of certain $R\mathrm{Co}_5$ compounds in strong magnetic fields

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The magnetostriction of $R\mathrm{Co}_5$ compounds (R = Y, La, Ce, Sm) was measured in pulsed fields up to 200 kOe. It is shown that in the basal plane the striction is due to the magnetostriction of the paraprocess and to the magnetostriction connected with rotation of the magnetization. The saturation of the latter amounts to 40×10^{-6} for YCo_5 and $LaCo_5$, $\sim-300\times10^{-6}$ for $CeCo_5$, and $\sim-500\times10^{-6}$ for $SmCo^5$.

1. To understand many phenomena in ferromagnets it is important to know their magnetostriction. This pertains also to magnetically-homogeneous compounds of the $R\mathrm{Co}_5$ type (R is a rare-earth metal or yttrium), in which the magnetocrystal anisotropy constant is very large ($K\sim10^8$ erg/cm^3). These compounds are of interest because they are used to manufacture permanent magnets with unusual characteristics. In particular, an unprecedented magnetic energy, 32×10^6 G-Oe, corresponding to the theoretical limit,[1] was obtained with an $SmCo_{5.3}$ single crystal. However, the coercive force of the magnet turns out to be much lower than the theoretically expected value, which is determined by the anisotropy field $H_A=2K/I_s$ (I_s is the saturation magnetization). One of the possible causes of this phenomenon is the magnetoelastic anisotropy, which can lead in individual sections of the crystals to a low effective magnetic anisotropy. However, we have so far no data on the magnetostriction in $R\mathrm{Co}_5$ compounds. The present paper fills this gap in part.

2. The measurements were performed on single-crystal spheres of 2 mm diameter (R = Y, La, Ce, and Sm) and on polycrystalline rods measuring $1.3\times1.3\times6$ mm, cut from isotropic and anisotropic permanent magnets prepared by compressing power and subsequent sintering (R = Y, Ce, and Sm).

The magnetostriction was measured by the method of removable piezoelectric pickups.[2] The period of the natural oscillations of the measuring system was 0.13 msec. A pulsed magnetic field up to 200 kOe and duration 5 msec was obtained by discharging a capacitor bank into a wire-wound solenoid. The inhomogeneity of the field at a distance 5 mm from the center of the solenoid did not exceed 2%. The field was measured with an error of 5%. The center of the sample was made to coincide with the center of the solenoid with accuracy ±1 mm.

The measurement of the magnetostriction on anisotropic samples in a direction transverse to the easy magnetization axis (EMA) was made complicated by the fact that when the EMA is not strictly perpendicular to H the sample is acted upon by a torque which is sensed by the piezoelectric pickups together with the magnetostriction. As a result not only the signal amplitude but also, as it turns out, the magnitude and sign of the phase shift between the signal and the field, depend on the angle between the easy magnetization axis and H. Special measurements have shown that the sought position of the sample should be taken to be such at which the phase shift is minimal. This position was found by varying the mutual position of the solenoid and the sample. The accuracy with which the sample was set by the described method was on the order of 0.1–0.5°.

After remounting the samples many times, the scatter of the values of the striction relative to the arithmetic mean value, in a field 200 kOe, was ±10–25%, with the exception of the $SmCo_5$ samples, for which the scatter for measurement across the EMA reached ±50%.

3. From the plots of the magnetization of the single crystals with R = Y, La, Ce, and Sm across the EMA we obtained respectively the following anisotropy fields: H_A = 110, 150, 170, and 450 kOe. (The measurements were carried out by an induction method[3] in pulsed fields up to 240 kOe.) The value of H_A for $SmCo_5$ was estimated by extrapolating the magnetization curve to the saturation value. The obtained values of H_A agree with those given in[4].

Figure 1 shows the striction curves $\lambda(H)$ measured on single crystals along and across the EMA. It is seen that $\lambda>0$ along EMA and increases linearly with the field. For $CeCo_2$, the slope $d\lambda/dH$ is $\approx25\times10^{-10}$ Oe^{-1}, and for the remaining $R\mathrm{Co}_5$ we have $d\lambda/dH\approx3\times10^{-10}$

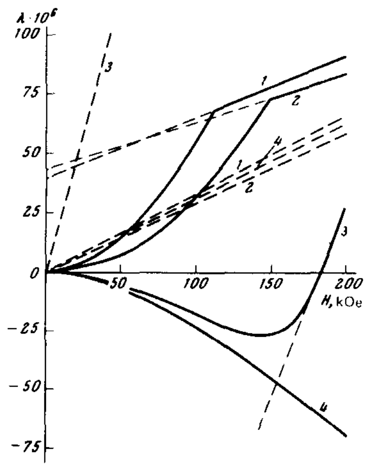

FIG. 1 Plots of $\lambda(H)$ along and across the easy magnetization axis (dashed and solid curves, respectively): 1—YCo_5, 2—$LaCo_5$, 3—$CeCo_5$, 4—$SmCo_5$.

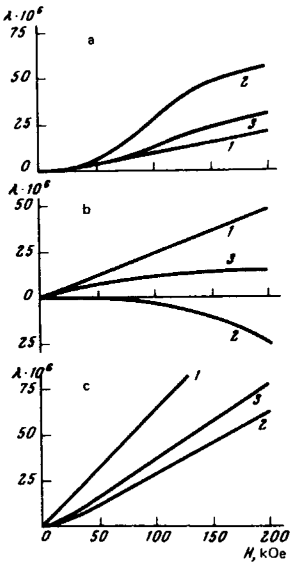

FIG. 2. Plots of $\lambda(H)$ for polycrystalline samples: a—YCo_5; b—$SmCo_5$, c—$CeCo_5$; 1—along the magnetic-texture axis, 2—across this axis, 3—isotropic sample.

Oe^{-1}, i.e., lower by one order of magnitude. Practically the same slope is possessed by the sections of the $\lambda(H)$ curves in fields $H > H_A$, measured across the EMA of crystals with $R = $ Y, La, and Ce. This indicates that the striction, which varies linearly with the field, is the magnetostriction λ_n of the paraprocess. Thus, in the basal plane we have $\lambda = \lambda_n + \lambda_b$, where λ_b is the magnetostriction connected with the rotation of the magnetization. The saturation of this magnetostriction is obtained by extrapolating the linear section of the $\lambda(H)$ curves to $H = 0$, namely $\lambda_s \approx 40\times10^{-6}$ for YCo_5 and $LaCo^5$, and $\lambda_s \approx -300\times10^{-6}$ for $CeCo_5$. For $SmCo_5$, $\lambda < 0$ in the direction transverse to the EMA. After determining the contribution of λ_n in accordance with the dashed curve of 4, we find that $\lambda_b = \lambda - \lambda_n = \sim -100\times10^{-6}$ in a field 200 kOe. Extrapolating $\lambda_b(H)$ to $H = 450$ kOe, we obtain $\lambda_s \sim -500\times10^{-6}$.

Figure 2 shows plots of $\lambda(H)$ for polycrystalline samples of YCo_5, $SmCo_5$, and $CeCo_5$. It is seen from a comparison with Fig. 1 that in polycrystals the striction is for the most part less than in single crystals. This may be due to the porosity of the samples, to the incomplete magnetic texture, and also to the difference in the shapes between the single-crystal and polycrystalline samples (including the difference between the shapes of the standard nickel samples used for calibration in each case). Qualitatively, however, the $\lambda(H)$ curves of polycrystals and single crystals agree in form. Thus, for all the compounds $\lambda > 0$ along the magnetic-texture axis and increases linearly with the field. For YCo_5, for which λ_n and λ_b are positive, the curve across the texture axis (curve 2) lies higher than the other curves and changes slope in the region $H \approx H_A$. In $SmCo_5$, to the contrary, curve 2 lies lower than the remaining curves, which also agrees with the course of the $\lambda(H)$ curves of the single crystal. The entire curve 2 of $CeCo_5$ lies in the region >0, and thus does not agree with the $\lambda(H)$ curve in the basal plane of the single crystal. This can be attributed to the incomplete magnetic texture in the polycrystal, recognizing at the same time that λ in a single crystal is much larger along the EMA than across it.

It follows thus from the results that: a) RCo_5 compounds have a large positive magnetostriction of the paraprocess. This magnetostriction is of the same order in YCo_5, $LaCo_3$, and $SmCo_5$ as in cobalt,[5] and is larger by one order of magnitude in $CeCo_5$. b) Measurements on YCo_5 and $LaCo_5$ show that the magnetostriction connected with the rotation of the magnetization in the subsystem of the cobalt ions is positive, and its saturation value amounts to $\approx 40\times10^{-6}$. In $CeCo_5$ and $SmCo_5$, to the contrary, this magnetostriction is negative and is larger in absolute magnitude by approximately one order. c) The large magnetostriction in $SmCo_5$ shows that the magnetoelastic anisotropy can be one of the causes of the decrease of the magnetocrystalline anisotropy in the region of the defects, and it is therefore why the coercive force of permanent magnets made of this material is relatively low.

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