Letters

Magnetic Domain Patterns in Small Single Crystal $SmCo_5$ Particles

The publication of Hoffer and Strnat [1], where the extremely high magnetic anisotropy of YCo_5 was demonstrated, initiated much intensive research on the magnetic properties of the ferromagnetic rare-earth cobalt alloys. Several authors [2-4] have shown that high quality permanent magnets with energy products as high as 23 MGOe can be produced from $RECo_5$ compounds where RE stands for Y, La, Ce, Pr, Nd, or Sm. The good magnetic properties of the hexagonal $RECo_5$ compounds stem from the fact that these intermetallic compounds combine high saturation magnetisation with high uniaxial magnetic anisotropy. High coercive fields can be obtained in powders by simple grinding of the compound.

For reasons as yet unknown $SmCo_5$ powders show the highest coercive field, ${}_MH_c$, of typically 10000 to 20000 Oe. It has also been demonstrated [5, 6] that the coercive field depends markedly on particle size. The coercive field increases with decreasing particle size, goes through a maximum for particles of $\sim$ 10 μm diameter and decreases again for smaller particles. The critical diameter below which the formation of a Bloch wall is energetically unfavourable (that is, the particle consists of a single domain) is, for $SmCo_5$, $\sim$ 0.3 μm. This is much smaller than the size for which the optimum magnetic properties occur. Thus the magnetisation reversal of a fully magnetised 10 μm particle must proceed by nucleation and growth of domains of opposite polarity [5, 7, 8]. It is therefore important to study the exact structure of the domain patterns and the mechanism of nucleation and displacement of Bloch walls in small $RECo_5$ grains. Here we report on the first observation of domain patterns on small (typically 10 to 100 μm) $SmCo_5$ single crystals.

A commercial $SmCo_5$ compound (manufacturer: Th. Goldschmidt AG, Essen, Germany) was ground in a vibration mill in air. This produces mostly single-crystal particles. After etching (1 min in a solution of 100 ml H_2O, 10 ml HCl, 1 ml H_2O_2) the powders were embedded in a resin and aligned in an intensive magnetic field of $\sim$ 80000 Oe. Then the samples were demagnetised as thoroughly as possible in a decreasing alternating field. Afterwards the samples were polished and the magnetic domains were observed by means of the magnetic Kerr effect using a Zeiss Ultraphot 3 microscope equipped with polarisation optics.

Figs. 1 and 2 show the domain structures on small $SmCo_5$ single crystals, the hexagonal axes being perpendicular and parallel to the plane of observation respectively. Similarly prepared $SmCo_5$ powder with a particle size between 10 and 25 μm has a coercive field ${}_MH_c$ of about 10000 Oe. Fig. 3 shows the domain pattern on a *c*-plane surface of a large $SmCo_5$ particle. These

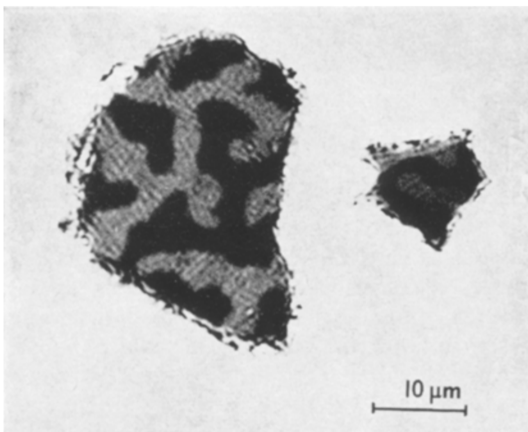

Figure 1 Magnetic domain pattern on small single-crystal $SmCo_5$ particles. The *c*-axis is perpendicular to the plane of observation. Such $SmCo_5$ powder has a coercive field ${}_MH_C$ of $\sim$ 10000 Oe.

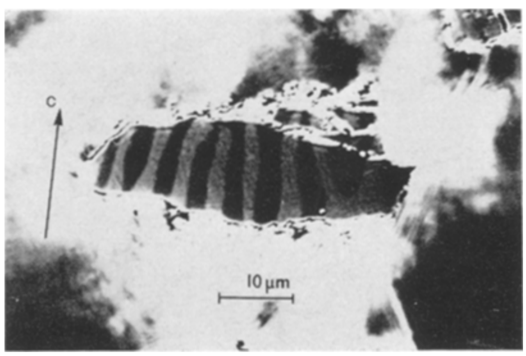

Figure 2 Magnetic domain pattern on a small single-crystal $SmCo_5$ particle. The *c*-axis is parallel to the plane of observation. Such $SmCo_5$ powder has a coercive field ${}_MH_C$ of $\sim$ 10000 Oe.

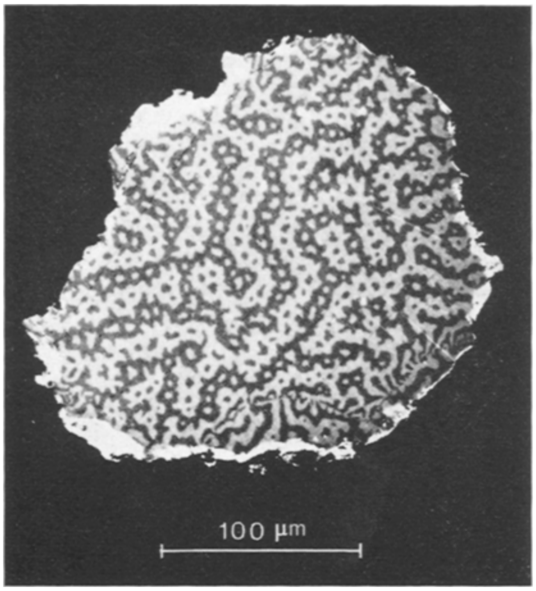

Figure 3 Magnetic domain pattern on a large $SmCo_5$ particle. The *c*-axis is perpendicular to the plane of observation.

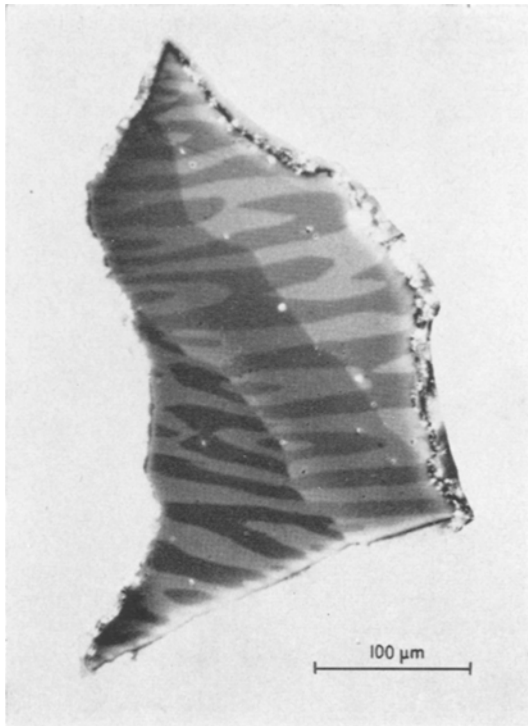

Figure 4 Magnetic domain pattern on a polycrystalline $SmCo_5$ particle.

domain structures correspond approximately to the demagnetised state of the particles. The domain structure of the small $SmCo_5$ crystals consists of sheets containing the axis of easy magnetisation (the *c*-axis) and extending through the crystal (fig. 2). Cone-shaped surface domains of reversed magnetisation appear in thick crystals (Fig. 3); these surface domains are absent on crystals smaller than about 25 μm. The domain patterns of $SmCo_5$ resemble closely those of hexagonal Co [9-11] and MnBi [12]. They are typical for a hexagonal crystal with a direction of easy magnetisation parallel to the *c*-axis and a large magnetic anisotropy [13, 11]. Fig. 4 shows the domain pattern on a polycrystalline particle. Most domains are continuous at the grain boundaries. In some instances reverse domains appear to have been nucleated at a grain boundary. This may explain the low coercive field of polycrystalline $SmCo_5$.

Using the magnetic Kerr effect we have observed the magnetic domains on $SmCo_5$ particles as small as 10 μm. Preliminary work indicates that the same technique can be used to study the nucleation and growth of domains in $RECo_5$ particles. A systematic study is under way.

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