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Temperature Dependence of Domain Width in Thin Layers of $BaFe_{12}O_{19}$

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Changes in magnetic domain width in $BaFe_{12}O_{19}$ single crystals were measured on the c-plane by Faraday effect in the temperature range from -100°C to 250°C. The increase of the width with temperature was almost linear within this temperature range and the temperature coefficient was 8.9×10^{-4} per 1°C. The change in the wall energy was also calculated from the domain width and the coefficient was -2.3×10^{-3} per 1°C.

The both results deviate slightly from the theoretical values caluculated on a simple model.

Introduction

Observations with various techiques of magnetic domains at various temperatures were reported by several researchers[1)-4)]. But the quantitative treatments were very few in number. Meanwhile, Kooy and Enz[5)] observed the domain structures in thin layers of $BaFe_{12}O_{19}$ by Faraday effect and gave a clear explanation on the relation between the domain structures and the strength of applied magnetic field. Saturation magnetization I_s and anisotropy constant K of $BaFe_{12}O_{19}$ were reported by Rathenau[6)] and it is expected from the results that the thin layers of the crystal show simple slab domains and that it does not change to the Curie point.

In this report, the experimental results on the relation between the domain width and temperature in the compound are described, comparing them with the theoretical values on a simple model.

Specimen

Crystals were prepared by cooling 1.7 g Fe_2O_3 with 50 g $BaCl_2$ in an alumina tube in oxygen atmosphere from 1250°C at the rate of 5°C/Hr, as reported by Brixner[7)]. Then, the mixture was washed in hot HCl solution. After magnetic separations, thin transparent hexagonal platelets were found among comparatively thick crystals. Their typical dimension was 0.5 mm in diameter and 1 to 10 μ in thickness. Each crystal was fixed separately with Cemedine* on a cover glass for microscopic observation. By X-ray investigations, it was proved that the platelet is a single crystal of $BaFe_{12}O_{19}$ and the main surface is perpendicular to the c-axis.

* Trade name of an adhesive.

Apparatus

A polarizing microscope with a high temperature objective of refraction type was used for observation. Magnification of the microscope was about 400×. The specimen was heated by a nichrome furnace or cooled with liquid nitrogen in a specially designed stage, evacuated by a rotary pump. A tungsten lamp with red filter was used as a light source. The arrangement is schematically shown in Fig. 1.

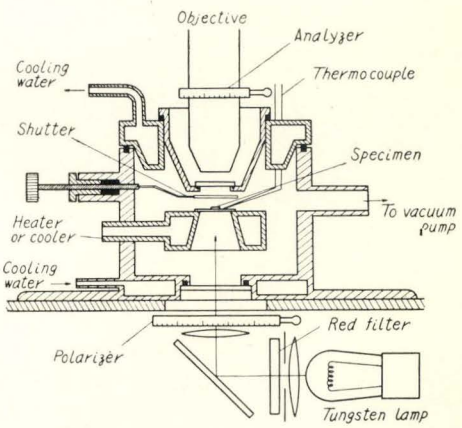

Fig. 1. Arrangement of polarizing microscope and heating or cooling stage.

Results

Microphotographs of the domains at room temperature are shown in Fig. 2.

In the figure, (a) and (c) are taken at the opposite position of the analyzer, and black

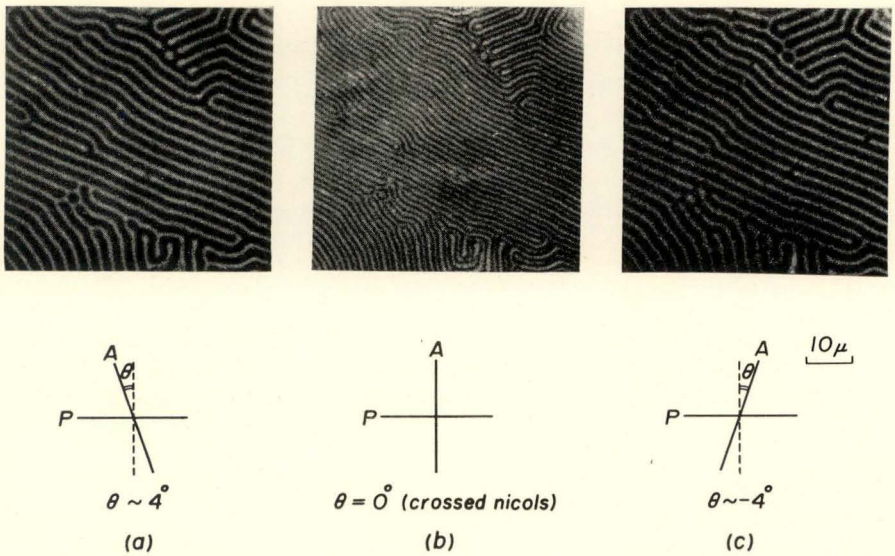

Fig. 2. Examples of domains in a $BaFe_{12}O_{19}$ layer at room temperature observed by Faraday effect. Positions of analyzer are shown under the photographs. Thickness of the crystal is 6 μ.

domains in (a) are changed to white ones in (c). (b) shows a crossed Nicols state, where the domain wall can be seen as a black stripe. Domain width was determined to be a mean width of about five black and white domains each on the enlarged photographs, of which the total magnification was about 1200×.

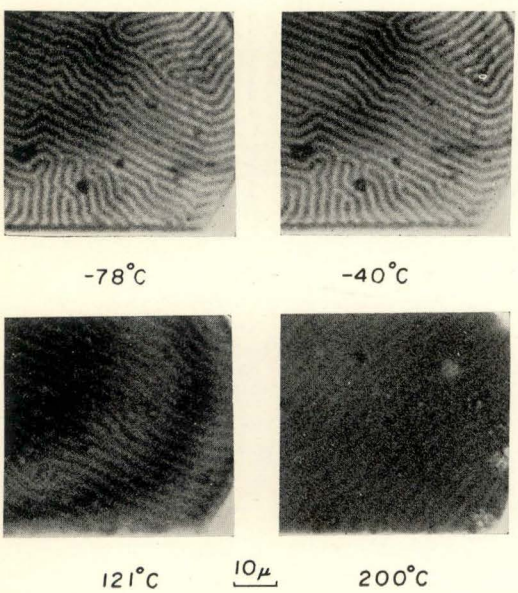

Fig. 3. Domains at various temperatures in the same part of a crystal, 6 μ thick.

Examples of the domains at various temperatures are shown in Fig. 3.

The width becomes wider with rising temperature. Since the saturation magnetization of the compound rapidly decreases[6], the domain pattern by Faraday effect loses its contrast at higher temperatures. In the present experiment, changes in width could be followed up to about 250°C. The observed changes in width are plotted against the temperature in Fig. 4. Observed results from several crystals of various thickness, ranging from 3 to 6 μ, showed a good coincidence with one another.

If crystal thickness is denoted by L, the optimum domain width D can be expressed

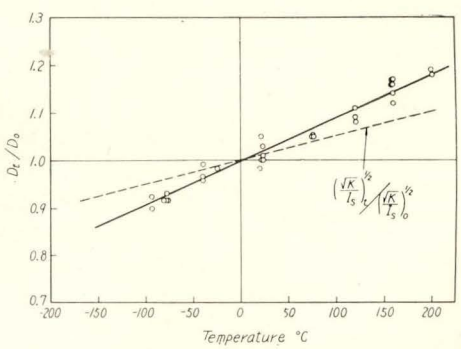

Fig. 4. Observed and caluculated domain width *vs.* temperature curves of $BaFe_{12}O_{19}$.

for the simple slab domain as follows:[8]

$$D^2=(\sigma_w L)/(1.705 I_s^2) \qquad (1)$$

where σ_w is the wall energy per unit area. Since σ_w is proportional to $I_s K^{1/2}$, where K is the anisotropy constant, formula (1) can be written as follows:

$$D^2=ALK^{1/2}/I_s \qquad (2)$$

Thus, for the simple model, the change in domain width with temperature is given by

$$D_t/D_0=(K^{1/2}/I_s)_t^{1/2}/(K^{1/2}/I_s)_0^{1/2} \qquad (3)$$

and the change in wall energy can be expressed as

$$(\sigma_w)_t/(\sigma_w)_0=(I_s D)_t^2/(I_s D)_0^2 \qquad (4)$$

The caluculated curve by formula (3) is also shown in Fig. 4.

Both curves are almost straight in the range of the experiments and the mean temperature coefficient of the measured domain width between -100°C and 200°C was 8.9×10^{-4} per 1°C. The ratio of wall energy is plotted against temperature by formula (4) in Fig. 5. The change of $I_s K^{1/2}$ is also illustrated in the same figure.

Observed temperature coefficient of the wall energy between -100°C and 200°C was -2.3×10^{-3} per 1°C.

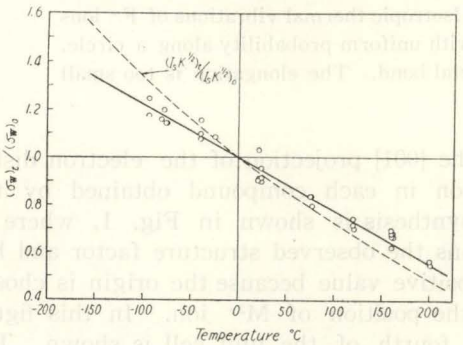

Fig. 5. Ratio of wall energy against temperature.

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DISCUSSION

J. Smit: The temperature dependence of the exchange energy, used for the calculation of the wall energy, was taken to be proportional to that of I_s^2. This is valid for a ferromagnetic, but for a ferrimagnetic one has to consider the magnetizations of the sub-lattices. For substances which show a rather strong decrease in saturation magnetization with increasing temperature, as for $BaFe_{12}O_{19}$, it can be made plausible that the exchange energy of a Bloch wall varies slower than does I_s^2, as is observed. Suppose two sublattices with magnetizations I_1 and I_2, such that $I_1>I_2$. The greater magnetization is supposed to decrease more rapidly with temperature than the smaller one, giving rise to a resultant magnetization which decreases even more rapidly. If it is assumed that the exchange energy of a Bloch wall varies with temperature as M_1M_2, this temperature dependence is therefore slower than M_s^2, because both M_1 and M_2 vary less rapidly than does M_s. This is particularly clear for the extreme case of a ferrite with a compensation point for M_s, at which the exchange energy is certainly not zero. This may explain the observed less rapid temperature dependence of the deduced Bloch wall energy as compared with that of $M_sK^{1/2}$.