Experimental report

03/02/2016

Proposal: **5-54-188** **Council:** 10/2014

Title: Study of the „ice-rule“ fulfilling in ferromagnetic inverse opals with enhanced anisotropy

Research area: Physics

This proposal is a new proposal

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Samples: Mesoporous nanostructured thin film of Co

Instrument	Requested days	Allocated days	From	To
D33	6	4	02/05/2015	06/05/2015

Abstract:

The ferromagnetic inverse opal-like structure (IOLS) are interesting as a three-dimensional nanoscale analogue of highly frustrated systems called spin-ice. Magnetic moments in such systems obey so called “ice-rule”, standing, that two moments should go into tetrahedron and two – out. 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 distribution of the magnetic moments within the IOLS. In spin ice anisotropy is so strong, that makes magnetic moments there Ising-like. In attempt to closer the analogy we have performed acid etching of the samples to make the “bridges” thinner and, thus, enhance the anisotropy. The main aim of this work is to prove the applicability of the “ice-rule” to description of the magnetization distribution in ferromagnetic inverse opal-like structures.

Study of the „ice-rule“ fulfilling in ferromagnetic inverse opals with enhanced anisotropy

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Inverse opal-like structures (IOLS) can be synthesized by filling the voids of opal templates with suitable structure-forming precursors and subsequent removal of the initial microspheres to leave three-dimensionally ordered porous materials. The inverse opals based on ferromagnetic metals (Ni, Co, etc.) represent a new class of 3-dimensional nanoscale ferromagnetic structures, which are geometrically frustrated at room temperature. It was shown by microradian diffraction of synchrotron radiation that the spherical voids of the synthesized samples are presumably ordered in a face-centered cubic structure with a period of 760 ± 10 nm [1].

In our previous experiments at SANS-2 (GKSS, GeNF) [1-3] we have shown that the local configuration of the magnetization coincide with the spatial network of IOLS following the directions determined by the symmetry of the structure. The experiment we carried out at D33 was aimed to study the evolution of the magnetic structure of the IOLS with increasing anisotropy. In order to enhance the anisotropy, we have tried to make thinner structural elements of the IOLS by etching the samples in acid-methanol solution. However, scanning electron microscopy (SEM) studies have shown that only the topmost layers of the samples were etched. Thus, in fact, we have investigated magnetic structure of the IOLS samples, which are thin films of about 1 cm^2 with different thickness of 3.5, 8.5, and 13 μm.

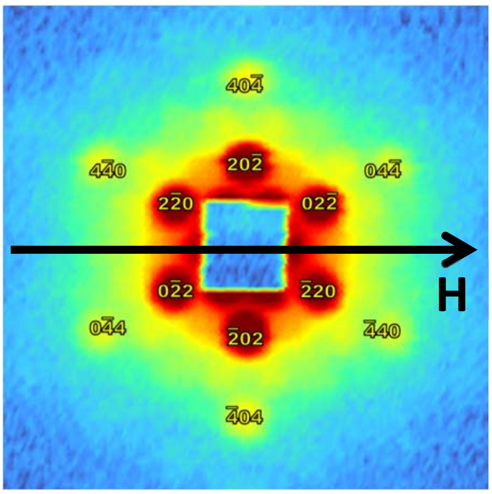

Fig. 1. Typical diffraction pattern for the Co IOLS

In the experiment a non-polarized neutron beam with a wavelength $\lambda = 1.3$ nm, and a bandwidth $\Delta\lambda/\lambda = 0.1$ was used. The sample was mounted perpendicularly to the beam. An external magnetic field H up to 1.5 T was applied in the sample's plane along the $[1\bar{2}1]$ axis. The measurements were performed at 300 K.

An example of typical diffraction pattern recorded in the experiment is presented in Fig. 1. One can see that it consists of several clearly resolved sets of hexagonally arranged reflexes.

For further analysis all reflexes were divided into two subgroups: $20\bar{2}$ and $\bar{2}02$ reflexes (“vertical” peaks) correspond to crystallography planes parallel to the field, whereas $02\bar{2}$, $\bar{2}20$, $0\bar{2}2$ and $2\bar{2}0$ reflexes ("diagonal" peaks) correspond to planes under 30° with respect to the field direction. The intensities of the magnetic reflections were averaged over the subgroup in order to improve the statistics. Pure magnetic intensity has been extracted from the experimental data by subtracting the data taken in the demagnetized state. In order to obtain peak integral intensity, Q-dependencies for all peaks were fitted by the sum of square Lorentz (small-angle diffuse scattering) and Gauss (Bragg peaks) functions.

In Fig. 2 one can see field dependencies of the magnetic intensity for all three samples studied in the experiment. In the inset the lowest intensity point (coercive force) is presented. It is clear, that the magnetizing process strongly depends on the sample thickness. For instance, the saturation field increases noticeably with the thickness, while the coercivity changes slightly.

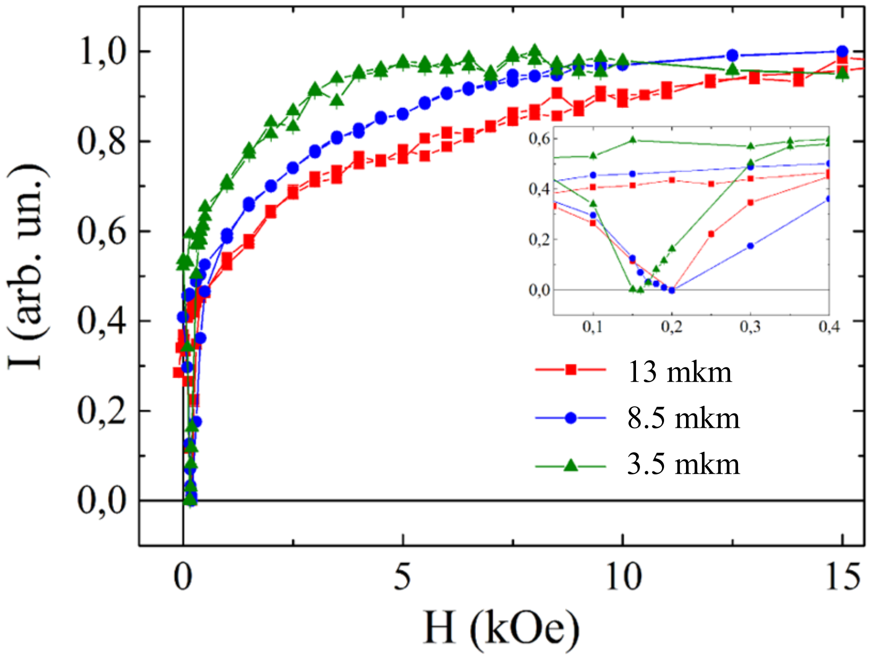

Fig. 2. Pure magnetic scattering intensity of the $20\bar{2}$-type Bragg peak of the Co IOLS samples as a function of the external field.

We thank the responsible of the D33 SANS facility Dirk Honecker for the allocated time and for the excellent support during the experiment.

References

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