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SMARTer for magnetic structure studies

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Abstract. SMARTer, a 36-meter small angle neutron scattering (SANS) spectrometer was installed at the Neutron Scattering Laboratory (NSL), National Nuclear Energy Agency of Indonesia – BATAN in Serpong, Indonesia and has performed the experiment for studying the magnetic structures of Cu(NiFe), CuCo and FeSiBNbCu metal alloys. The experiments were conducted at room temperature and up to 1 T (10 kOe) of external magnetic field. At zero fields, isotropic scattering identified as nuclear scattering is dominant. When a magnetic field is applied in a horizontal direction perpendicular to the neutron beam, the response of the magnetic scattering permits extraction of the field-induced re-arrangement of the magnetic moment. With increasing field the distortion is more pronounced and the magnetic scattering dominates the intensity and affects the peak position. Radial and angular averaging from experimental data are given to show the details of magnetic structures.

Keywords. Small angle neutron scattering; magnetic structure; Cu(NiFe); CuCo; FeSiBNbCu.

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1. Introduction

Small angle neutron scattering (SANS) is a powerful technique in characterizing the static and dynamic structures of particles in the nanometer scale range of 1–100 nm. Information on the average size and its distribution, spatial correlation, as well as shape and internal structure of particles can be obtained from SANS scattering intensity profiles. Quantitative analysis on number or volume density from investigated structures in the surrounding medium can be determined from an absolute scale of scattering intensity. Thus, SANS is a valuable technique for characterization in materials science and biology; e.g. alloys, ceramics, polymers, colloids, vesicles, viruses, etc.

Besides the nuclear interaction, magnetic interaction with matter also occurs due to the magnetic moment of the neutron which can be as strong as the nuclear interaction. This property gives neutrons an advantage over X-rays where magnetic interaction is very weak and difficult to measure. Given the nuclear and magnetic interactions of neutrons with matter both compositional and magnetic structures and their correlations can be studied. Thus, magnetism in solid state physics and condensed matter research is an important application of neutron scattering. The SANS technique probing structures on the nanometer scale finds applications in micromagnetism, magnetic clusters embedded in a solid nonmagnetic matrix, magnetic clusters suspended in fluids (e.g. ferrofluids), magnetism in nanostructured materials, vortex lattices in superconductors, etc. [1].

In the present paper, we report the results of magnetic experiments for the first time using a SANS spectrometer facility in BATAN Serpong, Indonesia. Assessment of the performance of the spectrometer is made with known magnetic samples from high magnetic scattering intensity such as Cu(NiFe) metal alloy to weak magnetic scattering intensity such as soft magnetic nanocrystalline metallic ribbons (FINEMET) of FeSiBNbCu. All samples show a pronounced magnetic anisotropic scattering which depends on the applied external magnetic field. Interlaboratory data comparison and implementation of data reduction and analysis of GRASP program [2] for magnetic structure studies were also carried out.

2. Materials and methods

A Cu(NiFe) sample which has a precipitation of Fe/Ni-rich ferromagnetic phase (α'-phase) embedded in a Cu-rich paramagnetic matrix was prepared from Cu–24 at% Ni–8 at% Fe composition. Details of this sample preparation are described elsewhere [1]. The CuCo metal alloy sample was produced from nanometer-sized crystalline clusters by the intergranular corrosion (IGC-technique). The synthesis started from metallic glasses which undergo a decomposition and nanocrystallization upon annealing at temperatures near their glass transition temperature T_g. A FINEMET sample of $Fe_{73.5}Si_{15.5}B_7Nb_3Cu_1$ known as a soft magnet was also prepared by the IGC-technique from the melt spun amorphous alloy and then annealed [3].

The SANS measurements were carried out at the Neutron Scattering Laboratory (NSL) in Serpong, Indonesia, using a 36-m SANS BATAN spectrometer. Details of this spectrometer are described elsewhere [4]. All samples were exposed to a neutron wavelength of 3.90 Å with the sample-to-detector position of 6 m at room temperature. This experimental setting covers the momentum transfer range of $0.01 < Q < 0.1$ Å^{-1} where $Q = 4\pi \sin(2\theta)/\lambda$, and 2θ is the angle between the incident and scattered beams. The sample was in a sample holder between the pole shoes of an external electromagnet with the magnetic field perpendicular to the incident unpolarized neutron direction. The magnetic field was varied from 0 to 1 T (0 to 10 kOe). The SANS scattering intensity data from all samples were corrected for scattering background, dark current and electronic noise.

3. Result and discussion

Two-dimensional scattering profiles showing isotropic and anisotropic scattering patterns for all magnetic samples under an external magnetic field up to 10 kOe compare well with data taken at PSI, Switzerland and these results are reported

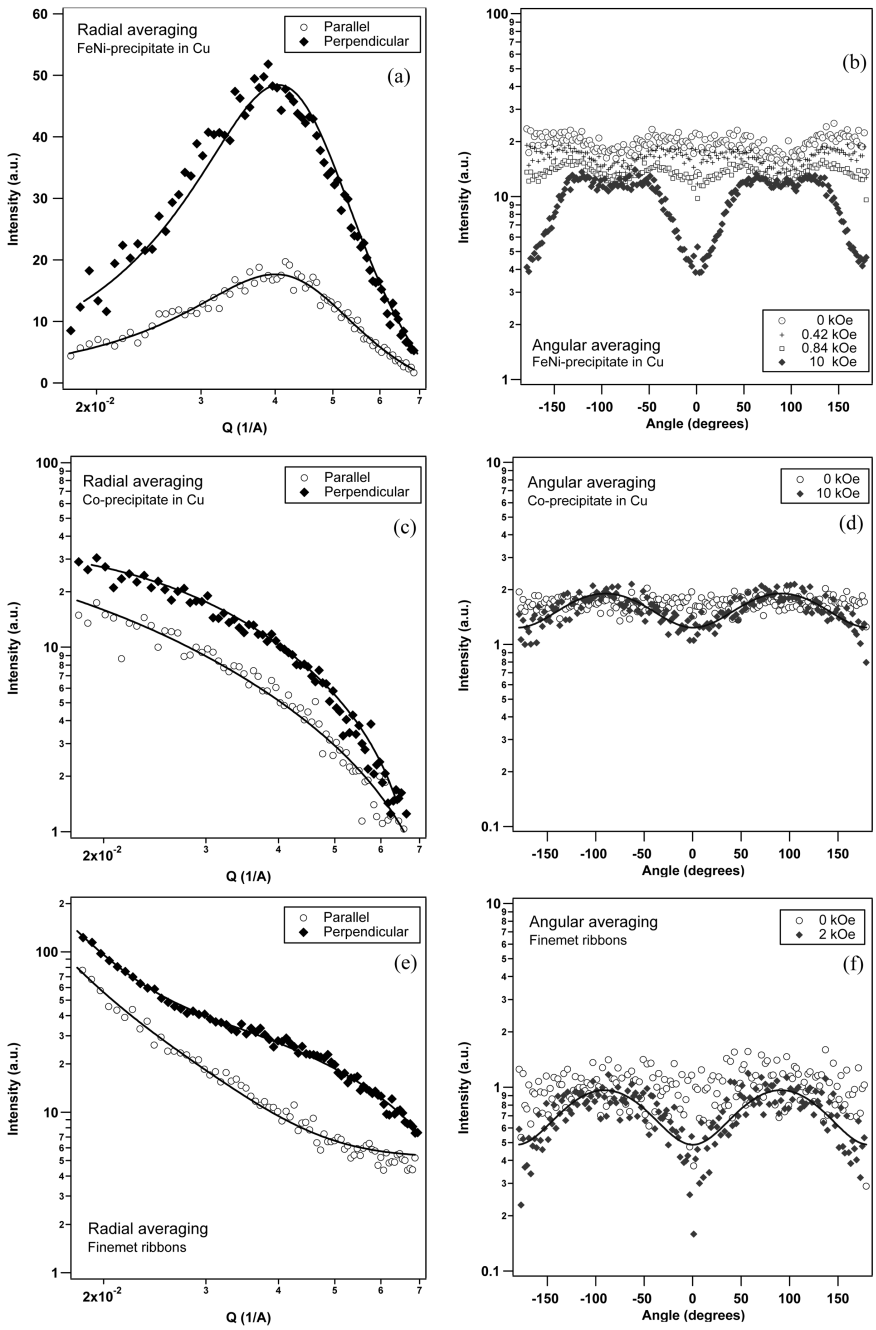

Figure 1. The radial and angular averaging analyses of magnetic samples: (**a**) and (**b**) Cu(FeNi), (**c**) and (**d**) CoCu, and (**e**) and (**f**) FINEMET ribbons of $Fe_{73.5}Si_{15.5}B_7Nb_3Cu_1$. All measurements were taken using SMARTer, 36-m SANS BATAN spectrometer and analysed by means of GRASP program.

elsewhere [5]. The isotropic and anisotropic scattering contributions which attribute to nuclear and magnetic scattering, respectively, can be separated by fitting the intensity pattern described by [1]

$$\frac{\mathrm{d}\Sigma}{\mathrm{d}\Omega}(Q) = A(Q) + B(Q)\sin^2\Psi + C(Q)\sin^4\Psi, \tag{1}$$

where for unpolarized neutrons the last term vanishes, $C(Q) = 0$ and Ψ is defined as the azimuthal angle between the horizontal direction and the scattering vector q.

Figure 1 shows the radial and angular averaging for all samples in varied magnetic fields. The applied magnetic field is sufficient to nominally fully saturate or polarize the ferromagnet along the field direction. Ideally, all magnetic moments align with the field and there should be no magnetic scattering intensity for scattering vectors q parallel to the magnetic moment direction, and a maximum in magnetic scattering intensity for q perpendicular to the moment direction. This is clearly shown in figures 1a, 1c, and 1e where the magnetic scattering from FeNi and Co ferromagnetic precipitate in Cu paramagnetic matrix and FINEMET samples appears for scattering vector q perpendicular to the moment direction when magnetic field 10 kOe is applied. For the field parallel to the moment direction the scattering intensity is predominantly from nuclear scattering interaction.

The data have also been analysed using a constant momentum transfer Q to examine the average magnetic scattering intensity with the angle around the multidetector image. The results are showed in figures 1b, 1d and 1f. It is noticeably clear that the peaks from an angular averaging analysis on a sample with a weak magnetic scattering intensity are still pronounced at the angle of $-90°$ and $+90°$ from the magnetic moment direction (figures 1d and 1f).

4. Conclusions

We have described the use of SMARTer, a 36-m SANS BATAN spectrometer for magnetic experiments and data analyses. It can be concluded that this spectrometer has the capability and sensitivity for the experiments on magnetic samples even when these have weak magnetic scattering intensities. The data reduction and analysis program were also well suited for analysing the magnetic experimental data.

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