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A neutron detector to monitor the intensity of transmitted neutrons for small-angle neutron scattering instruments

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Abstract

A semiconductor-based neutron detector was developed at Argonne National Laboratory (ANL) for use as a neutron beam monitor for small-angle neutron scattering instruments. The detector is constructed using a coating of ^{10}B on a gallium–arsenide semiconductor detector and is mounted directly within a cylindrical (2.2 cm dia. and 4.4 cm long) enriched $^{10}B_4C$ beam stop in the time-of-flight Small Angle Neutron Diffractometer (SAND) instrument at the Intense Pulsed Neutron Source (IPNS) facility at ANL. The neutron beam viewed by the SAND is from a pulsed spallation source moderated by a solid methane moderator that produces useful neutrons in the wavelength range of 0.5–14 Å. The SAND instrument uses all detected neutrons in the above wavelength range sorted by time-of-flight into 68 constant $\Delta T/T = 0.05$ channels. This new detector continuously monitors the transmitted neutron beam through the sample during scattering measurements and takes data concurrently with the other detectors in the instrument. The ^{10}B coating on the GaAs detector allows the detection of the cold neutron spectrum with reasonable efficiency. This paper describes the details of the detector fabrication, the beam stop monitor design, and includes a discussion of results from preliminary tests using the detector during several run cycles at the IPNS.

Keywords: Transmission; Thermal nuetron; Detector; GaAs; Solid state

1. Introduction

Small-angle neutron scattering (SANS) is a general-purpose technique used extensively for the study of materials with micro- and nanostructures whose sizes fall in the range of 1 to 100 nm. As part of the SANS data collection it is required to normalize the scattering data for the absorption of the samples as well as for the incident neutron flux. While the incident neutron flux is measured concurrently with the SANS data, using a beam monitor, the transmission coefficients are typically measured after the scattering data is collected. This dual measurement requires a significant amount of useable beam time. It would be advantageous to simultaneously measure the transmitted intensity with the scattering data to improve the data quality as well as to effectively use the valuable beam time. To accomplish this, a beam monitor was developed and installed within the cylindrical beam stop of the SAND instrument [1]

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at the IPNS. This enables the simultaneous measurement of SANS data, incident flux, and transmitted intensity.

The requirements for this application are a compact detector that can be mounted inside the small beam stop. The detector should also have adequate neutron efficiency to yield sufficient statistics during a sample run. It should have excellent gamma rejection to function in a high gamma background and it should be radiation hard since it is continuously exposed to the intense direct neutron beam. Ideally, the detector should also be relatively simple and read out with standard electronics, as well as being economical and easily replaced. A ^{10}B-coated GaAs neutron detector has been demonstrated to be an ideal choice for this application [2].

2. Detector

2.1. GaAs detector

Schottky barrier bulk GaAs diodes are fabricated from commercial bulk semi-insulating (SI) GaAs wafers. The back surfaces are lapped, polished, cleaned, and then blown dry with nitrogen. The backsides are implanted with ^{29}Si ions at a dose amounting to 5×10^{13} ions/cm^2. The implants are activated with a rapid thermal anneal in argon. Next, a stacked layer of Ge and Pd is vacuum evaporated and annealed. Vacuum evaporation of a stacked layer of Ti and Au completes the processing of the backside of the devices.

Front-side processing of the devices includes lapping and polishing of the samples to thin the wafers to a 250 μm total thickness. The wafers are then polished and cleaned. The basic pad area designs are patterned onto the surfaces with photoresist. A final etch of the patterns is performed and the surface is cleaned and dried.

A stacked layer of Ti and Au is evaporated over the wafer to form the Schottky contact. ^{10}B is then evaporated onto the Schottky contact. The individual devices are cleaved from the GaAs wafers, and then fastened with silver-based epoxy to alumina mounts. The ^{10}B coating thickness is 0.5 μm with a coverage area of 19 mm^2 and the alumina mounting has a diameter of 1.27 cm.

2.2. Beam-stop design

To minimize the background scattering, the detector is mounted inside the beam stop. The compact size of the GaAs detector allows it to be mounted directly inside the 2.2 cm diameter by 4.4 cm long cylinder used as a beam stop on the SAND instrument (Fig. 1). This beam stop is made of sintered boron carbide—B_4C (99% enriched ^{10}B). With this high ^{10}B content, the beam stop is an extremely efficient neutron absorber. B_4C is a hard and brittle material so electrical discharge machining is used to create the beam stop cavities.

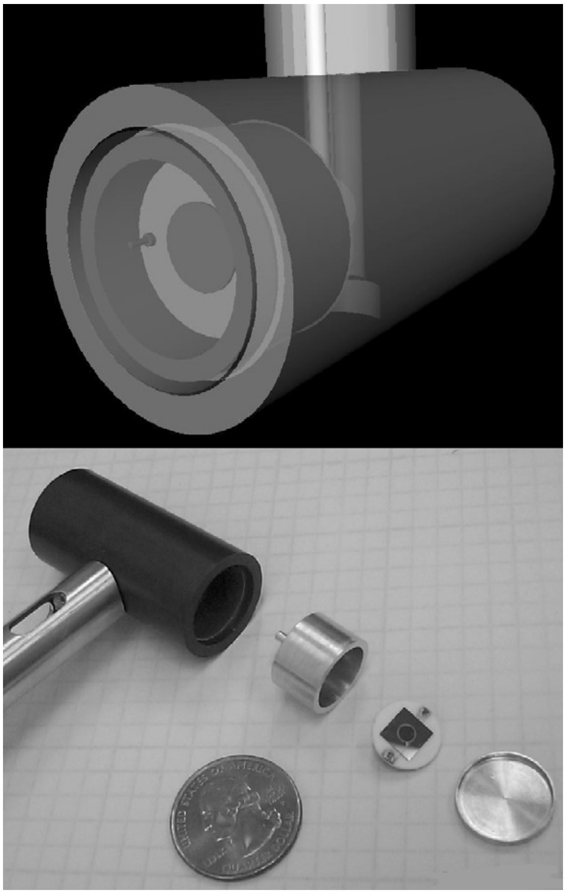

Fig. 1. Top-translucent 3-D rendering of detector assembly bottom-photograph of detector assembly.

The detector is mounted inside a cylindrical aluminum housing that is inserted into the beam stop. The housing provides the necessary shielding from electromagnetic interference. Since B_4C is conductive, the Al housing is electrically isolated with Teflon tape. Inside the Al housing is a ceramic circuit board that provides the mounting and electrical connections to the detector.

The electrical connection from the Al housing to the outside of the instrument is made through a 90 cm long RG-178 cable. The cable ground is crimped directly onto the Al housing of the detector and the center conductor is soldered onto the ceramic circuit board. The opposite end of the cable is connected to a vacuum-tight isolated feed-through that terminates outside the instrument.

The only materials not contained inside the beam stop and in the secondary neutron flight path are the RG-178 cable and a thin-walled aluminum support rod, neither of which produce any measurable scattered background.

2.3. Electronics

The GaAs detector functions similar to other solid-state detectors and requires no custom electronics. A charge-sensitive preamplifier that resides outside the instrument chamber is used to convert the charge from the detector into a low impedance voltage signal. A linear pulse-shaping module amplifies and filters this signal. A timing single channel analyzer (TSCA) is used to discriminate the pulse height of the signal. The TSCA output is used to develop the event signal needed for measuring the time-of-flight at the IPNS.

The detector capacitance is approximately 10 pFs. The cabled connection has a relatively high capacitance of 85 pFs (0.95 pF/cm). This extra capacitance adds an appreciable amount of white noise to the system. However, since the detector is used only for counting and not for spectroscopy, this is not an issue.

3. Measurements

The GaAs beam stop detector is currently used on the IPNS SAND to supplement the data collected from the existing beam transmission monitor. Comparisons of detector efficiency and transmission ratios are being evaluated as a function of neutron energy. In addition, the stability and longevity of this detector are being evaluated.

To verify the quality and validity of the data from the new beam stop detector, pulse height spectra and time-of-flight measurements were made. For all of these measurements the detector was mounted in the instrument, under vacuum, and the source of neutrons was generated from the solid methane moderator at the IPNS. The data covers a neutron wavelength range from 0.5 to 14 Å sorted into different wavelength channels by time-of-flight.

Fig. 2 shows a sample pulse height spectra from the GaAs detector with and without a Cd disk blocking the beam. For this measurement the data was collected for 15 min. The spectrum is typical of ^{10}B-coated GaAs detectors with the broad peak at channel 500 corresponding to the α from the ^{10}B(n,α) reaction and compares well with the earlier measurements. Comparison of the two spectra shows that most of the pulses above channel 300 correspond to neutrons and that the gamma rejection capability of the detector is significant. Typically, the discriminator threshold is set at the dip near channel 350.

Fig. 3 shows time-of-flight measurements of the counts from the detector with and without the Cd

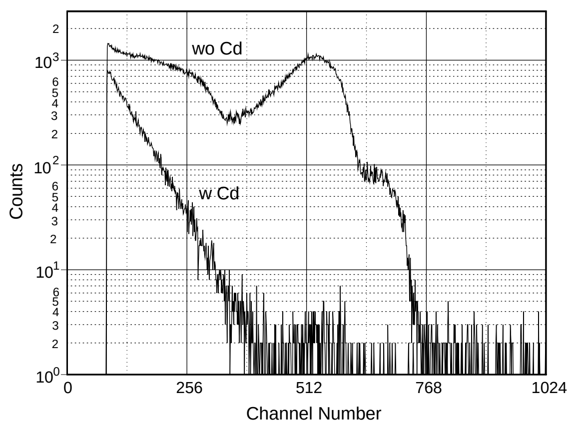

Fig. 2. Pulse height histogram of GaAs detector and with and without Cd disk.

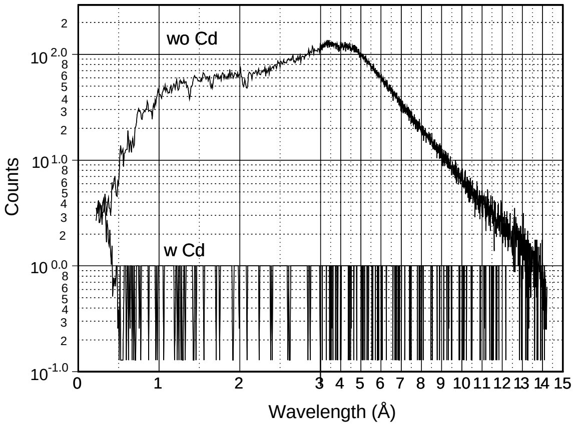

Fig. 3. Time of flight histogram of GaAs detector with and without Cd disk (linear x-axis split at 3 Å).

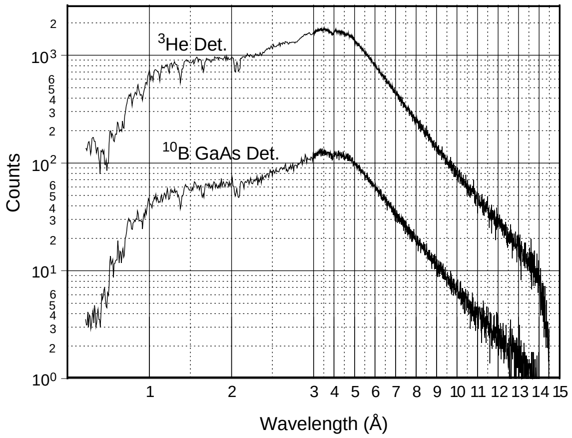

Fig. 4. Time of flight histogram of GaAs and ^{3}He detector.

disk. The insensitivity of the detector to background gamma rays is demonstrated by the rapid drop off in the number of counts at the 0.5 Å Cd neutron transmission cutoff. The dips in the spectra in Fig. 3 are due to the multiple Bragg diffraction from the aluminum in the SAND beam line.

Fig. 4 shows time-of-flight data from both the ^{3}He and GaAs beam intensity monitors. Notice that there is essentially no difference in the shape of the two spectra. For the data shown, the count rate of the ^{3}He detector is approximately 15 times that of the GaAs detector. This is due to the differences in the intrinsic efficiencies of the detectors as well as the detector geometries and discriminator settings. Future work will address ways to improve the efficiency of the GaAs detector. However, the efficiency of the present detector is sufficient to obtain the necessary statistics for the measurement of the transmitted beam intensity.

4. Conclusion

The ^{10}B-coated GaAs detector provides a suitable detector for monitoring the transmitted neutron beam intensity. The compact size of the detector allows it to fit inside the beam stop of the SAND instrument and allows for concurrent transmission measurements. This increases data accuracy and effective use of valuable neutron beam time.

The detector has operated for a period of 18 months with little change in gain and leakage current. The data collected thus far agrees well with the data from the ^{3}He monitor used for transmission measurements. The GaAs detector appears to be an attractive candidate for monitoring transmitted neutron beams at neutron scattering instruments.

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