DEPENDENCE OF THE MAGNETIC STRUCTURE OF A COBALT CRYSTAL ON ITS SIZE

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By means of powder patterns, the changes of magnetic structure of a cobalt monocrystal have been observed in the basal plane upon decrease of the crystal thickness from 515 to 15μ. It has been established that at small thicknesses ($< 200\mu$) the domain width varies directly with the square root of the crystal thickness; at larger thicknesses some deviation from this rule is observed.

INTRODUCTION

As is known, the magnetic properties of ferromagnetics in many respects depend on their type of magnetic structure. Change of the type of magnetic structure of ferromagnetics leads to change of their magnetic properties.[1] The type of magnetic structure depends on many factors. In particular, for given physical properties of a ferromagnetic its type of magnetic structure is related to its geometrical dimensions. Upon passage to fine powders or to thin films, the decrease of size of a ferromagnetic leads to a simplification of the type of magnetic structure.[2,3] In very small particles, after attainment of a certain critical dimension, the magnetic structure becomes the simplest of all, transforming to a single-domain structure.

Change of the type of magnetic structure with change of size of the crystal should occur for two reasons: 1) In crystals in which the basic domains[4] pass through the whole thickness of the crystal, there exists the following definite relation between the thickness d of each basic domain and its length L (in the direction along which the magnetization is oriented): $d \sim \sqrt{L}$.[5] Therefore with decrease of L, the thickness of the domains will also decrease. 2) The shape and size of the closure domains is also related to the size of the basic domains. Therefore the structure of the closure domains will change systematically with decrease of size of the basic domains, especially in cases in which, because of the small dimensions of the ferromagnetic, the formation of closure domains is hindered.

The question of the change of magnetic structure with change of size of a ferromagnetic has been specifically studied only in the case of a triaxial ferromagnetic (silicon iron).[2] Similar investigation of magnetically uniaxially ferromagnetics has not been carried out; in the literature there are only fragmentary experimental data,[6-8] from which it is possible to conclude that somewhat different magnetic structures are observed in thick and in sufficiently thin crystals of certain magnetically uniaxial materials (manganese-bismuth alloy, barium ferrite).

The object of our work was a study by a visual method (the powder-pattern method) of the change of magnetic structure of a monocrystal of cobalt on progressive decrease of its thickness.

EXPERIMENTAL METHOD

The investigation was carried out on a monocrystalline specimen in the form of a disk of diameter 4 mm and initial thickness 0.52 mm. The surface of the disk was parallel to the basal plane of the cobalt crystal. The magnetic structure was observed on this plane by the powder-pattern method. The thickness of the disk-specimen was progressively decreased from 515 to 90μ by mechanical grinding followed by electrolytic polishing. Further thinning of the specimen to 15μ was accomplished by means of electrolytic etching alone. For electropolishing and etching, a 10% solution of chromic anhydride in orthophosphoric acid, of concentration 85%, was used.

For different thicknesses of the cobalt crystal, a comparison was made of the powder-pattern pictures in the middle part of the specimen, where the thickness of the crystal was also determined by means of an optical indicator within an accuracy of 2μ.

RESULTS OF THE OBSERVATIONS

Figure 1 shows photographs of powder patterns on the basal plane of a cobalt crystal for several specimen thicknesses. When the crystal thickness L is equal to 515μ (Fig. 1a), there is a compli-

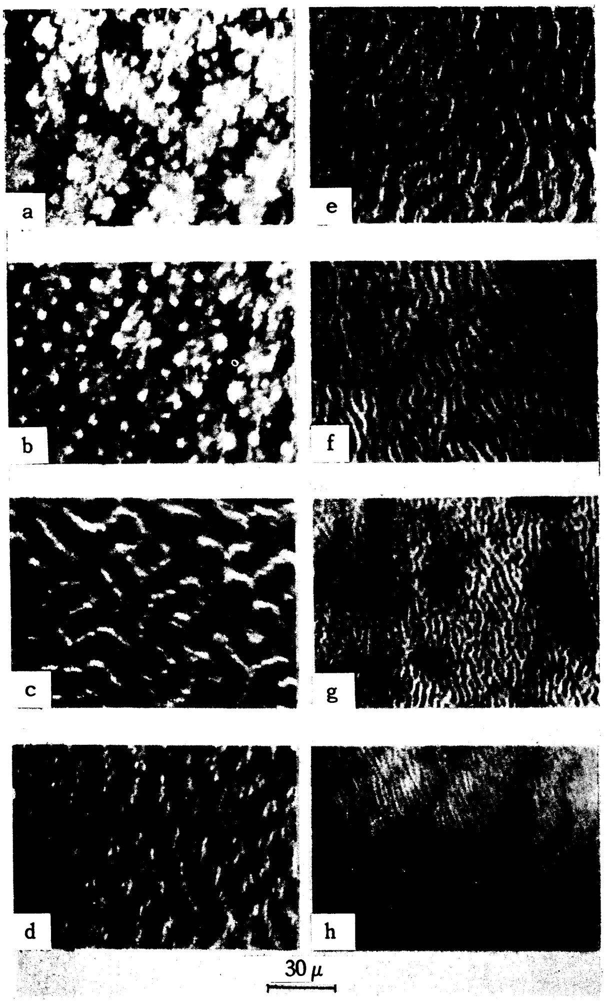

FIG. 1. Magnetic structure of a cobalt monocrystal, observed on the basal plane; crystal thicknesses: a) 515μ; b) 380 μ; c) 210 μ; d) 145 μ; e) 85 μ f) 45 μ; g) 30 μ; h) 15 μ.

cated star-shaped picture of the powder deposition. Coarse and fine stars form integral groups, which in their turn are grouped in labyrinths and zigzags. A similar picture is retained at crystal thickness 380 μ (Fig. 1b). At specimen thicknesses 210 to 85 μ (Fig. 1c, d, e), the basic labyrinth structure is more clearly visible, and also chains of stars. On further thinning of the crystal to 40 to 30 μ (Fig. 1f, g), only a labyrinth structure is observed; the labyrinths become less tortuous, and at thickness 15 μ the picture of the powder deposit is a series of slightly wavy, almost parallel lines (Fig. 1h).

On comparison of the powder-pattern photographs shown, it can be noticed that with decrease of the thickness of the cobalt crystal, the surface magnetic structure on the basal plane of the crystal becomes not only appreciably simpler, but also finer. We may take as a conventional measure of the degree of dispersion of the surface structure the value of d′, the mean width of the labyrinths. From the photographs shown in Fig. 1 it is clear that with thinning of the specimen from 515 to 15 μ, the value of d′ decreases manyfold.

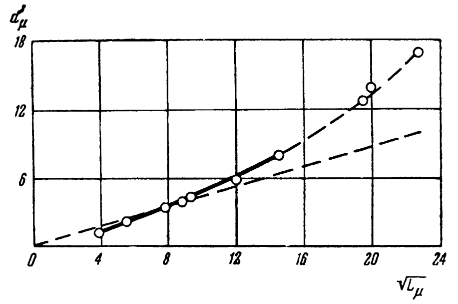

FIG. 2. Dependence of labyrinth width on thickness of a cobalt crystal. o, experimental data; ---, theoretical curve $d'_\mu = 0.43\sqrt{L_\mu}$.

Figure 2 shows the experimentally obtained dependence of the mean width d′ of the labyrinths on $\sqrt{L}$ (curve 1). The experimental curve is well approximated by the $d'_\mu = 0.43\sqrt{L_\mu}$ for thicknesses less than 200 μ.

DISCUSSION OF THE RESULTS OF THE OBSERVATIONS

The observed changes of magnetic structure of a cobalt crystal with decrease of its thickness can be qualitatively understood on the basis of the following considerations.

In the initial state, the magnetic structure of a cobalt monocrystal consists of two types of domain: the basic domains, running through the whole thickness of the crystal, and auxiliary cone-shaped (or wedge-shaped) domains, whose bases are visible in the form of "asterisks" on the basal plane of the crystal. In all domains, both basic and auxiliary, the magnetization is oriented along the hexagonal axis (that is, perpendicular to the specimen surface). The wavy form of the walls between the basic domains near the surface of the crystal[9] and the presence of a large number of wedge-shaped domains, different in form, in depth of penetration, and in size of the wedge base,[10] are apparently responsible for the complicated star-shaped and labyrinthine picture of the powder patterns that we observe on the basal plane of a crystal of thickness 400 to 500 μ (Figs. 1a and 1b). This surface magnetic structure probably differs appreciably from the simpler internal magnetic structure of cobalt.

By analogy with the changes of the magnetic structure observed in transformer iron,[2] where with thinning of the crystal the closure domains disappeared and only the basic domains remained, it may be assumed that in our case also, with diminution of the thickness of the cobalt crystal the wedge-shaped auxiliary domains first decrease in size and then disappear, so that at certain thicknesses (30 to 15 μ) the lines of the observed labyrinth structure are the terminations of the walls of the basic domains. In addition, according to Goodenough's ideas, on decrease of the crystal thickness there is a decrease of the amplitude of the wavy walls between the basic domains; and at some sufficiently small thicknesses, a configuration of plane-parallel layers will be energetically favorable. These principles apparently determine the observed simplification of the surface magnetic structure with thinning of the cobalt crystal (Fig. 1).

The presence of a magnetic structure with unclosed magnetic flux (complete absence of closure domains), of the plane-parallel layer type, was first predicted by Kittel[11] for very thin plates of cobalt of thickness $\sim 10^{-5}$ cm. Apparently if we take account of the possibility of a decrease of the magnetostatic energy of the crystal by disorientation of the magnetic vectors near the surface,[12] and of the presence of wavy walls not perpendicular to the surface,[9] then in a magnetically uniaxial crystal a magnetic structure without auxiliary wedge-shaped domains will be stable at crystal thicknesses greater than 10^{-5} cm.

As was mentioned above, with decrease of the thickness of a cobalt crystal, the value of the mean width d' of the labyrinths also decreases sharply. For small thicknesses, as is clear from Fig. 2, the relation between the crystal thickness L and the labyrinth width d' can be expressed by the quadratic dependence $d'_{\mu} = 0.43\sqrt{L_{\mu}}$. This provides the possibility, for sufficiently small crystal thicknesses ($< 200\,\mu$), of taking the value of d' as the thickness d of the basic domains. For larger thicknesses there is no possibility of directly relating the values of d and d' because of the complexity of the powder deposit picture.

CONCLUSION

The results of the investigation made and the analysis of them show that on passage to small thicknesses, the magnetic structure of a cobalt crystal, observed on the basal plane of the crystal, rapidly changes. This change of structure expresses itself in the fact that the auxiliary domains disappear and the width of the basic domains decreases. For thicknesses less than $200\,\mu$, the width of the basic domains is proportional to the square root of the crystal thickness.

[1] Shur, Shtol'ts, and Kandaurova, Физика металлов и металловедение (Physics of Metals and Metal Research) **5**, 412 (1957).

[2] Shur, Abel's, and Zaĭkova, Izv. Akad. Nauk SSSR, Ser. Fiz., **21**, 1162 (1957), Columbia Tech. Transl. p. 1149.

[3] Shur, Shtol'ts, Kandaurova, and Bulatova, loc. cit. ref. 1, **5**, 234 (1957).

[4] Ya. S. Shur and V. R. Abel's, Dokl. Akad. Nauk SSSR **104**, 209 (1955).

[5] L. D. Landau and E. M. Lifshitz, Physik. Z. Sowjetunion **8**, 153 (1935).

[6] B. W. Roberts, Trans. Am. Inst. Elec. Engrs. **78**, 192 (1955) [sic!].

[7] Sixtus, Kronenberg, and Tenzer, J. Appl. Phys. **27**, 1051 (1956).

[8] R. F. Pearson, Proc. Phys. Soc. (London) **B70**, 441 (1957).

[9] J. B. Goodenough, Phys. Rev. **102**, 356 (1956).

[10] W. Andrä, Ann. Physik **15**, 135 (1954).

[11] C. Kittel, Phys. Rev. **70**, 965 (1946).

[12] M. Fox and R. S. Tebble, Proc. Phys. Soc. **72**, 765 (1958).

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