Design and Fabrication of a Novel Self-Powered Solid-State Neutron Detector

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ABSTRACT

There is a strong interest in intercepting special nuclear materials (SNM) at national and international borders and ports for homeland security applications. Detection of SNM such as U and Pu is often accomplished by sensing their natural or induced neutron emission. Such detector systems typically use thermal neutron detectors inside a plastic moderator. In order to achieve high detection efficiency gas filled detectors are often used; these detectors require high voltage bias for operation, which complicates the system when tens or hundreds of detectors are deployed. A better type of detector would be an inexpensive solid-state detector that can be mass-produced like any other computer chip. Research surrounding solid-state detectors has been underway since the late 1990's. A simple solid-state detector employs a planar solar-cell type p-n junction and a thin conversion material that converts incident thermal neutrons into detectable α-particles and ^{7}Li ions. Existing work has typically used ^{6}LiF or ^{10}B as this conversion layer. Although a simple planar detector can act as a highly portable, low cost detector, it is limited to relatively low detection efficiency (~10%). To increase the efficiency, 3D perforated p-i-n silicon devices were proposed. To get high efficiency, these detectors need to be biased, resulting in increased leakage current and hence detector noise.

In this research, a new type of detector structure was proposed, designed and fabricated. Among several detector structures evaluated, a honeycomb-like silicon p-n structure was selected, which is filled with natural boron as the neutron converter. A silicon p^{+}-n diode formed on the thin silicon wall of the honeycomb structure detects the energetic α-particles emitted from the boron conversion layer. The silicon detection layer is fabricated to be fully depleted with an integral step during the boron filling process. This novel feature results in a simplified fabrication process. Three key advantages of the novel devices are theoretical neutron detection efficiency of ~48%, a self-passivating structure that reduces leakage current and detector operation with no bias resulting in extremely low device noise.

Processes required to fabricate the 3D type detector were explored and developed in this thesis. The detector capacitance and processing steps have been simulated with MEDICI and TSuprem-4, respectively. Lithography masks were then designed using Cadence. The fabrication process development was conducted in line with standard

CMOS grade integrated circuit processing to allow for simple integration with existing fabrication facilities. A number of new processes were developed including the low pressure chemical vapor deposition of conformal boron films using diborane on *very high aspect-ratio trenches and holes*. Development also included methods for “wet” chemical etching and “dry” reactive ion etching of the deposited boron films.

Fabricated detectors were characterized with the transmission line method, 4-point probe, I-V measurements and C-V measurements. Finally the detector response to thermal neutrons was studied. Characterization has shown significant reduction in reverse leakage current density to ~$8x10^{-8}$ A/cm^2 (nearly 4 orders of magnitude over the previously published data). Results show that the fabrication process developed is capable of producing efficient (~22.5%) solid-state thermal neutron detectors.