LALP-02-185

First Official Users on Asterix Search for Answers to Questions About Magnetic Behavior in Thin Films

Nanotechnology — science of the "small" — will soon revolutionize computer technology and other industrial applications as scientists seek to manipulate and explore novel *nano*structured magnetic materials. But before these novel materials can be put into practical use, the magnetic behavior of nanoscale structures that are nearly 1/80,000 the diameter of a human hair must first be understood. In particular, understanding magnetic behavior in ultrathin *layered* structures is critical, as these structures form the basis for high-density information storage technology.

A team of scientists from the University of California at San Diego (UCSD), Geoffrey Beach, Ami Berkowitz, and Sunil Sinha, recently performed experiments on the newly commissioned Asterix instrument at LANSCE to examine the ultrathin native oxide layers that form at the surface of high-moment magnetic metals (CoFe) at low oxygen exposure. Such native oxide layers play important roles in the metal/native oxide multilayer (MNOM), a nanostructured magnetic material recently developed at UCSD for use as a shield material in the next generation of high data density magnetic recording. Shielding layers are used in magnetic recording heads (the device which reads bits from and writes bits to the hard disk) to channel stray magnetic fields (e.g., from adjacent bits) away from the read sensor. At high data rates, conventional shield materials are limited by eddy currents, or electrical currents generated in a metal in response to a varying magnetic field. Eddy currents act to oppose changes in the magnetic field within a material; this makes it difficult for the shield to respond to variations in the stray field and thus reduces the shielding efficiency. In the MNOM, the oxide layers act as high electrical resistance barriers to eddy currents, enabling operation at frequencies up to several gigahertz. In addition, the native oxide layers are *magnetic*, which both increases the total magnetization of the MNOM (important in the writing process in magnetic recording) and magnetically couples the metallic and oxide layers. This magnetic coupling allows the direction of the MNOM magnetization to be switched very easily (i.e., the material is *magnetically soft)*.

Fig. 1. *Geoffrey Beach of the University of California at San Diego makes adjustments to the metal/native oxide multilayer sample on Asterix. The sample was used in recent experiments at LANSCE aimed at understanding the magnetic behavior in ultrathin layered structures.*

The MNOM structure consists of nanolayers (~ 2 nm) of a high-moment (strongly magnetic) CoFe alloy separated by thin native oxide layers (~ 1 nm), which are formed by exposing each metallic layer to a low pressure of oxygen. In previous experiments, the UCSD team had shown that the native oxide layers are in fact magnetic and that there is a correlation between the magnetic properties of the oxide and the multilayer as a whole. But questions about the native oxide layers remain—namely, why are they magnetically stable (surprising considering their thickness), and how do they couple magnetically to the metal? Answers to these questions are important not only for understanding the MNOM system but also for describing interface effects in nanolayered materials in general.

The *surface* atoms of small, thin structures have a greater influence on the surrounding atoms that make up the structure than do the surface atoms of thicker, bulk materials. In thin *layered* structures, such as the MNOM sample used in the Asterix study, interface effects (i.e., at the metal-oxide interfaces in the MNOM) often dominate the behavior of the material, thus producing novel properties. These properties, which are not often found in naturally occurring materials, may be of significant technological interest. However, studying interfaces and ultrathin layers is extremely challenging. In most experimental techniques, studying the magnetic properties of individual magnetic layers separately is difficult because only the properties *averaged over all the layers* can be obtained. Polarized neutron reflectometery (PNR) offers a unique advantage in that one can study magnetism at specific positions within a sample. In the UCSD studies, PNR has allowed the researchers to study the magnetic properties of the metal layers and the oxide layers separately—which, in turn, will help them to understand how the layers interact.

The sample used in the UCSD experiments had a simplified metal/native oxide/metal trilayer structure. The sample was placed in a magnetic field to orient its magnetization in the "up" direction (as it appears Fig. 2). A beam of polarized neutrons, with spin either parallel to ("up") or anti-parallel to ("down") the sample magnetization, was directed at the sample surface at a particular angle. The angle is related to the position in the sample that the neutrons are reflected from. The likelihood of a neutron being reflected depends on the magnitude and direction of the sample magnetization at that position. By measuring the numbers of up and down neutrons reflected from the sample at various angles (the reflectivity, shown in Figure 2), the *magnitude* of magnetization in the oxide and in the metal layers could be studied separately.

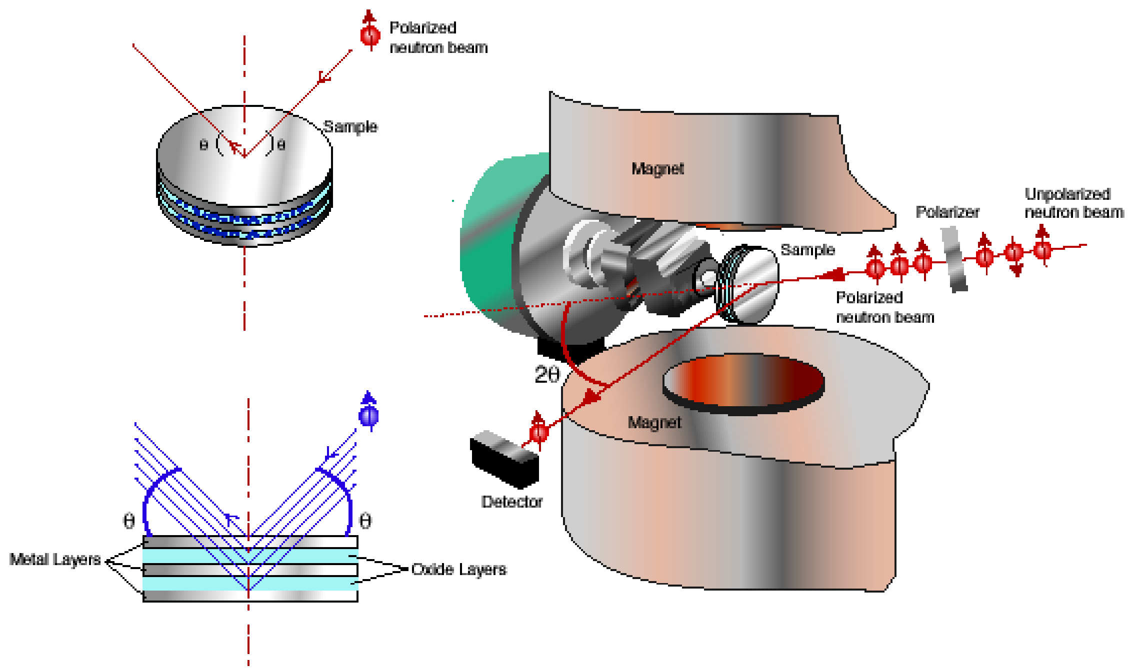

Illustration by Sharon Mikkelson

Fig. 2. *Three-dimensional rendering of the MNOM multilayer structure used in the Asterix experiments. In the PNR experiments, spin-polarized neutrons are directed at the sample. Both the polarization (i.e., neutron spin direction) and the intensity of the reflected beam are measured. Three measurements were taken: the angle, intensity, and polarization the reflected beam. The angle of the reflected beam relates to the depth in the sample that is being probed, whereas the intensity and polarization of the reflected beam describe the magnetic structure at that depth. In this way, the magnetization of the metal and oxide layers could be studied separately.*

A similar experiment was performed with the sample magnetization oriented nearly perpendicular to the neutron spin direction. By analyzing the reflectivity profile in this case, the *directions* of the magnetization in the individual layers could be determined and information about the magnetic coupling of the layers inferred. The results of this cutting-edge research will ultimately lead to an experimental basis for modeling the magnetic behavior in MNOM structures and perhaps provide insight into optimizing these ultra-thin structures for important industrial applications.