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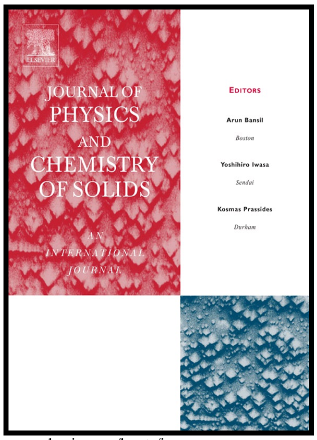

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Neutron diffraction from superparamagnetic colloidal crystals

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Abstract

We fabricated a superparamagnetic ordered structure via self-assembly of a colloidal crystal from a suspension of maghemite nanoparticles and polystyrene beads. Such crystals are potential candidates for novel polarizing beam-splitters for cold neutrons, complementing the available methods for polarizing neutrons. Different bead sizes and nanoparticle concentrations were tested to obtain a crystal of reasonable quality. Neutron diffraction experiments in the presence of an external magnetic field were performed on the most promising sample. We demonstrate that the diffraction efficiency of such crystals can be controlled by the magnetic field. Our measurements also indicate that the Bragg diffraction regime can be reached with colloidal crystals.

Keywords: colloidal crystals, superparamagnetic nanoparticles, neutron scattering

1. Introduction

Spin-polarized neutron beams are required for experiments in fundamental and condensed matter physics [1–4]. In previous articles we have described holographic gratings functioning as neutron beam-splitters [5–9] and some ideas and preliminary results on using superparamagnetic nanoparticles to construct polarizing beam-splitters [7, 10, 11]. It is known that the total scattering cross-section of nanocrystalline ferromagnets may vary over some orders of magnitude under the influence of magnetic fields [12]. By using a magnetic grating or a non-magnetic grating complemented with magnetic nanoparticles, one can control the diffraction of neutrons by tuning the refractive-index modulation of the grating via an external magnetic field. If the magnetic part of the refractive index modulation exactly cancels the nuclear part for one of the neutron spin states, the grating will only diffract neutrons in the other spin state, thus producing polarized beams. Here, we report on the first neutron diffraction experiment on a periodic structure with superparamagnetic properties, intended to assess the above idea. The structure we used was fabricated by incorporating maghemite ($\gamma - Fe_2O_3$) nanoparticles in a colloidal crystal self-assembled from polystyrene beads. Colloidal crystals are ordered structures that self-assemble from colloidal particles, whose diameters are typically between 100 nm and 2000 nm. Such crystals have lattice constants comparable to the wavelength of visible light and are therefore of particular interest in photonics, either by themselves or as templates for other materials [13, 14]. Various applications of magnetic colloidal crystals have been demonstrated, such as controlling the distance between particles [15–17], controlling the self-assembly process [18–20], and construction of Faraday rotators [21], all focused on modification of optical properties of materials.

Because of the submicrometer size of the particles, colloidal crystals are also suitable for fabrication of optical elements for cold neutrons. Neutron scattering studies on magnetic colloidal crystals based on ferromagnetic nickel and cobalt have recently been reported by Grigoriev *et al* [22] and Grigoryeva *et al* [23]; in contrast, the present study examines a colloidal crystal with superparamagnetic properties. The main advantage of using superparamagnetic instead of ferromagnetic materials is their very narrow hysteresis, allowing easier control over the magnetisation of the crystal, which is important for our long-term goal.

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