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Asymmetric Hysteresis Loops
in Co-rich Ferromagnetic Alloys

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We have discovered[1] that after certain annealing treatments, some magnetic materials display a markedly asymmetric hysteresis loop, as shown in Fig.1. A similar loop was reported without comment by Fujimori et al. in 1981.[2]

The asymmetric loop develops easily and readily in materials made of amorphous alloys near the zero magnetostriction composition $(Co_{0.94}Fe_{0.06})_x(SiB)_{1-x}$, but is not limited to these compositions. The measurements reported here were carried out on ribbons made from $Co_{70.5}Fe_{4.5}Si_{10}B_{15}$, rapidly solidified and subsequently processed, and measuring about 1.2 mm wide by 20 to 25 µm thick. Most of our samples are 7.5 cm long. To produce the single asymmetric magnetization reversal (AMR) of Fig. 1, a ribbon is treated by annealing for several hours at a temperature of 350 to 400°C, in an applied magnetic field of about 100 mOe directed parallel to the ribbon axis. This field is comparable to the earth's field, which means that to obtain reproducible results the earth's field must be cancelled or measured.

After the magnetic field anneal, the direction of magnetization during the anneal is stable. To reverse this direction, a relatively large negative field must be applied to the sample, and at a critical field, the magnetization reverses in a single sudden Barkhausen jump. As the field is reversed again from negative to positive, the magnetization returns smoothly and reversibly to the original (annealing field) direction. The slope of this reversible curve is controlled by the demagnetizing field of the sample.

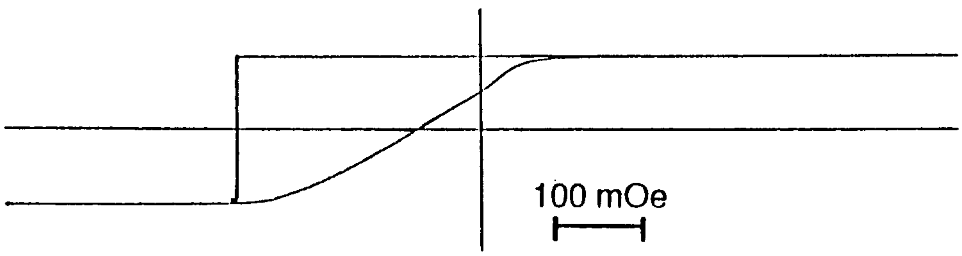

Fig. 1. Hysteresis loop showing Asymmetric Magnetization Reversal (AMR)

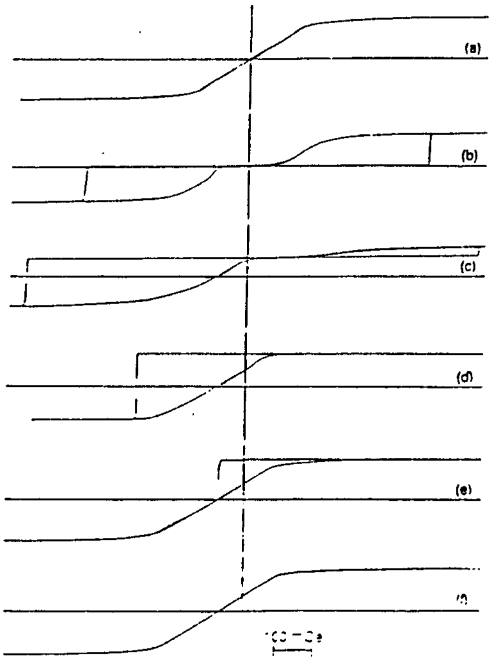

Fig. 2. Hysteresis loops of amorphous ribbon (a)as-cast and after annealing in fields of (b)0, (c)25, (d)100, (e)300, and (f)1000 mOe.

The shape of the hysteresis loop depends sensitively on the field applied during annealing: Fig.2 shows the loops resulting from annealing fields (8 hr at 380°C) of 0, 25, 100, 300, and 10000 mOe. We can identify four types of loop, each of which results from annealing in a particular field region. In region I ($0<H_{ann}<75$ mOe), the loop shows two Barkhausen jumps, one negative and one positive; we call this a *double asymmetric magnetization reversal*, because each of the partial loops is asymmetric. In the special case of annealing in zero field, the two partial loops are equal. When the annealing field range exceeds about 85 mOe, a single AMR results. The single AMR region, however, is divided into region II ($85<H_{ann}<150$ mOe) where the change in magnetization at the critical field is complete (going approximately from positive to negative saturation) and region III ($175<H_{ann}<1000$ mOe) where the jump is partial. After high-field ($H_{ann}>5000$ mOe) annealing (region IV), the loop appears normal, but is shifted relative to the H=0 axis; we call this a *shifted symmetric magnetization reversal*.

Most of our measurements have been made on samples annealed in air. These ribbons develop an obvious gray oxide coating. However, similar results are obtained by annealing in hydrogen, which leaves the sample surfaces clean and shiny. Nevertheless, we are dealing with a surface effect, because light chemical etching of the surface (for both air-annealed and hydrogen-annealed samples) eliminates the asymmetric magnetization reversal.

The asymmetric loop can also be destroyed by subjecting the annealed sample to a sufficiently high ac or dc magnetic field (at room temperature); fields of the order of 100 Oe are required. This strongly suggests that the annealing treatments create a metastable domain structure, which can be destroyed by the application of a sufficiently high field. A very recent publication reproduces our zero-field annealing results, and presents domain observations.[3]

References

1. US Patent 5029291, July 2, 1991
2. H. Fujimori, H. Yoshimoto, and T. Masumoto, J. Appl. Phys., 52, (1981)1893
3. Rudolf Schäfer, Wing K. Ho, Jiro Yamasaki, Alex Hubert, and Floyd B. Humphrey, IEEE Trans. Magn., MAG-27, (1991)3678.