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Fluorinated nanodiamonds as unique neutron reflector

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Abstract. We consider recent developments on nano-diamond reflectors for slow neutrons, which dramatically improve their efficiency.

Keywords: Neutron optics, neutron source, neutron reflector

With the pronounced worldwide trend of increasing the range of useful neutrons towards smaller energies, driven in particular by large-scale structure diffractometers, reflectometers, time-of-flight and spin-echo techniques as well as by particle physics, the progress is limited by low fluxes of the less energetic part of the cold neutron spectrum. The drop in flux is caused by a fundamental reason: independently of the choice of materials for neutron reflectors, they are composed of atoms. Atoms in solids and liquids are separated by distances of a few tenth of nm. If the neutron wavelength is larger than that, neutrons are weakly scattered by atoms/nuclei, and the diffraction is limited by the inter-plane distances available; thus neutrons penetrate through a reflector with low interaction with its material and are lost.

For fabrication of efficient slow-neutron reflectors, currently there is no alternative to the mimicking of conventional reflectors by means of replacing atoms/nuclei with nanoparticles of low-absorbing highly-scattering materials – thus changing the characteristic length scale, and consequently the neutron wavelength corresponding to the efficient neutron reflection [3]. Nanodiamonds [1] is an evident choice for the material of such reflectors, as the absorption cross section of carbon is exceptionally low, the coherent scattering length is very high and the volume density is higher than that for other carbon materials. The characteristic sizes of available nanodiamonds are found to be in the range of optimum theoretical values. The reflectivity of available nanodiamonds was measured to be much higher than that for any alternative reflector [2]. However, it remained low for neutron velocities above 160 m/s mainly because of the high content of hydrogen impurities.

We overcome this principal difficulty using fluorinated nanodiamonds [4]. We performed a detailed analysis of samples of this material using several complementary techniques as explained below. Using X-ray diffraction, we found that diamond cores (sp^3) of nanoparticles remain unaffected upon fluorination, while sp^2 carbon disappears nearly completely from nanoparticle shells. Combination of Raman scattering and infrared absorption qualitatively confirms the disappearance of sp^2 carbon, carbon-hydrogen bonds, oxygen-hydrogen and carbonyl containing functional groups. The analysis of multinuclear solid-state NMR data essentially confirms the results of vibrational

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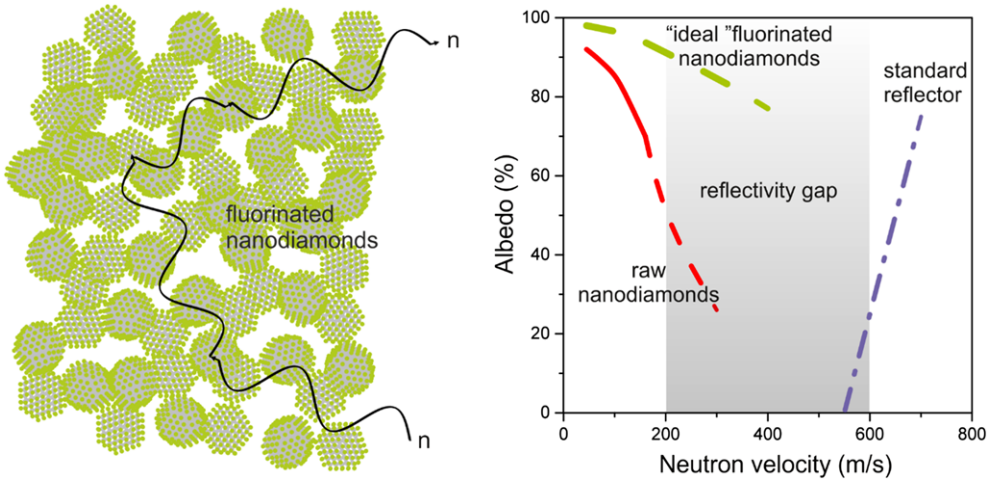

Fig. 1. The left insert illustrates the diffusion of slow neutrons in powder of fluorinated nanodiamonds. On the right, neutron albedo is shown as a function of neutron velocity for: (i) Raw nanodiamonds with the thickness of 3 cm (solid red line, data from [2]), (ii) Extrapolated albedo from the same raw-nanodiamond layer (dashed red line), (iii) Simulated albedo from "ideal" infinitely thick layer of impurity-free optimal-size diamond nanoparticles (dotted green line); fluorinated nanodiamonds are expected to provide albedo between these two lines, approaching the "ideal" line, (iv) Cut-off velocities for graphite (dashed–dotted violet line). The incident neutron flux is assumed to be isotropic. These estimations are preliminary and should be confirmed in the future by direct measurements.

spectroscopy, while being more quantitative. The ultimate mean of hydrogen content determination was prompt-γ analysis, which showed that hydrogen content in nanodiamonds is drastically reduced by the fluorination achieving a level 35–60 times lower than before fluorination. Neutron activation analysis reveals impurities, which become radioactive in high neutron fluxes, also impurities that strongly absorb neutrons. Their content can be reduced by the purification of nanodiamonds in strong acids at high temperature. However, the degree of purification still has to be improved in the future.

The most important effect of fluorination of nanodiamonds is the removal of hydrogen and sp^2 carbon, which decreases absorption of neutrons and increases their scattering respectively. Using this information, we evaluated the albedo of slow neutrons from reflectors consisting of such powder. In Fig. 1, we present the reflectivity from reflectors of different type as a function of neutron velocity, and comment on the quality of such new reflection in the caption to the figure.

In ref. [4] we proposed a new class of reflectors based on designed fluorinated nanodiamonds, which can provide a continuous reflectivity curve with high albedo thus minimizing the existing "leak" of neutrons through the so-called reflectivity gap. The high diffusive and quasi-specular reflection will allow improving dramatically the performance of neutron sources, the efficiency of neutron delivery, and thus the fluxes of slow neutrons at neutron instruments. It might also allow designing a new generation of neutron sources and experiments.

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