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SCANNING ELECTRON MICROSCOPY WITH POLARIZATION ANALYSIS (SEMPA) STUDIES OF SURFACE MAGNETIC MICROSTRUCTURE

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Abstract

Scanning Electron Microscopy with Polarization Analysis (SEMPA) provides a new and versatile means of imaging surface magnetic microstructure with high resolution. When a ferromagnetic sample is probed by the highly focussed electron beam of an SEM, secondary electrons are generated whose spin polarization is directly proportional to the magnetization in the region sampled by the beam. By measuring this spin polarization, the direction and magnitude of the sample magnetization can be imaged with 10 nm spatial resolution. A review of the SEMPA technique and recent results will be presented.

A current scientific challenge with many ramifications for magnetic technology is to image surface magnetic microstructure with the highest possible spatial resolution. Fabrication of high performance magnetic storage media, for example, requires a detailed understanding of the factors which determine the size and shape of magnetic domains, the direction of the magnetization within each domain, and the changes of the magnetization within a domain wall. While the energy terms which govern the formation of micromagnetic structures are well known, actual domain configurations often depend on details of sample history and can only be calculated for idealized materials with simple geometries. Consequently, high resolution imaging is necessary to evaluate the domain configurations which result from different sample preparations and is necessary to observe changes induced by external influences such as temperature, stress, or applied magnetic field.

Scanning Electron Microscopy with Polarization Analysis (SEMPA) provides a new and versatile means of imaging surface magnetic microstructure with high spatial resolution. Unlike conventional methods of domain imaging in an SEM which rely on the magnetic fields of the specimen for contrast, the signal from SEMPA is directly proportional to the sample magnetization. Unlike methods based on the Bitter technique or on the Kerr effect, SEMPA is not constrained to the optical resolution limit of about one micron. Although transmission Lorentz microscopy achieves high spatial resolution, it requires specimens less than 300 nm thick. SEMPA is not limited to thin samples and therefore does not require complex thinning procedures which can alter the magnetic properties of the sample.

The principle of the SEMPA technique is illustrated in Figure 1. A focussed beam of electrons is scanned across the specimen causing secondary electrons to be emitted. The magnitude and direction of the spin polarization of the secondary electrons emitted from a ferromagnet is directly proportional to the magnitude and direction of the magnetization in the region probed by the incident beam. By measuring the secondary electron spin polarization as the incident beam is rastered across the specimen, one obtains an image of the surface magnetization.

Since three orthogonal polarization directions of the secondary electrons are measured, SEMPA images the surface vector magnetization. It is important to note that the electrons which produce this vector image are simultaneously used to generate an independent secondary image. SEMPA therefore provides the valuable opportunity to directly correlate magnetic structure with surface topography and work function.

To illustrate the contrast and resolution available in SEMPA, images of a zero magnetostriction Co based ferromagnetic glass (Allied 2705M) are shown in Figure 2. The projection of the sample magnetization along two orthogonal axes lying in the specimen surface are shown in the top and middle frame, respectively. The linear intensity scale uses white (black) for the maximum value of the magnetization component pointing along the positive (negative) direction. The top frame shows portions of four domains with magnetization nearly aligned with the vertical axis. The magnetization within the domain walls is seen in the middle frame to be along the horizontal direction, perpendicular to the length of the wall. This shows that the domain walls at the surface are of the Néel type. Note that a singularity in the middle Néel wall is clearly visible. The resolution available in the SEMPA apparatus at NIST is determined by the 30 nm resolution of the SEM which is currently used. Preparations to install a higher performance SEM are underway and a resolution of 10 nm should be possible.

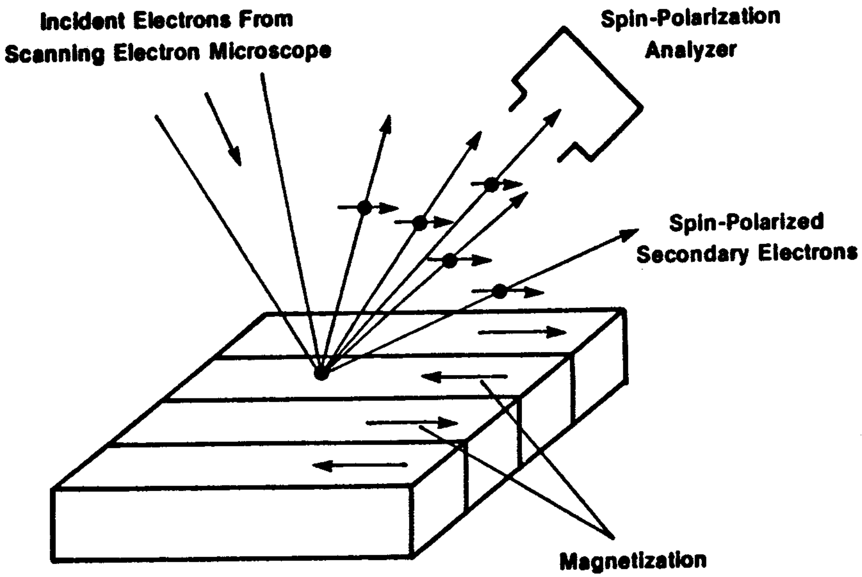

Figure 1. Principle of Scanning Electron Microscopy with Polarization Analysis (SEMPA).

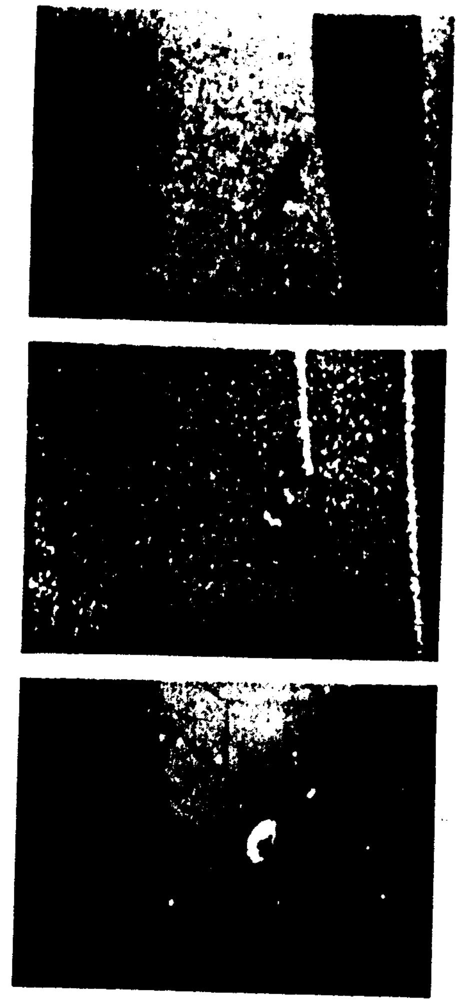

Figure 2. SEMPA images of a Co based ferromagnetic glass showing the components of the magnetization along the vertical (top frame) and horizontal (middle frame) directions. The simultaneously obtained SEM topography image is also shown (bottom frame). The images are 70 microns across.