process of non-uniform demagnetization (for instance fanning with the chain of sphere model). Is there any criterion such as particle interaction which allows us to decide whether the changes in magnetization are uniform or non-uniform, since the coercive force can now be explained by their model?

P. RHODES: For sufficiently small particles magnetization changes will take place by uniform rotation and the coercivity is then determined directly by the calculated shape anisotropy factor.

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Magnetic Image Contrast in Electron Mirror Microscopy

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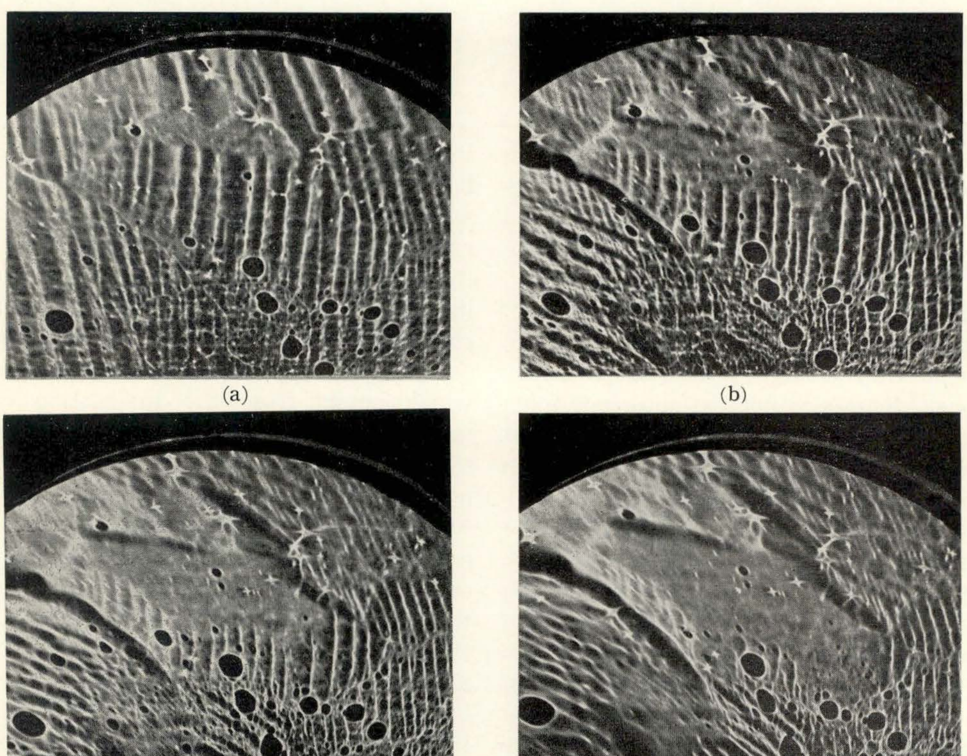
The feasibility of electron mirror microscopy for visual observation of magnetic stray fields on surfaces will be demonstrated. Magnetic image contrast as well as the criteria which permit the discrimination of magnetic patterns from patterns of other origin will be briefly discussed. Electron mirror micrographs of domain patterns and of magnetic patterns recorded on magnetic tapes and films will be shown. A motion picture depicting magnetic domains in motion as well as emerging magnetic stray fields on grain boundaries in silicon iron will also be presented.

Electron optical methods for visual observation of magnetic domains have been introduced only rather recently. This is somewhat surprising because even conventional electron transmission microscopy can be utilized for this purpose as Hale, *et al.*[1], Boersch, *et al.*[2] and others[3] have shown. Transmission microscopy requires, of course, specimens thin enough to be penetrated by electrons. If this is not the case, one must rely on electron optical methods which depict surfaces. Electron emission microscopy can then be used as an instrument for the observation of magnetic domains as Spivak, *et al.*[4] have shown. Another possibility is electron mirror microscopy[5] which can be utilized not only for the visual observation of the distribution of such electrical properties as surface potentials, conductivities, etc., but serves equally well in depicting magnetic domain patterns[6] and artificial magnetic patterns recorded on magnetic media[7].

In electron mirror microscopy the specimen constitutes an electron optical mirror biased slightly negative with respect to the electron source, i.e., the cathode. The electrons therefore do not reach the mirror-specimen but are reflected at the zero equipotential which is to be located close enough to the specimen to carry the geometric relief and the magnetic or electrical relief of the specimen proper. In the magnetic case the image contrast forming deflection is caused by that component ($F=e\dot{r}B_z$) of the Lorentz force $\boldsymbol{F}$ which stems from the interaction of the magnetic field normal to the plane of the mirror-specimen (B_z) with the radial component of the electrons' velocity ($\dot{r}$). The sensitivity of electron mirror microscopy to magnetic fields is therefore zero at the electrical center of the mirror-specimen, i.e., where the radial component of the electrons' velocity becomes zero. This feature, which might appear detrimental, is actually advantageous because it establishes a convenient criterion for distinguishing patterns of magnetic origin from patterns which stem from the geometrical relief structure or from those which are of electrical origin. The procedure for determining whether a pattern is of magnetic origin is therefore very simple. The shifting of patterns in question to the electrical center makes them disappear if they are magnetic in origin. If they are shifted through the center to the opposite side of the viewing screen, a reversal in the brightness of the border lines must also occur, i.e., dark border lines must become bright and bright lines dark. If the magnetic origin of a pattern has been established in the abovementioned fashion, the loss of image contrast in the electrical center can be easily circumvented by shifting the electrical center outside the viewing screen. The peculiar kind of image formation in the magnetic case prefers contrast-wise magnetic pattern elements which extend radially rather than those which extend azimuthally. This constitutes a somewhat undesirable property which can be remedied, however, as the need arises by simply rotating the specimen stage.

Electron mirror microscopy has been used in our laboratory for exploratory studies of domain structures in barium ferrite, nickel ferrite and thin permalloy films, etc. Investigations have also been extended to magnetic patterns recorded by conventional means on magnetic tapes and by Curie point writing with an electron beam on MnBi films[8]. It appears that electron mirror microscopy may be particularly valuable for the visual observation of magnetic domains in motion. A motion picture taken from the screen of the electron mirror microscope shows as a function of the applied magnetic field the complex domain pattern movements occurring in a silicon iron sample mounted on a magnetic specimen stage[6]. Fig. 1 shows as an example a sequence of four electron mirror micrographs from the motion picture taken at increasing applied magnetic field. Within one grain of the silicon iron sample spike-like domains with a magnetization opposite to the applied magnetic field gradually disappear with increasing field until the grain is magnetized to saturation. Another motion picture, also taken in the electron mirror microscope with a silicon iron sample as a specimen, shows the emergence of magnetic stray fields on grain boundaries[9] as a



(a) (b) (c) (d)

Fig. 1. Domain pattern changes with increasing applied magnetic fields (0–240 amp turns) revealed by electron mirror microscopy. Specimen: Silicon-iron (Magnification approximately 37×).

function of the applied field. It demonstrates how differently various grain boundaries can behave magnetically, a fact which might be of significance in further resolving the controversy concerning grain size effects on magnetic properties.

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DISCUSSION

C. D. GRAHAM, Jr.: My impression from looking at your movies is that the domain wall motion was reversible, in the sense that the domain walls returned exactly to their original positions when a small field is applied and removed. Is this impression correct, and, if so, is the same effect observed when large fields, enough to saturate the sample, are applied and removed?

L. MAYER: Careful direct observation of the screen reveals that some domain wall motion is reversible. However, many domain patterns do certainly not return to their original position. This behavior applies for small applied fields as well as for fields strong enough to cause near saturation conditions. By observing the domain pattern motions with applied magnetic a.c. fields of slowly increasing amplitude one can observe on the screen this different behavior quite readily. Motion picture recordings however become somewhat difficult because of the beat frequencies between the frequency of the applied a.c. field and the frequency of the frame change of the motion picture.

L. F. BATES: I congratulate the author on his excellent pictures. I should like to ask if his specimen was in a state of strain, as I could explain some of the observed phenomena in terms of strain, as in cube-textured silicon iron.

L. MAYER: Thank you. Some of the silicon-iron specimens might have been in a state of strain. However, the single crystal silicon iron sheet which showed the more regular domain pattern movements had been carefully vacuum annealed. No strain is induced by the mounting of the specimen on the specimen stage nor does the electron mirror microscopical method of depiction induce any strain.

R. M. BOZORTH: I should like to ask the cause of the black spots and white crosses on the photographs.

L. MAYER: The black spots are either caused by tiny protrusions or by microscopically small insulating particles or insulating inclusions. These insulating areas are charged up negatively by the few electrons from the tail of the Maxwellian distribution, reaching the specimen despite its slightly negative bias potential. The white crosses on the other hand are caused either by small holes in the specimen or again by insulating area, which charge up positively because more positive ions are impinging there than electrons. By changing the bias potential and observing the corresponding change in the appearance of the black spots and white crosses one can determine whether they are of an electrical or a geometric nature. In the motion picture shown most of the black spots and white crosses were caused by insulating inclusions.