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INVESTIGATIONS OF MAGNETIC MICROSTRUCTURES USING SCANNING ELECTRON MICROSCOPY WITH SPIN POLARIZATION ANALYSIS

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A field emission scanning electron microscope was fitted with electron spin polarization analyzers in order to image submicron magnetic microstructures. Spin polarization analysis of the emitted secondary electrons provides a direct measurement of the magnitude and direction of the magnetization in the area probed by the incident electron beam. The polarization measurement is independent of topographic contrast which is measured simultaneously. The polarization was measured using a new type of analyzer which is very compact, simple, and at least as efficient as a Mott detector. The small detector size allowed the use of multiple orthogonal detectors so that all three components of the magnetization vector could be measured. This apparatus was used to examine the domain structure of various Fe–3% Si crystals.

Currently there is a great deal of interest in the use of secondary electron spin polarization analysis along with scanning electron microscopy in order to image magnetic microstructure with high spatial resolution [1–4]. Scanning electron microscopy with polarization analysis, SEMPA, is based upon the result that the low energy secondary electrons generated when a ferromagnetic material is probed by an electron beam are spin polarized. The polarization reflects the net spin density of the valence electrons in the ferromagnet [5–7]. The magnitude and direction of the secondary electron polarization is directly related to the magnitude and direction of the magnetization in the area probed by the finely focused electron beam. By rastering the incident electron beam across the specimen an image of the magnetic microstructure can be obtained and simultaneously a standard SEM topographic image is independently obtained. The technique was first tested by Koike

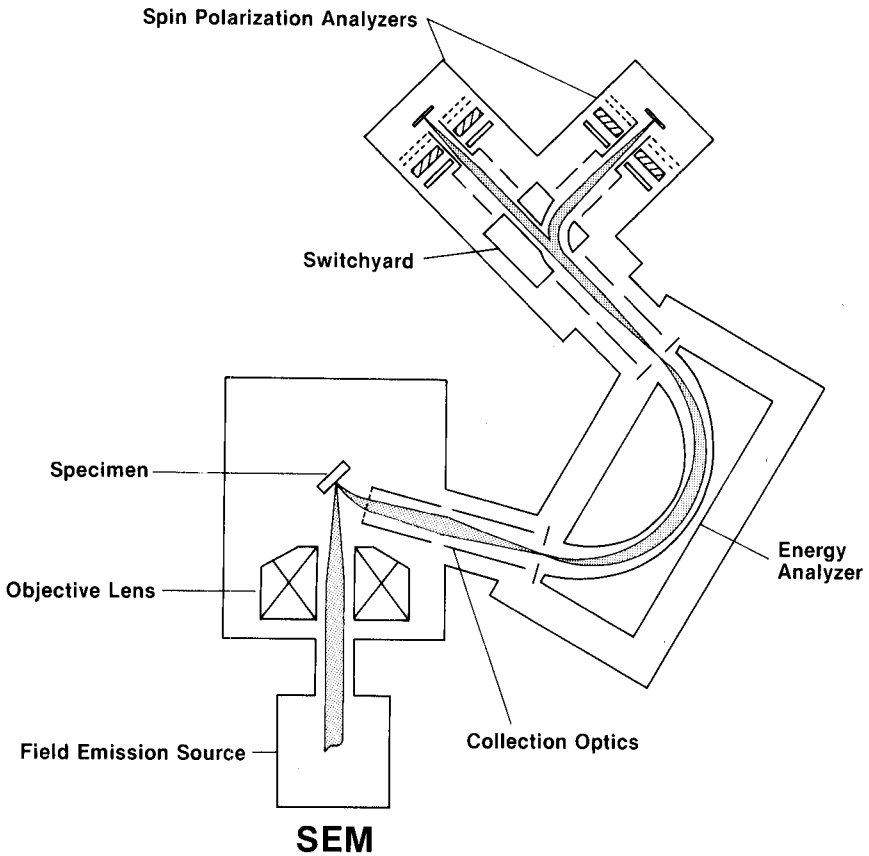

Fig. 1. Schematic diagram of the SEMPA apparatus.

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and Hayakawa who initially used a 10 μm diameter beam in conjunction with a 100 keV Mott spin analyzer to show that the polarization contrast was large and independent of topography [1]. They have recently increased the resolution of their instrument to 1 μm [8].

In our current work we have made significant advances in both spin polarization analysis and in spatial resolution. We have developed a very compact spin polarization analyzer of a new design which is based upon the spin dependent scattering of 150 eV electrons from an evaporated polycrystalline gold film. This detector is at least as efficient as a conventional Mott scattering polarimeter but is much more compact (fist-sized) and easier to use. The use of a polycrystalline target with its resultant diffuse scattering also makes the detector much less sensitive to variations of incident electron angles and energies than detectors that use single crystal targets. Because of its small size, the addition of the detector to a high resolution electron microscope is relatively easy and does not degrade the performance of the microscope.

A schematic of our apparatus is shown in fig. 1. We use an SEM with a field emission electron source that can produce beam diameters of 10 nm or less at currents of several nA. Secondary electrons from the sample are accelerated to 1500 eV by a collection lens which then focuses them into a hemispherical energy analyzer. In the magnetic imaging mode the purpose of the energy analyzer is to filter out the elastically scattered electrons. The energy analyzer's primary function, however, is to allow eventually for elemental mapping by scanning Auger spectroscopy. All three components of the spin polarization are measured by electrostatically switching between two orthogonal analyzers. Since each detector only measures the transverse components of the polarization, orthogonal detectors are required to measure all three projections of the magnetization vector.

For our initial specimens we chose Fe–3% Si single crystals whose surfaces were cut perpendicular to the [100] direction. These samples were cleaned by ion bombardment followed by annealing. Fig. 2 shows polarization images at two magnifications of the striped domains in these crystals. The magnetization is in the plane of the surface and perpendicular to the stripe direction. The zig-zag boundaries in Fe–Si crystals have been explained by Chikazumi and Suzuki [9]. These 64×64 pixel pictures were obtained in 5 min using a 10 nm diameter beam with an incident beam current of 3×10^{-12} A. Planned improvements in the analyzer electronics should decrease the exposure time by at least two orders of magnitude. The difference in polarization between domains is about 60%. The best spatial resolution achieved was 50 nm, and this was limited by specimen stage vibrations. By eliminating these vibrations we should be able to obtain the 10 nm resolution of this SEM.

With both of these improvements in resolution and polarization analysis, SEMPA should become an extremely useful tool in the study of sub-micron magnetic microstructures. In particular, the unique capabilities of SEMPA will be important in understanding how topographic structure and local chemistry affect these magnetic microstructures.

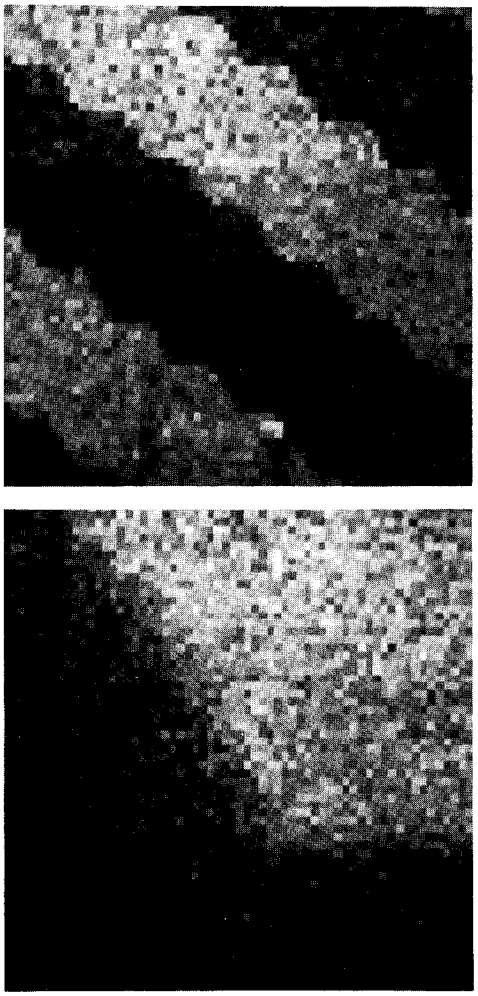

Fig. 2. Polarization images of magnetic domains in Fe–3% Si. The top and bottom photographs are 50×50 μm^2 and 5×5 μm^2, respectively.

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