Tests of holographically generated diffraction gratings with very cold neutrons

J. Klepp [1], C. Pruner [2], P. Geltenbort [3], H. Rauch [3,4], R. A. Rupp [1] and M. Fally [1]
[1] *Faculty of Physics, University of Vienna, A-1090 Vienna, Austria*
[2] *Department of Materials Science and Physics, University of Salzburg, A-5020 Salzburg, Austria*
[3] *Institut Laue Langevin, BP 156, F-38042 Grenoble Cedex 9, France*
[4] *Atominstitut, Vienna University of Technology, A-1020 Vienna, Austria*

The aim of the reported experiment was to test holographic gratings, recorded in nanoparticle-polymer composites, at the very cold neutron (VCN) beam line of PF2. The results of our first tests show that our future goal – neutron optical devices and, in particular, interferometry based on such materials – could be feasible with VCN.

All neutron-optical phenomena, i.e., those arising from coherent elastic scattering, are governed just by the neutron optical potential or, equivalently, the neutron refractive-index [1]. Thus, an important task in the design of neutron-optical elements is structuring the neutron refractive-index of materials in an efficient way. For this purpose we utilize materials that are sensitive to light, combined with holographic techniques to produce diffraction gratings for neutron-optics. Due to the photo neutron- refractive effect [2], the treated materials exhibit a periodic neutron refractive-index pattern, arising from a light-induced redistribution of SiO2 nanoparticles in a polymer matrix. Experiments with holographically produced gratings containing polymer-dispersed liquid-crystals (H-PDLC) [3] or deuterated poly(methylmethacrylate) culminated in the successful test of a triple-Laue interferometer for cold neutrons [4]. Nanoparticle-polymer composites [5] offer advantages for efficient tuning of the refractive-index modulation by suitable choice of the species among an abundance of usable nanoparticles, their size and volume-ratio (polymer matrix/nanoparticles). Thus, beam-splitters and even mirrors for neutron interferometry seemed within reach. Recently, the experimental demonstration of a 50:50 beam splitter for $\lambda \simeq 2$ nm neutrons has been achieved [6]. Since the neutron refractive-index depends on the wavelength squared, we want to use the largest wavelengths possible, keeping in mind intensity losses due to scattering and absorption in our materials at VCN wavelengths. It was the aim of our experiment, to test if further neutron optics experiments with holographic gratings are meaningful at the VCN beam line of PF2.

In short, the sample preparation is as follows: Two glass microscope slides are glued together enclosing a fixed gap provided by a spacer-foil of some μm to mm thickness. The liquid monomer-nanoparticle mixture is sucked into the gap by capillary force. For more details, see Ref. [8]. A sinusoidal hologram with a grating spacing of the order of μm is recorded in the material by laser interferometry (see also [4, 6, 7]).

A SANS experiment to measure the diffraction efficiency of various samples was set up at PF2 VCN (see the sketch in Fig. 1). The VCN beam incident from the curved neutron guide was reflected by a Ti/Ni-mirror so that a spectrum with intensity maximum at about 3.75 nm was obtained. Several collimation slits (Cd) provided for a beam cross section of $2 \times 5\,\mathrm{mm}^2$ and horizontal/vertical angular divergence of not more than 2/5 mrad. The collimation distance was roughly 3 m. The sample was mounted on a rotation stage

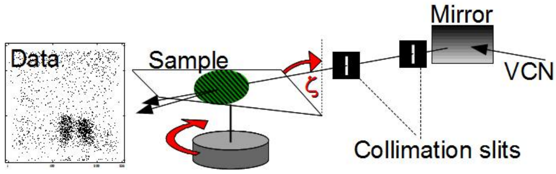

Figure 1: Experimental setup for measuring the diffraction efficiency of holographic gratings recorded in nanoparticle-polymer composites.

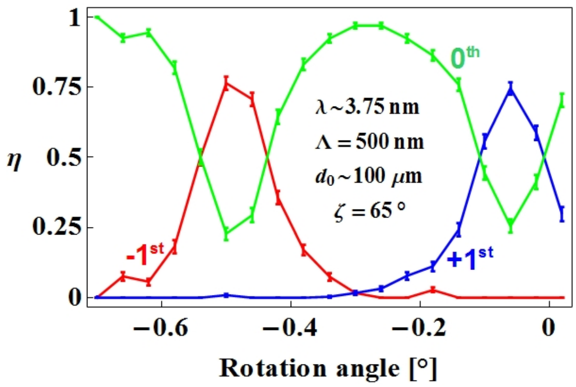

Figure 2: Rocking curve in Laue geometry: -1^{st} (red), $+1^{\mathrm{st}}$ (blue) and 0^{th} (green) order diffraction efficiencies at neutron wavelength of $\lambda = 3.75\,\mathrm{nm}$ of a holographic grating recorded in SiO_2 nanoparticle-polymer composite.

with 0.001° stepwidth. The sample holder is constructed such that the grating can be rotated through an angle ζ about an axis defined by the grating vector. The Pendellösungs length of nanoparticle-polymer composite gratings is of the order of mm [7]. Therefore, the diffraction efficiency at the Bragg angle can be conveniently adjusted changing the effective thickness of the grating by tilting the sample as it has been done with crystals (see Refs. [1, 9]. The best result was achieved with a grating of $d_0 \sim 100\,\mu$m thickness and a grating constant of $\Lambda = 0.5\,\mu$m recorded in a SiO_2 nanoparticle-polymer composite at $\zeta = 65^\circ$. The diffraction efficiency at the Bragg-angle reached about 75% as shown in Fig. 2.

Diffraction occurs clearly in the two-wave coupling (Bragg) regime, so that no intensity is lost to unwanted diffraction orders, as it would be the case for thin gratings. Furthermore, the FWHM of the rocking curve is of the order of 0.1°so that reliable adjustment of successive gratings – as necessary for

e.g. neutron interferometry – should be feasible with considerable effort.
The main problems of the experiment were:

1. The small sample diameter (roughly 1 cm), that strongly limited the transmitted flux at large tilt angles ζ.

2. For our first tests, the microscope object carriers that contain the recording material were made of normal glass instead of quartz glass. This causes unnecessary absorption and incoherent scattering, especially at large ζ.

3. The recording material was not deuterized, which again causes incoherent scattering at large ζ.

4. As simulations showed, a very broad spectrum can cause also broadening – and therefore diminished peak diffraction efficiency – of the rocking curves already for grating constants of 0.5 microns.

The first two points can easily be overcome for future experiments by slightly modifying the recording laser setup and using quartz glass as sample containers. Sample diameters of about 3 cm have already been reached in Ref. [4]. The third problem can probably be solved in collaboration with the EMBL-ILL deuteration lab. However, this is perhaps the most time-consuming issue of our list. A solution to the last point will hopefully be tested in the near future: We want to test 0.2 mm thin Si wafers to reflect the longer wavelength components of the beam, transmitting a little attenuated but narrower wavelength band to the sample. Thereby we want to reach the conditions for mirror-like behaviour of our holographic gratings.

[1] V. F. Sears, *Neutron Optics* (Oxford University Press, New York-Oxford, 1989)

[2] R. A. Rupp, J. Hehmann, R. Matull, K. Ibel, Phys. Rev. Lett. **64**, 301 (1998)

[3] M. Fally, I. Drevensek-Olenik, M. A. Ellabban, K. P. Pranzas, J. Vollbrandt, Phys. Rev. Lett. **97**, 167803 (2006)

[4] C. Pruner, M. Fally, R. A. Rupp, R. P. May, J. Vollbrandt, Nucl. Instrum. Methods Phys. Res., Sect. A **560**, 598 (2006)

[5] N. Suzuki, Y. Tomita, T. Kojima, Appl. Phys. Lett. **81**, 4121 (2002)

[6] M. Fally, J. Klepp, Y. Tomita, T. Nakamura, C. Pruner, M. A. Ellabban, R. A. Rupp, M. Bichler, I. Drevensek Olenik, J. Kohlbrecher, H. Eckerlebe, H. Lemmel, H. Rauch, accepted for publication in Phys. Rev. Lett.

[7] J. Klepp, C. Pruner, M. A. Ellabban, Y. Tomita, H. Lemmel, H. Rauch, M. Fally, Nucl. Instrum. Methods Phys. Res., Sect. A, doi:10.1016/j.nima.2010.06.360

[8] N. Suzuki, Y. Tomita, Appl. Opt. 46, 6809 (2007)

[9] V. A. Somenkov, S. Sh. Shilstein, N. E. Belova, K. Utemisov, Solid State Communications **25**, 593 (1978)

Proposal-number: 3-14-278
Instruments: PF2 VCN