Development of A Self Biased High Efficiency Solid-State Neutron Detector for MPACT Applications

Fuel Cycle R&D

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1 Executive summary

Neutron detection is an important aspect of Materials Protection, Accounting and Control for Transmutation (MPACT). Currently He-3 filled thermal neutron detectors are utilized in many applications; these detectors require high voltage bias for operation, which complicates the system when multiple detectors are used. In addition, due to recent increase in homeland security activity and the nuclear renaissance, there is a shortage in He-3 supply and these detectors become more expensive. Instead, cheap solid-state detectors that can be massively produced like any other computer chips were developed during this project. The new detector does not require a bias for operation, has low gamma sensitivity and fast response. The detection system is based on a honeycomb-like silicon device, which is filled with B-10 as the neutron converter; while a silicon p-n diode (i.e., solar cell type device) formed on the thin silicon wall of the honeycomb structure detects the energetic charged particles emitted from the B-10 conversion layer. The simulated detector efficiency for thermal neutrons (0.0253 eV) of optimized structure detectors was 45%. The fabricated detectors had a measured efficiency of 28% for thermal neutrons (0.0253 eV) lower than the design simulation. The reason for this discrepancy was attributed to a non-optimal structure of the fabricated detectors. Detectors size of 8 cm² was demonstrated using a single preamplifier and without degradation in the efficiency. This large size is essential for the construction of low-cost large area detection systems. A neutron coincidence detector was constructed using 8 detectors each with area of 4 cm² and associated electronics. The coincidence system was tested with a Cf-252 neutron source and compared with analytical calculations. The research project results in 2 PhD theses, one Master's Thesis, 4 journal publications, 4 conference publications that provide detailed description of the technical work. Further the research results were presented in four professional conferences (Refs.13-17).

2 Objectives and Accomplishments

The project proposal had three major objectives:

1. Demonstrate a working solid-state detector with intrinsic efficiency of ~40% that operates without bias voltage and has a low gamma sensitivity.
2. Demonstrate a large area detector by combining several smaller detectors that are fabricated and tested on a single wafer.
3. Demonstrate coincidence counting using the solid-state neutron detector.

A summary of the accomplishments related to each of the goals are described below:

2.1 Demonstrate a working solid-state detector with intrinsic efficiency of ~40% that operates without bias voltage and has a low gamma sensitivity.

This is a major goal of this project. The results are documented in several publications starting with optimization calculations [1,2]. These calculations were done in order to find the optimum geometry of such device and the highest possible efficiency. The results of this study and the good structural integrity lead to our choice of a honeycomb Si structure with holes that are about 2um across with 2um thick Si walls and 40 um depth. The holes in the Si were filled with B-10. References [1] and [2] also contain detailed information on the principle of operation of the detector.

The fabrication process was described in details in several publications that resulted from this research [4 - 8]. A PhD thesis provides detailed information on the earlier of fabrication process [10], another PhD thesis describing the current improvement to the fabrication process is still in progress.

Detectors were with surface area from 0.0625 to 16 cm² were manufactured and tested in neutron irradiation. A neutron detection efficiency of 28% as measured with thermal neutrons (0.0253 eV) was achieved. The nominal efficiency of most batches was about 24% and the efficiency was uniform (+/- 3%) in batch production. The gamma sensitivity was measured with a Co-60 source that provided a dose of 10 mR/h and was found to be about 0.001%.

2.2 Demonstrate a large area detector by combining several smaller detectors that are fabricated and tested on a single wafer.

The extremely low leakage current [6.1×10^{-9} Acm⁻² at -1V] of the continuous junction detector developed by our group is the key to large area detectors [5]. The current batch of detectors contained an array of 2.5mm x 2.5mm detectors and we connected 15 detectors in parallel to form a 1 cm² detector. We then connected in series up to 16 modules to form a 16 cm² detector. Such detector was operated using one standard ORTEC 142AH preamplifier. The ability to construct a large area detector that requires simple electronics and no bias makes this design very attractive for large area applications. The performance degradation due to the large surface area was minimal; giving ~19% efficiency with 8 cm². This can be improved when the efficiency per device is improved with a better optimized and controlled fabrication process.

2.3 Demonstrate coincidence counting using the solid-state neutron detector

A neutron coincidence counter using solid-state neutron detectors can replace He-3 tubes in a conventional moderated coincidence counter [11]. For such detector to operate effectively the overall fast neutron detection efficiency is typically about 20% [11]. We constructed a prototype coincidence counter using only 8 modules of 4 cm² detectors embedded in a cylindrical polyethylene moderator as shown in Figure 1. The detectors were connected to a Mesytec MSI-8 preamplifier-amplifier and discriminator. The signals from the 8 discriminators were connected to a logical OR gate. The logical signal from the OR gate was connect to a multi-channel scales (MCS) such that the time interval between detected neutrons was recorded. Although the overall neutron detection efficiency of such system is low and many more detectors are required for efficient operation, we were able to demonstrate that such setup will work. The distribution of time interval between pulses was compared to theoretical calculation for a random source and shows very good agreement.

Figure 1 – (a) Eight 4 cm² detectors module packaged in eight Al boxes with eight cables to connect to eight different channels of preamps with logical OR output. The inset shows the detector module inside an Al box, (b) Detectors embedded in HDPE around a ²⁵²Cf source, and (c) the solid state coincidence counter system with ²⁵²Cf source at center.

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