Measurements of the Properties of a Si Detector for Ultracold Neutrons

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Coventionally, ^{3}He proportional counters are used to detect ultracold neutrons (UCN). However, next generation UCN sources promise UCN densities in the order of 10^4 cm^{-3} and thus UCN numbers of up to 10^8 [1] leading to counting rates of several 10^3 s^{-1}. In this case, the relatively slow charge collection time of ^{3}He detectors will become a serious problem. Therefore, a new type of UCN detector will be required for future experiments.

Other drawbacks of ^{3}He-detectors include the inability to operate them at very low temperatures and the need for gravitational acceleration of UCN prior to detection. A solution to these problems is to use semiconductor detectors, specifically Si PIN diodes. As neutrons cannot be detected directly with a semiconductor detector, the detector surface has to be covered with a converter material. We chose ^{6}LiF because the conversion reaction ^{6}Li(n,α)t is a two-body reaction with the reaction products being emitted in opposite directions. Thus, either the α or the triton will almost certainly hit the detector.

^{6}LiF has a rather large positive scattering length and thus reflective potential for UCN. To remedy this, a multilayer structure consisting of ^{6}LiF and a material with negative scattering length is evaporated onto the detector. Structures using Ti have been described in [2,3]; in that case, problems arose due to the formation of TiO_2 on the detector surface, leading to a total positive scattering length. For this reason, we chose ^{62}Ni instead of Ti. The structure we developed has the following composition: One layer of V (100 Å thickness) to prevent oxidization, 90 layers of ^{62}Ni and ^{6}LiF (30 Å and 45 Å thickness, respectively), 115 layers of ^{62}Ni and ^{6}LiF (30 Å and 70 Å thickness, respectively) and one layer of ^{58}Ni (850 Å thickness) as reflector.

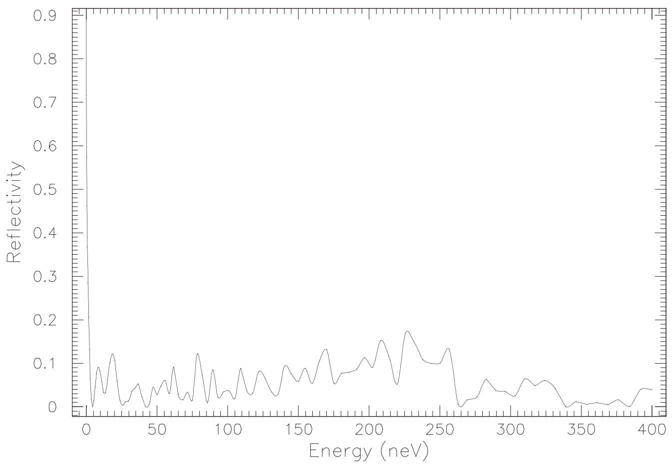

Fig. 1: Calculated reflectivity of the multilayer structure

We calculated the reflectivity for this structure with a neutron optics program; the result is shown in fig. 1.

The multilayer structure was evaporated onto the detector and examined at the tandem accelerator of the Maier-Leibnitz-Laboratory by ERD analysis; this is described in detail in [4,5]. To test the performance of the detector, two experiments were performed last year at the UCN source of the Institut Laue-Langevin (ILL) in Grenoble, France. In the first experiment, the measured storage time of UCN in a gravity spectrometer was used to determine the reflectivity of the detector surface. An UCN absorber of known size was placed inside the spectrometer for calibration purposes. The result of this measurement as well as a comparison of countrates with a ^{3}He-detector is given in fig. 2. The negative reflectivity at low energies can be explained by a decreasing efficiency of the absorber [6], resulting in a wrong calibration. Correction for this yields a positive reflectivity.

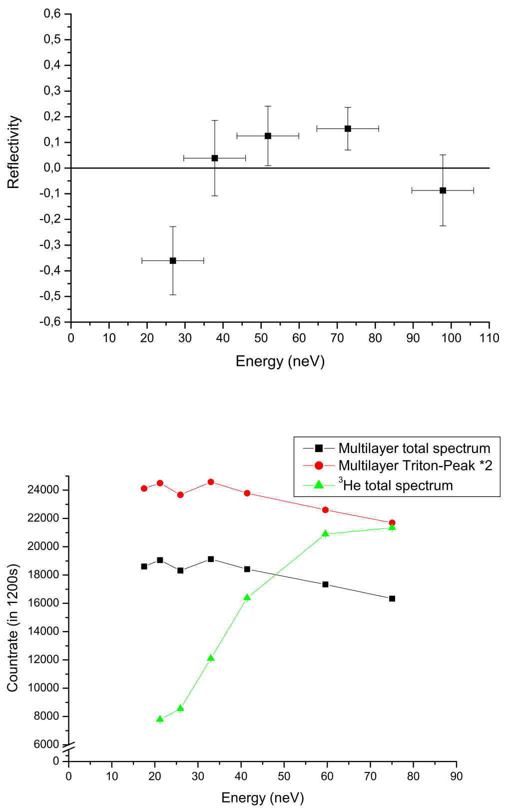

Fig. 2: Reflectivity of the multilayer structure measured by observing the storage time a gravity spectrometer (top) and comparison of the counting rates for the Si PIN diode detector and a ^{3}He gas counter (bottom).

In the second experiment, first the neutron flux through an empty sample chamber (essentially a neutron guide with to small holes, each with an area of about 1 cm^2) was determined. The multilayer detector was then put into this sample chamber and the neutron flux was remeasured. From the difference of the fluxes, the effective absorbing area and thus the reflectivity of the detector was obtained. The results of the measurement as well as a comparison between the multilayer detector and a ^{3}He-detector are given in fig. 3.

The uncertainties in energy result from the fact that the reflectivity was calculated for normal incidence of the neutrons on the detector. In the experiment however, there is a homogeneous angular distribution of the neutrons. Thus, the effective energy-distribution of the neutrons is smeared out.

These experiments have shown that the concept of a PIN diode detector coated with a multilayer structure works very well at low neutron energies. Several items will have to be further investigated, such as the difference between the calculated and the measured reflectivity, the behaviour of the detector at very low temperatures and the possible degradation of the multilayers with time. Also, we are planning on coating a Ti foil with a multilayer structure similiar to the one described in this article. Calculations of this setup also show a comparable reflectivity. This foil can be placed in front of a detector (with the multilayer side facing the detector), eliminating the need to evaporate directly onto the detector.

References

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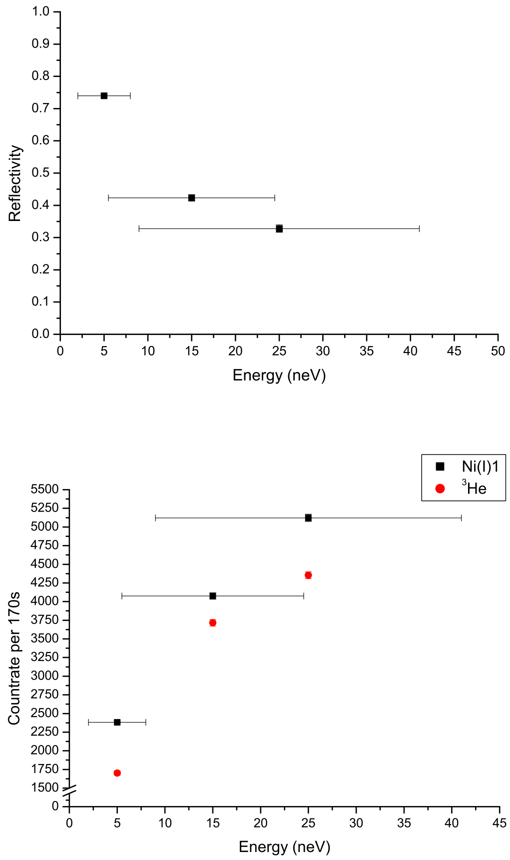

Fig. 3: Measured reflectivities of the multilayer structure (top) and comparison of the counting rates of the multilayer and a ^{3}He-detector (bottom).