Experimental report

27/10/2022

Proposal: EASY-977 **Council:** 4/2021

Title: Study of neutron quasi-specular reflection from powder of diamond nanoparticles as a function of the nanoparticle size

Research area: Physics

This proposal is a new proposal

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Experimental team:

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Samples: diamond

Instrument	Requested days	Allocated days	From	To
D17	20	20	26/08/2021	27/08/2021

Abstract:

Due to the enhanced coherent reflection, neutrons are efficiently scattered on powders of diamond nano-partciles. One application of this phenomenon is quasi-specular reflection from the powder surface at small grazing angles. We have discoved this phenomenon in an experiment at D17 instrument at ILL and improved the performance by fluorinating nanodiamonds, thus removing hydrogen-related losses [V.V. Nesvizhevsky, et al, Phys. Rev. A 97 (2018) 023629]. Further improvement is expected to come from the optimization of particle sizes as confirmed by preliminary measurements. We apply for 20 hours of beam-time to complement this study and get data needed for a publication. The experiment will be performed using the same method, in the same geometry. We have 7 samples ready; the time needed for the statistics taking and the sample change is about 2 hours. Plus test measurements.

Goal: the goal of this short test experiment was to explore the feasibility of a complete measurement of quasi-specular reflection of cold neutrons (CN) from designed powders of fluorinated detonation nanodiamonds (F-DND), in particular to optimize the efficiency of quasi-specular reflection as a function of F-DND mean size.

Background: This investigation is a part of NERF ANR project aiming to develop a new generation of reflectors for slow neutrons. The technology of F-DND production is developed in collaboration of Clermont Auvergne University and ILL. Details on this phenomenon could be found, for instance in refs. [1-5]. Quasi-specular reflection of CN can be used for more efficient extraction of CN from neutron sources and for focusing devices. The recent results in this field include the direct experimental demonstration [5] of the improved efficiency of quasi-specular reflection due to the fluorination of DND powders [4]. In addition, the effects of clustering of DND [6] and selecting DND sizes [7] on diffusive reflection of very cold neutrons (VCN) have been studied in details. However, an importance of the last two effects on the efficiency of quasi-specular reflection of neutrons have not yet been investigated both experimentally and theoretically.

A significant fraction of the experiment in this field had been previously done at the D17 instrument at ILL. That is why it was reasonable to perform the present test experiment at D17 as well. D17 allows to cover a broad range of incident neutron wavelength and a broad range of outgoing angles in both directions (perpendicular and parallel to the sample surface).

Description of the experiment: A general scheme of the experiment is shown in the figure.

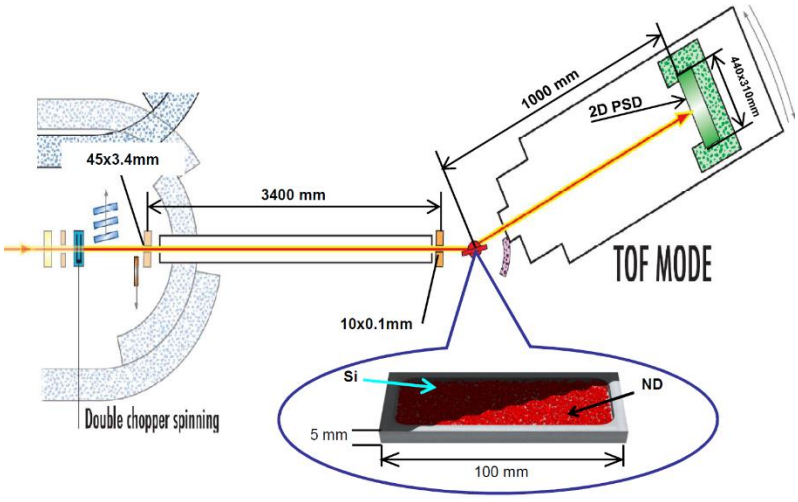

Fig. A scheme (top view) of measurements of quasi-specular reflection of CN from NDs powders. The insert shows a sample of NDs in the sample container: NDs stands for diamond nanoparticles; the box indicates the sample container; Si indicates the window of the sample container. The sharp end of the insert indicates the position of a sample installed on the translation-rotation stage. Neutrons arrive at the sample along the arrow from the liquid-deuterium cold neutron source in the ILL high-flux reactor (from left in the figure). A double chopper periodically interrupts the neutron beam, thus providing the time-of-flight measurements of the neutron spectrum. Various structures in front of the sample provide the suppression of unwanted beam-related backgrounds, neutron transport, and neutron beam collimation. Downstream of the sample, a two-dimensional position-sensitive ^{3}He detector (2D-PSD) within its shielding can move backward and forward inside the vacuum chamber, and/or rotate horizontally around the sample together with the vacuum chamber. An arrow downstream of the sample indicates schematically a neutron reflected quasi-specularly from the sample.

Experimental results: We performed a complete set of short test measurements of quasi-specular reflection of CN from F-DND samples with four mean sizes ranging from ~4 nm to ~40 nm, to all outgoing angles accessible at the D17 instrument.

As expected, the increase in the mean DND size:

- decreased the angular spread of reflected neutrons,
- increased the efficiency of quasi-specular reflection at long wavelength,
- decreased the efficiency of quasi-specular reflection at short wavelengths.

These dependencies could be understood as follows: the angle of neutron scattering at a single DND particle is proportional to the ratio of the neutron wavelength to the DND size. Therefore, an increase in the DND size decreases the characteristic angles of reflection. The interaction cross section increases with increasing the DND size, therefore the efficiency of quasi-specular reflection at long wavelengths increases. However, larger DND sizes increase the efficiency of Bragg scattering of neutrons on the crystal core of the DND particle, thus increase their losses from the quasi-specular direction. This phenomenon takes place below the Bragg cut-off, therefore, the efficiency of quasi-specular reflection at short wavelengths decreases. All these results confirm our initial expectations and could be considered as very positive.

However, the angular acceptance of the D17 instrument was not sufficient to cover the full range of outgoing angles in the vertical direction. Therefore, the direct measurement of the total probabilities of quasispecular reflection from the most promising samples was not possible.

In order to continue this research, two options are possible:

- To develop a complete theoretical model of quasi-specular reflection of neutrons including all relevant phenomena including Bragg scattering. Using such a model, one could try to take into account theoretically the fraction of neutrons scattered to the directions outside of the angular acceptance of the D17 detector. As several parameters of the problem have the same order of magnitude (the neutron wavelength, the DND size, the distance between neighbor DND particles in the powder, the Bragg cut-off wavelength), a theoretical model "from first principles" could be hardly developed.
- To perform such an experiment at another instrument which allows simultaneously to cover the complete range of outgoing scattering angles and the complete range of neutron wavelengths of interest. Such a configuration can be built at PF1B.

We are going to prepare such an experiment at PF1B in this special configuration and complete the present study there.

1. Nesvizhevsky, V.V., *Interaction of neutrons with nanoparticles*, **Phys. At. Nucl. 65** (2002) 400. 2. Nesvizhevsky, V.V., *et al*, *Application of diamond nanoparticles in low-energy neutron physics*, **Materials 3** (2010) 1768. 3. Cubitt, R., *et al*, *Quasi-specular reflection of cold neutrons from nano-dispersed media at above-critical angles*, **Nucl. Instr. Meth. A 622** (2010) 182. 4. Nesvizhevsky, V.V., *et al*, *Fluorinated nanodiamonds as unique neutron reflector*, **Carbon 130** (2018) 799. 5. Nesvizhevsky, V.V., *et al*, *Effect of nanodiamond fluorination on the efficiency of quasispecular reflection of cold neutrons*, **Phys. Rev. A 97** (2018) 023629. 6. Aleksenskii, A., *et al*, *Clustering of diamond nanoparticles, fluorination and efficiency of slow neutron reflectors*, **Nanomaterials 11** (2021) 1945. 7. Aleksenskii, A., *et al*, *Effect of particle sizes on the efficiency of fluorinated nanodiamond neutron reflectors*, **Nanomaterials 11** (2021) 3067.