occurs, because some magnetic hard material which is precipitated parallel to the {111} plane of $NiFe_2O_4$ hinders the magnetic domains from their free displacement and rotation in $NiFe_2O_4$. Then the domain movement becomes irreversible when the magnetic field strength is exceeded over H_c of the material, and finally the bulk reaches saturation. Thermal treatment only makes the specimen bring its virgin state, rather than initial state.

Our acknowledgements are made to Mr. S. Mita, Chief Engineer in authors' laboratory and Dr. H. Inuzuka, manager of its Solid State Department, for their interests and encouragements in the course of this research. The helpful advice of Prof. Ishikawa, Institute for Solid State Physics, University of Tokyo, has been invaluable in the pursuit of this work.

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JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN VOL. 17, SUPPLEMENT B-I, 1962
PROCEEDINGS OF INTERNATIONAL CONFERENCE ON MAGNETISM AND CRYSTALLOGRYPHY, 1961, VOL. I

Domain Structure and Magnetic Properties of Mn_5Ge_3

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Domain structure in the intermetallic compound Mn_5Ge_3 was investigated by the method of powder patterns, and the coercivity and anisotropy of this alloy were measured.

The surface of Mn_5Ge_3 samples (crystallographic type $D8_8$)[1], was carefully polished mechanically; on spreading a magnetic suspension thereon[2], powder patterns could be observed microscopically. Identical ones were observed on non-polished small crystals. This shows that mechanical processing introduces no deformations appreciably affecting the patterns.

Fig. 1 shows patterns on a surface approximately parallel to the esay axis (denoted by ***e***), whence intentionally not all scratches had been removed in order to gain insight into the changes in concentration of the colloid grains as dependent on the external magnetic field ***H***. Photo (a) is at $\boldsymbol{H}=0$. ***H*** applied parallel to ***e*** gives rise to a pattern of alternately lighter and darker areas. Reversion of ***H*** by 180° causes the darker areas to become light, and inversely. Thus, the direction of magnetisation of a single domain can be determined in a simple manner. The ***H*** values were insufficient here for producing a noticeable broadening of the one domains and narrowing of the remaining ones.

Reduction of the intense scattered fields on the surface perpendicular to ***e*** occurs through formation of dagger-like sub-domains reaching into the bulk of the basic domains. The cross sections (perpendicular to ***e***) of the Bloch walls of these sub-domains form chains of single small circles (Fig. 2a) or of wreaths of circles (Figs. 2b and 3), according to the basic domain width. At very small thickness of the crystal dagger-like domains no longer arise.

Experimentally, the basic domains can be inferred to have the shape of plates (Fig. 4a)

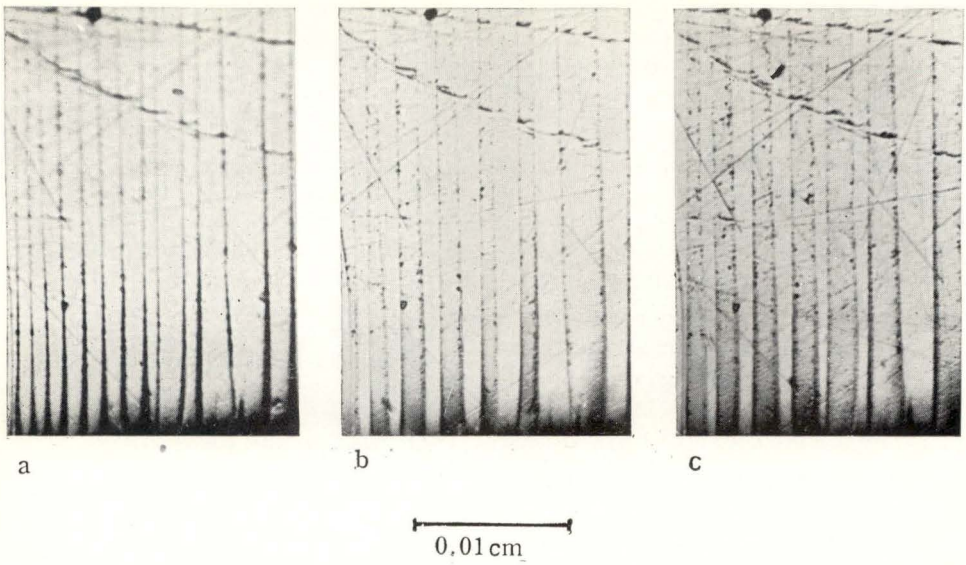


Fig. 1. Powder patterns on surface approximately parallel to easy axis e: (a) at $H=0$; (b) at $H\approx 50$ Oe parallel to e; (c) at $H\approx 50$ Oe antiparallel to field of (b).

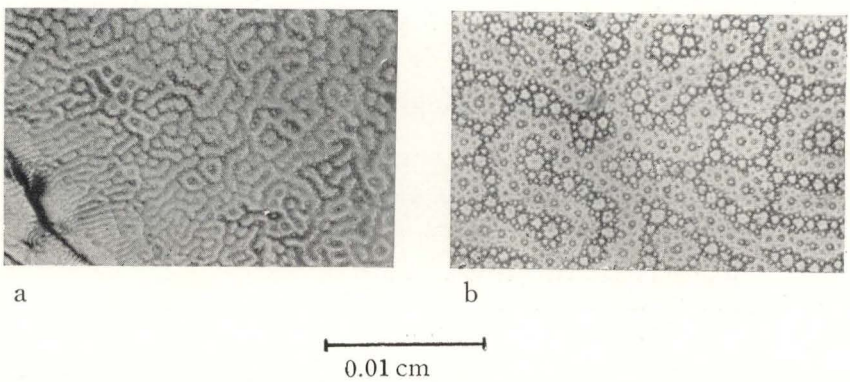


Fig. 2. Powder patterns on surface approximately perpendicular to e, at $H\approx 100$ Oe perpendicular to surface: (a) chains of single small circles; (b) chains consisting of wreaths of small circles.

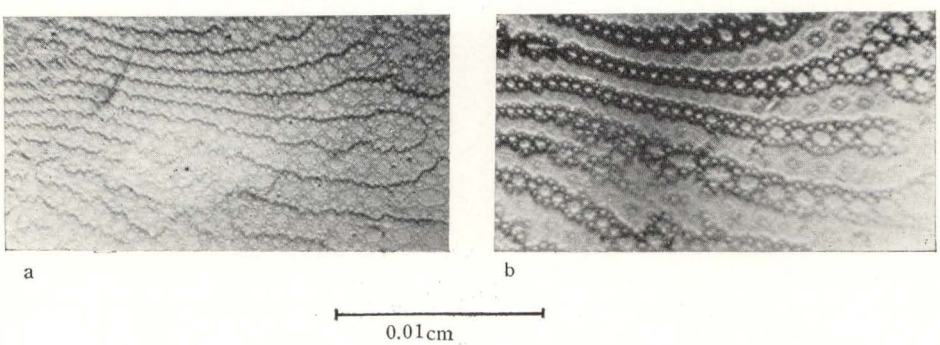
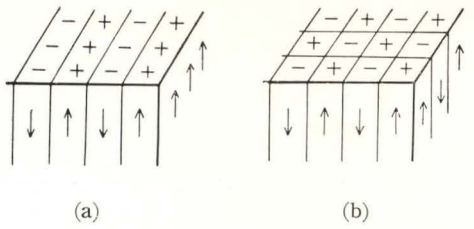


Fig. 3. Powder patterns on surface approximately perpendicular to e: (a) at $H=0$, the thick dark lines trace basic domain Bloch walls; (b) at $H\approx 100$ Oe perpendicular to surf ace.



(a) (b)

Fig. 4. Models of basic domain structure: (a) plates; (b) parallelepipedes.

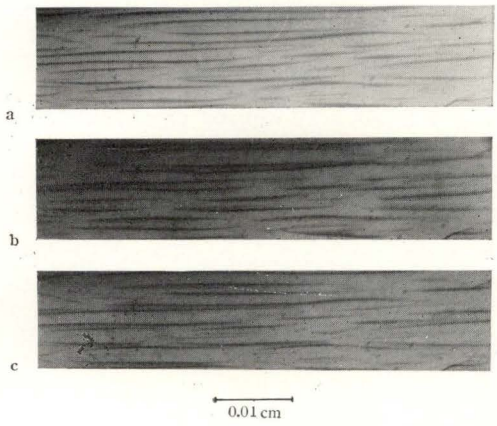


Fig. 5. Powder patterns on surface at sharp (obtuse) angle with $\boldsymbol{e}$: (a) at $\boldsymbol{H}=0$; (b) at $\boldsymbol{H}\approx 70$ Oe parallel to surface; (c) at $\boldsymbol{H}\approx 70$ Oe antiparallel to field of (b). $\boldsymbol{H}$ leads to broadening or narrowing of the component patterns.

rather than of energetically less advantageous[3] parallelepipedes (Fig. 4b).

Moreover, transition types were observed (Figs. 5 and 6) when surface and $\boldsymbol{e}$ were at an angle $\neq 0°$ and $\neq 90°$, giving rise to a non-zero component normal of the magnetization vector on the surface. From Figs. 5 and 6, the apparently complicated patterns are readily seen to consist of different rotationless groupings of a single simple element (Fig. 7). The simplest domain corresponding to an element of Fig. 7 can be considered to be boat-shaped as in Fig. 8.

The energy of Bloch wall per unit area, computed[4] for Mn_5Ge_3 from the dependence of the domain width on the crystal thickness is $E_w=3{,}7$ erg/cm^2. The anisotropy constant measured for Mn_5Ge_3 is $K=1{,}2\cdot 10^6$ erg/cm^3.

Some authors[5] sintered samples of Mn_5Ge_3 powder obtaining about 26 Oe coercive force. Ours, consisting of large crystals, exhibited a coercive force of less than 1 Oe.

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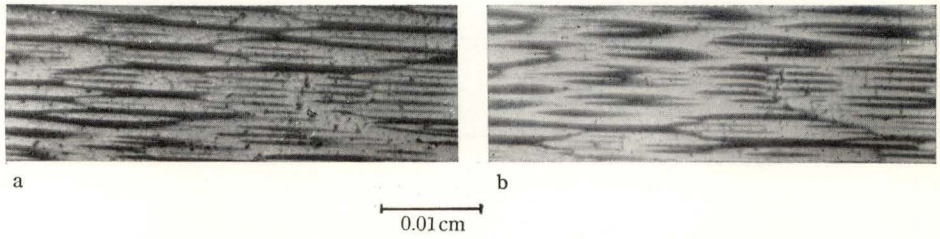

Fig. 6. Powder patterns on surface at sharp (obtuse) angle with $\boldsymbol{e}$: (a) at $\boldsymbol{H}\approx 100$ Oe perpendicular to surface; (b) at $\boldsymbol{H}\approx 100$ Oe antiparallel to field of (a).

Fig. 7. Simplest element of powder patterns in Figs. 5 and 6.

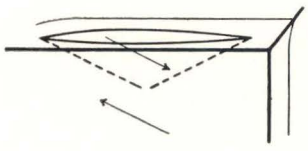

Fig. 8. Boat-shaped domain.

DISCUSSION

P. RHODES: Is the value of the intrinsic magnetization of this compound known?

S. E. SZCZENIOWSKI: The saturation magnetization $4\pi M_s$, at room temperature amounted to several thousand gauss.

T. OHOYAMA: Prof. Yasukochi, Dr. Kanematsu and I have investigated Mn–Ge alloys from the view-point of intrinsic magnetization, as was partly reported in another session. According to our experiments, saturation magnetization, σ, of Mn_5Ge_3 was about 140 emu/g if extrapolated to 0°K. The Curie temperature was determined from σ^2–T curve to be 304°K.

May I ask the procedure of the preparation of your specimens?

S. E. SZCZENIOWSKI: The samples of Mn_5Ge_3 were prepared in sealed evacuated quartz tubes in a high temperature oven from sublimated manganese and germanium purified by zone melting.

P. RHODES: What were the dimensions of the crystallites in the specimen used?

S. E. SZCZENIOWSKI: The size of crystallite might be about 1 mm or even less than 1 mm.

G. ASANO: What is the particle size of the sample having coercive force of 26 oe.? What is the critical size of single domain particles?

S. E. SZCZENIOWSKI: The value of 26 oe. reported by Quigg *et al.* was found for fine grained sintered powder. The low value of coercivity (1 oe. in the present case) depends on rather large dimensions of crystallites, up to 1 mm.

P. RHODES: Is it not surprising, in view of the fact that the coercivity is less than 1 oe., that the domains you show in Fig. 1 did not broaden or narrow in an applied field of about 50 oe.?

S. E. SZCZENIOWSKI: The width of domains visible in Fig. 1 was not appreciably influenced by a magnetic field of the order of 50 oe. although coercivity was found to be low. In this case the surface of the specimen, the domain walls, and the direction of the field were all parallel to the easy direction of magnetization.

L. F. BATES: I note that the scheme of basal domain structure corresponds to Fig. 5 (c) given in the paper by Craik and myself, so that Mn_5Ge_3 behaves like magnetoplumbite. I do not feel happy about the boat domain suggestion; I wonder if we are not dealing with domains of reverse magnetization set up in the interior of the (polycrystalline) material.