Modulated Neutron Beam for Magnetic SANS and High-Resolution Radiography

Scientific Importance

Small Angle Neutron Scattering (SANS) enables the statistical structural characterization in the ~1 to a few hundred nm ranges. To investigate samples with long range length scales, that is beyond 200nm, it imposes a great challenge to conventional SANS instruments. We propose to extend the accessible length scale of SANS using Spin Echo Modulated SANS (SEMSANS) by spatially modulating the neutron polarization vector using magnetic Wollaston prisms (MWP). As was shown in Figure 1(a). scattering from the sample reduces the visibility (normalized amplitude) of the intensity modulation on the detector. The ratio of the visibilities of the intensity modulation $\frac{A_s}{A_0}$, measured with and without a sample, gives the same projection of the sample density autocorrelation function $G(z)$, namely $\frac{A_s}{A_0} = e^{\sigma_t[G(z)-1]}$. By allowing the sample after the polarization analyzer, SEMSANS can be used to study the correlation of magnetic samples as a function of magnetic field (<1.5T). With SEMSANS, we will investigate the magnetic interactions in $(Fe_{0.7}Ni_{0.3})_{86}B_{14}$ alloy, a HiB-NANOPERM-type soft magnetic nanocrystalline material, which exhibits an ultrafine microstructure. The understanding of such microstructure is crucial to the optimization of the magnetic softness of Fe-based nanocrystalline materials.

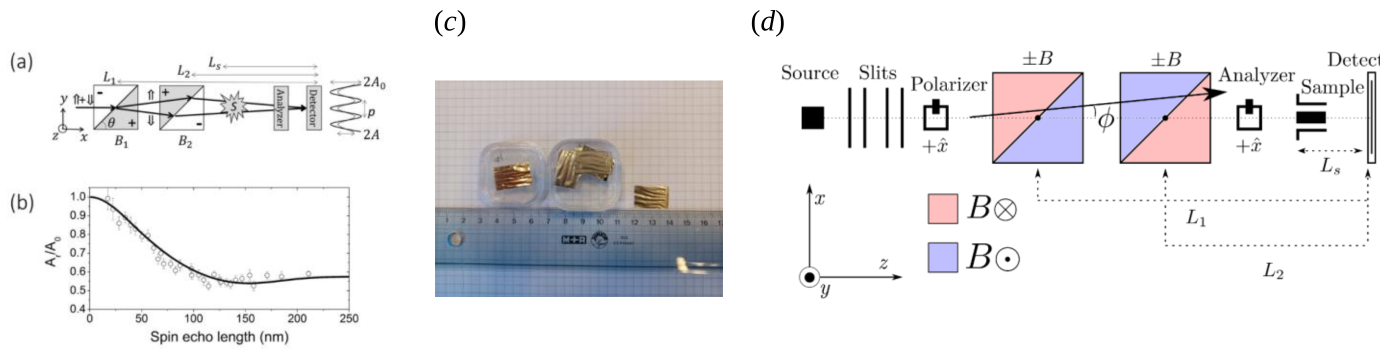

Figure 1. (a) The SEMSANS setup using superconducting magnetic Wollaston prisms[1], (b) the correlation function of a silica colloidal sample previously measured with SEMSANS, (c) the Fe–Ni–B-based nanocrystalline permalloy and (d) the angle encoding radiography (AER) setup. For clarify, we have omitted translation and rotation stages for the diffraction grating (labeled sample), the center guide field between the 2 MWPs, and the 2 nutators at the front and exit of the MWP pair.

With the same setup, by reconfiguring the magnetic fields inside the MWP, we also propose to demonstrate the application of polarized neutron in high resolution neutron radiography, which is named Angle-Encoded Radiography (AER). For AER, the modulation of the neutron's polarization encodes the neutron's divergence angle at it passes through the sample. The total neutron intensity measured without polarization analysis provides the usual transmission radiograph of an object. However, the polarization of the beam measures the Fourier transform of the transmission function with a period determined by the current in the MWPs. By choosing special currents determined by the relative distances between the source, sample, and detector, various Fourier components of the sample's transmission function can be measured allowing for a better spatial resolution than is available with the zeroth order component (i.e. the usual transmission radiograph) alone; the theoretical resolution in AER is $R_{AER} \approx \alpha L_s$, where α is the angular separation between the encoding fringes of the polarization modulation (determined by the currents in the MWP) and Ls is the distance from sample to detector. Therefore, assuming sufficient beam polarization, AER has no limitations on the image resolution. In practice, the limit on the resolution will likely be determined by the wavelength spread.

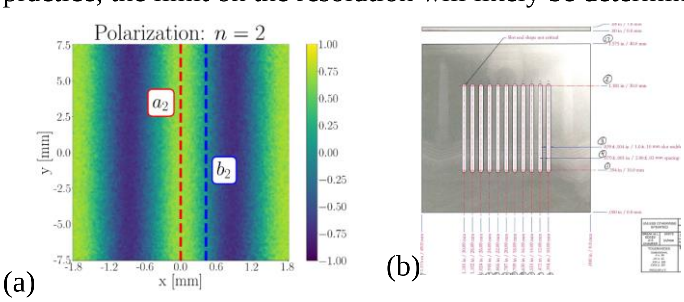

Figure 2. a) Simulated 2D polarization data from McStas for the second harmonic. The lines labeled a_2 and b_2 are the lines where the cosine and sine Fourier coefficients are extracted. b) CAD drawing of the 1.5 inch^2 borated aluminum diffraction grating sample.

Experiment Plan

The experiment will be organized in two parts, where the first part is to measure the correlation function of $(Fe_{0.7}Ni_{0.3})_{86}B_{14}$ permalloy and the second part is to demonstrate the AER experiment on a grating. To setup the apparatus, it will take a couple of days based on our previous experience. To tune and calibrate the setup for the following measurements, it would take another day. An electromagnet will be used to generate a vertical field of 1T to align the magnetic domains of the permalloy sample. Since SEMSANS is a one-dimensional technique, we will need to rotate the magnet by 90 deg to measure with the magnetic field parallel and perpendicular to the encoding direction to separate magnetic and nuclear contributions, akin to what is done in regular 2D SANS. For the sample, we will stack about 5 Nanoperm sheets (each having a thickness of about 20 microns) and wrapped them into Al foil. The foil was then clamped between two metal plates. The size of the window is about 10 X 10 mm (see Figure 1(c)). For each orientation of the electromagnet, we will need ~4 days.

For AER, the physical setup for the experiment will be the same as the SEMSANS experiment, with sample placed after the spin analyzer. We plan to use a v-cavity as a polarizer and an s-bender mounted on a translation and rotation stage for the analyzer. We will use two IU nutators for polarization transport. AER needs at least a 1D spatial-resolving detector, so we plan to use the new 2D Timepix 3 camera. As a backup, we would also like to have the Anger camera available. A static guide field may be needed between the polarizer and first MWP. At least 3 Lakeshore power supplies are needed: 1 for all but one MWP triangle, 1 for a single MWP triangle if linear correction mode is needed, and 1 for the center guide field; the 2 nutators will also need their own power supplies, for a total of at least 5 power supplies. We will start with a beam size of 1 cm^2, but we plan to use the largest beam size that has a sufficient polarization. Each triangle should have nearly the same field current (i.e. the SESANS current choice), and we will measure the AER signal at various currents between 2-20 amps. For each current, we will measure with sample in and sample out (to normalize out the instrumental polarization), hence the need for the sample translation stage. The sample rotation stage should only be need once for initial sample alignment.

Safety Considerations

The IU MWP pair is similar to the ORNL Wollaston prism and hence it will have the same equipment needs and safety procedures as the ORNL MWP. The borated aluminum diffraction grating will need to go through the usual sample check-in procedure. We will need to survey the fringe magnetic field produced by the magnets to ensure the personnel safety and the S bender safety. Cooling water is required for the magnets. The power supplies and magnets will need to be inspected by the electricians.