$SmCo_5$ CRYSTALS WITH MAGNETIC ENERGY 32 MILLION GAUSS-OERSTED

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A single-domain state with magnetic energy 32 million G-Oe was obtained in bulky single crystals of $SmCo_5$ by delaying the formation and growth of the magnetization-reversal nuclei. This is the theoretical limit of this material and never before attained in permanent magnets at room temperature.

The maximum magnetic energy $(BH)_{max}$ of a permanent magnet is equal to $4\pi^2 I_s^2$ (I_s is the saturation magnetization of the material). This corresponds to a state with induction $4\pi I_s$ in an internal negative field numerically equal to $2\pi I_s$. Such a state can be realized in principle in single crystals with an anisotropy field $H_A \geq 2\pi I_s$ saturated in a magnetic field applied along the easy magnetization axis. Sufficiently large single crystals, however, begin to demagnetize as a rule in a field $|H_c| << 2\pi I_s$, owing to the onset and growth of magnetization-reversal nuclei (RN).

There is still no clear idea of the conditions and mechanism of RN formation. It can only be stated that they are produced in those spots of the crystal where local imperfections lower the anisotropy field. One should expect that in crystals with very high values of the anisotropy field it would be possible to delay the formation and the growth of the RN up to a negative internal field equal to $2\pi I_s$. It is of interest in this connection to consider compounds of the type RCo_5 (where R is a rare-earth element), which have unusually high uniaxial magnetic anisotropy constants ($\sim 10^8$ erg/cm^3).

We have investigated single crystals of the compounds $SmCo_{5+x}$, with values of x from 0 to 0.5. They were obtained from large-grain ingots fused in a high-frequency oven and homogenized at 1200°C with subsequent quenching in water. Metallographic and x-ray microanalytic investigations of the ingots have shown that at cobalt contents from 66.1 to 68.4 wt.% the alloys are structurally and chemically homogeneous, in accordance with the phase diagram of [1]. Spherical samples of $\sim$2 mm diam were prepared from individual grains by rolling on polishing cloths. To remove the layer damaged by the rolling, the samples were chemically etched and then electrolytically polished. The magnetic properties were measured with a vibromagnetometer in an electromagnet having a maximum field 30 kOe.

Figure 1 shows plots of the saturation induction and of the anisotropy field against the alloy composition. It is seen that $4\pi I_s$ increases linearly with increasing cobalt content. The anisotropy field, at small deviations from stoichiometric composition, depends little on the concentration, dropping noticeably only for the alloy richest in cobalt. We note that the anisotropy field of $SmCo_5$ is equal to $\sim$440 Oe, which is much higher than

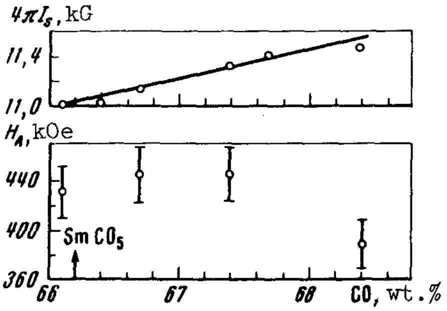

Fig. 1. Concentration dependence of the saturation induction and of the anisotropy field of $SmCo_{5+x}$ alloys.

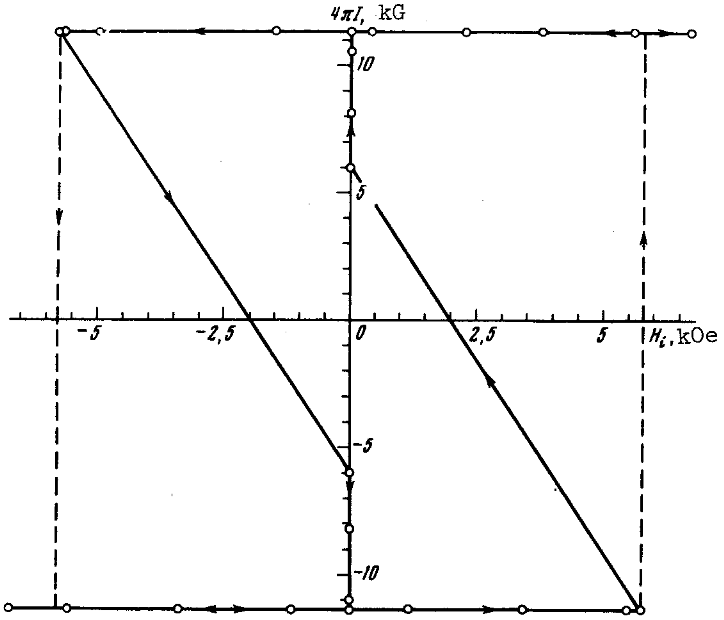

Fig. 2. Hysteresis loop of spherical $SmCO_{5.3}$ sample (solid line). The dashed line shows the hysteresis loop for the material (closed magnetic circuit).

the previously reported values (210 - 290 kOe according to the data of [2] and 390 kOe according to [3]).

Prior to etching and polishing, the samples were demagnetized already in a positive external field. The surface layer apparently contains defects that facilitate greatly the onset (or preservation) of RN capable of growing in a relatively weak negative internal field. After removal of the layers deformed during their production, the samples had also a slight hysteresis after magnetization in fields lower than a definite value. However, after applying a 30-kOe field along the easy-magnetization axis, the samples retained the magnetization not only in a zero field but also in appreciable negative external fields. In a certain field H_c, a jumpwise reversal of magnetization occurred. Consequently, the removal of the deformed layer greatly hindered the formation and the growth of the RN.

By way of example, Fig. 2 shows the hysteresis loop of a sample of $SmCo_{5.3}$ plotted in coordinates $4\pi I$ and H_i, where I is the magnetization and H_i is the intensity of the internal field. The amplitude of the magnetizing field was 30 kOe. We see that the sample retains the value $4\pi I = 4\pi I_s = 11300$ G up to $H_i = -5800$ Oe. Thus, the maximum magnetic energy of this sample is 32 million G-Oe, i.e., the theoretically possible value. This is the first time that such an energy was obtained for permanent magnets at room temperature. Similar results were obtained with certain alloys of different composition.

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[2] K.J. Strnat, IEEE trans. on Magnetics Mga-6, 182 (1970).
[3] E. Tatsumoto, T. Okamoto, H. Fujii, and C. Inoue, J. de Phys. 32, C-1-550 (1971).