Cubic boron nitride: A new prospective material for ultracold neutron application

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Abstract

For the first time, the neutron wall potential of natural cubic boron nitride (cBN) was measured at the ultracold neutron source of the reactor TRIGA Mainz. We used a time-of-flight method and found a value of $V = 305 \pm 15$ neV. This is in good agreement with the result extracted from neutron reflectometry data and with theoretical expectations. Because of its high critical velocity for ultracold neutrons and its good dielectric characteristics, cubic boron nitride coatings (isotopically enriched) will be useful for a number of applications in ultracold neutron experiments.

The storage of ultra cold neutrons (UCN) in material bottles is based on the reflection of the neutron caused by the strong coherent interaction with the atomic nuclei of the surface material. Quantum mechanically, this can be described by an effective potential which is commonly referred to as Fermi pseudo or optical material wall potential $U_F = V - W$. Herein, V describes the reflectivity and depends on the atomic density N_i and on the coherent scattering length b_i of the material composition:

$$V = \frac{2\pi\hbar^2}{m_n} \cdot \sum_i N_i b_i. \tag{1}$$

The wall potential defines a critical velocity $v_c = \sqrt{2V/m_n}$ up to which neutrons are totally reflected from the surface. Therefore, V has to be as high as possible to increase statistics in UCN storage experiments. Besides this, certain experiments like the search for a permanent electric dipole moment of the neutron (nEDM) require additional properties of the material like high electrical resistivity, non-magnetic properties, and high vacuum compatibility.

Looking for new materials, we got interested in cubic boron nitride (cBN). Due to its chemical composition and its hardness, the theoretical expectation value for natural cBN is $V \approx 320$ neV. This has to be compared with the so far highest known wall potential commonly used in UCN experiments: ^{58}Ni with $V \approx 346$ neV. Nickel, however, is conductive and magnetic.

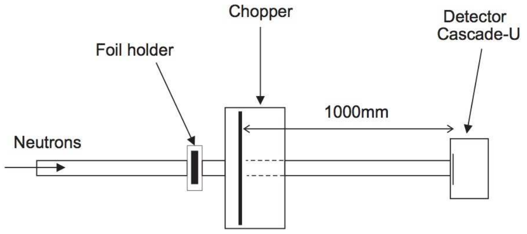

Figure 1: Draft of the experimental setup, not at scale.

Using the time-of-flight (ToF) technique in a dedicated experiment at the UCN source of the reactor TRIGA Mainz, we measured the energy-dependent transmission of UCN through a natural cBN sample of about 300 nm thickness coated on a silicon wafer and determined its critical velocity. The experimental setup is shown in Fig. 1. The cBN sample was placed in a foil holder in front of a chopper following a flight path of about 1 m towards the UCN detector. Fig. 2 shows the obtained time-of-flight spectra with and without sample. From these data, the velocity-dependent transmission properties of the cBN are derived.

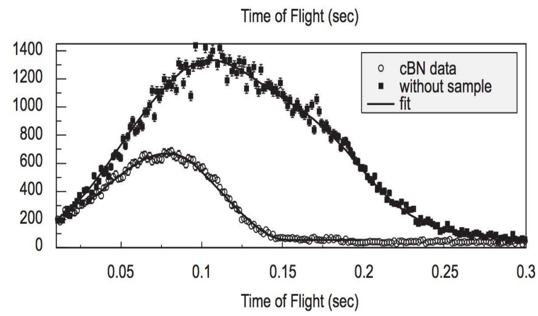

Figure 2: Obtained time-of-flight data with/out cBN sample.

Details about the analysis are described in [1]. We found a value $V = 305 \pm 15$ neV. Independently, the wall potential was also measured by cold neutron reflectometry: $V = 300 \pm 30$ neV. Both measured values agree with each other and are in good agreement with the theoretical expectation obtained from Eq. 1. In addition, the insulator properties of the cBN sample were investigated and a value for the specific resistivity $R > 3.4 \times 10^{16}\ \Omega \cdot$ cm was found.

In conclusion, cubic boron nitride is a very promising material for coatings with high wall potential and high resistivity. Tests in the near future will focus on isotopically pure ^{11}cBN ($V_{theor.} = 351$ neV). With this material, the high absorption cross section of ^{10}B can be overcome.

[1] Yu. Sobolev et al., NIM A 614, 461 (2010), *Cubic boron nitride: A new prospective material for ultracold neutron application*

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