Experimental report

03/02/2016

Proposal: 5-54-175 **Council:** 4/2014

Title: Study of magnetic properties of inverted opal-like structures by the small-angle neutron scattering

Research area: Physics

This proposal is a new proposal

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Samples: Mesoporous nanostructured thin film of Co - inverse opal-like structure

Instrument	Requested days	Allocated days	From	To
D33	5	4	11/12/2014	15/12/2014

Abstract:

The proposal is aimed to investigate the local magnetization distribution in a three-dimensional network constructed by the magnetic elements of the size of 400 - 500 nm. 3D network is an inverse opal-like (IOL) Co film which is prepared by well known templating technique. The ferromagnetic inverse opal-like structure are interesting as a three-dimensional nanoscale analogue of highly frustrated systems called spin-ice. Since, in analogy to the spin "ice rule", the magnetic flux conservation law for the elements of the structure must be fulfilled, we have developed a model for the distribution of the magnetic moments within the IOLS. Present proposal is aimed to improve the "ice-rule" model suggested in for the geometry, when the field is applied along the [111] direction, i.e. perpendicular to the sample plane. In this case, at the certain value of the magnetic field the "ice-rule" will not be executed and "monopoles" can arise in highly frustrated nanoscale system. In addition, we propose to measure field-dependent diffraction patterns in geometries when sample is oriented perpendicular to the neutron beam propagation while th

Study of magnetic properties of inverted opal-like structures by small-angle neutron scattering

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The objects of study were inverse opal-like Ni and Co films, which have been prepared using the following template technique [1]: First, polystyrene spheres with mean diameter of 540 nm formed a colloidal crystalline face-centered-cubic (fcc) template on top of a conductive substrate (polished Si single crystal, covered by the 20 nm Au layer) covering an area of 1 cm^2 with a thickness of 13 μm. Subsequently, the voids between the spheres were filled with Ni or Co via an electrochemical crystallization process. Finally, the microspheres were dissolved in toluene.

The ferromagnetic inverse opal-like structure (IOLS) is interesting as a three-dimensional nanoscale analogue of highly frustrated systems called spin-ice [2]. In our previous SANS experiments at SANS-2 (GKSS, GeNF) [3, 4] it was revealed that the local configuration of the magnetization coincide with the spatial network of IOLS following the directions determined by the symmetry of the structure. Since in analogy to the “spin ice rule” the magnetic flux conservation law for the elements of the structure must be fulfilled, we have developed a model for the moment distribution within the IOLS based on “ice rule” [4].

In order to investigate the magnetic structure for different types of the interplay between the external field and the “ice-rule” we performed this experiment for field directions along the [111], [101] and [100] axes of the fcc-ordered [3] IOLS.

A polarized neutron beam with a wavelength λ = 1.7 nm, and a bandwidth $\Delta\lambda/\lambda$ = 0.1 was used. An external magnetic field H up to 1.5 T was applied along the beam direction. In the initial position the sample was perpendicular to the beam and field, i.e. the field was along the [111] axis of the sample. Then the sample was rotated by -35° around the vertical $[20\bar{2}]$ axis to direct the field along the [101] axis. Finally the sample was rotated by +55° with re-

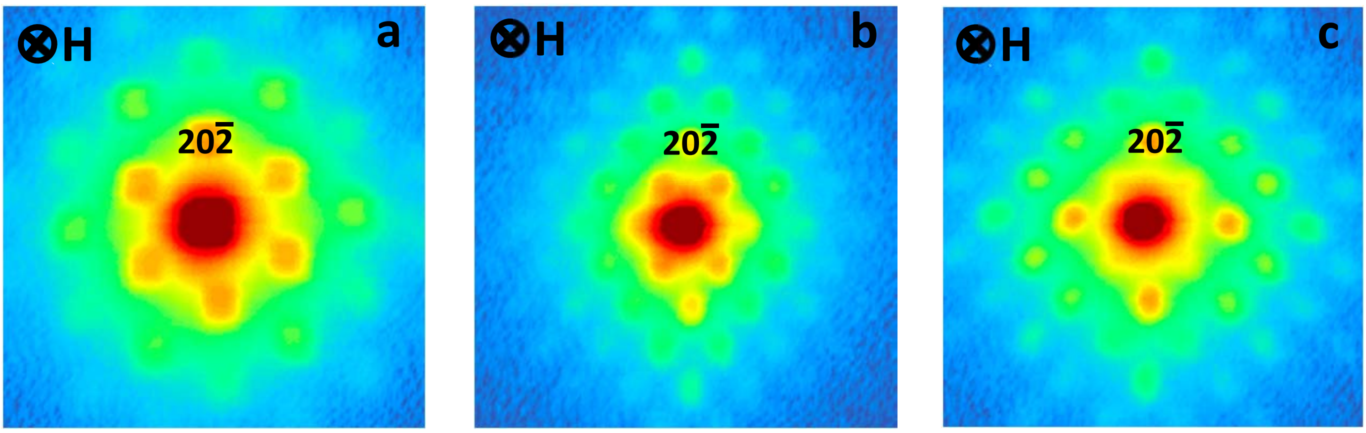

Fig. 1. Typical diffraction patterns for the Co IOLS with the field is applied along the [111] (a), [101] (b), and [100] (c).

pect to the initial position to direct the field along the [100] direction. For all three geometries we have taken field-dependent diffraction patterns with two beam-polarization states (+P, -P). All measurements were performed at room temperature. We have tried to perform the experiment both for Ni-based and Co-based IOLS, but due to low ratio of magnetic and nuclear scattering length for Ni, we deal only with the cobalt samples. Diffraction patterns in the highest field (H = 1.5 T) are presented in Fig. 1.

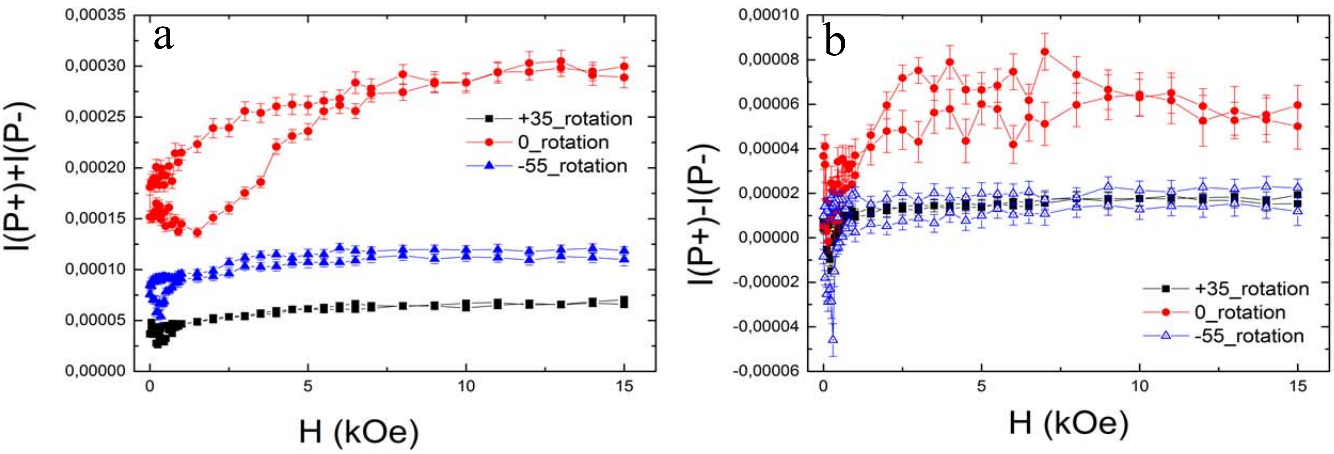

Fig. 2. Pure magnetic (a) and nuclear-magnetic interference (b) contributions to the neutron scattering intensity as function of the field for the $20\bar{2}$ Bragg peak.

Integral intensities of Bragg peaks corresponding to the scattering on the planes of the {202} family have been analyzed. Q-dependencies for these peaks were averaged in order to improve statistics and fitted by the sum of squared Lorenz function (diffuse scattering near Q=0) and Gauss function (Bragg peaks). The pure magnetic contribution to the neutron scattering intensity was extracted by adding the data for the states with +P and –P, while the nuclear-magnetic interference contribution was extracted by subtracting the data for these states. In Fig. 2 both contributions for the $20\bar{2}$ Bragg peak are presented. The step-like dependence is related with an abrupt magnetizing of the magnetic subsystems, directed along one of the <111> axes. Herewith, for different directions of the field, the sample is magnetized differently: For H || [111] a strong hysteretic behavior in a wide field range has been observed. For the two other geometries the saturation takes place at smaller fields which is due to the fact that in the latter case the field competes with the "ice rule".

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