MSND® Technology Introduction

Microstructured Semiconductor Neutron Detectors (MSND®)

Planar diodes coated with neutron reactive materials have been investigated as alternative neutron detectors for over 50 years. The reactions most investigated are the $^{10}B(n,\alpha)^{7}Li$ and the $^{6}Li(n,t)^{4}He$ reactions. Although the thermal neutron cross of ^{10}B (3840 b) is higher than that of ^{6}Li (940 b), the reaction product energies for ^{10}B (α 1.47-MeV, ^{7}Li 840-keV) are much less than that for ^{6}Li (t 2.73-MeV, ^{4}He 2.05-MeV). Widespread acceptance of coated planar detectors has been slow due to physical constraints that limit intrinsic thermal neutron detection efficiency (ε_{th}) to less than 5% [1]. The limitation is mainly due to reaction product self-absorption, where reaction products can not reach the detector interface beyond a certain optimized film thickness. In the cases of ^{10}B and ^{6}LiF coatings, that optimized thickness limits the ε_{th} to <5%.

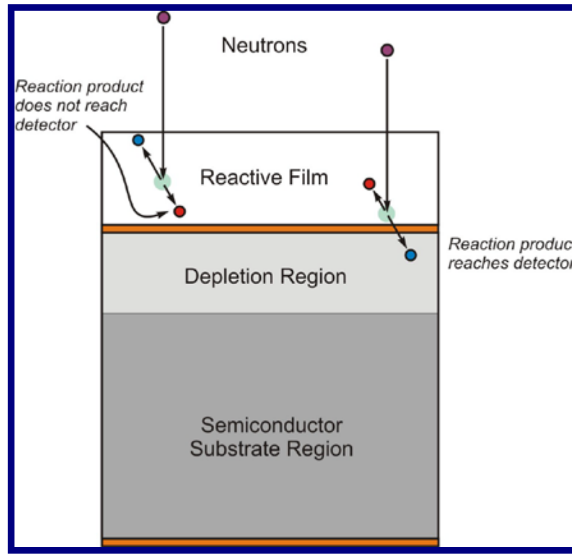

Fig. 1. For a coated planar detector, reaction product self-absorption limits film thickness, and consequently the detection efficiency.

Microstructured semiconductor neutron detectors (MSND®), first investigated in the Kansas State University SMART Laboratory, were developed to overcome the disadvantages of planar coated diode detectors while retaining many of the advantages, such as compactness, low-power requirements and low-cost. The devices are constructed by etching features into a semiconductor substrate, diffusing a *pn* junction within the structures, and subsequently backfilling the structures with neutron reactive material [2]. As a result, the amount of neutron reactive material adjacent to the semiconductor material can be increased while increasing the probability of detecting the reaction products. The device structure can achieve ε_{th}>35% for single sided devices and up to 70% ε_{th} for dual stacked devices [3].

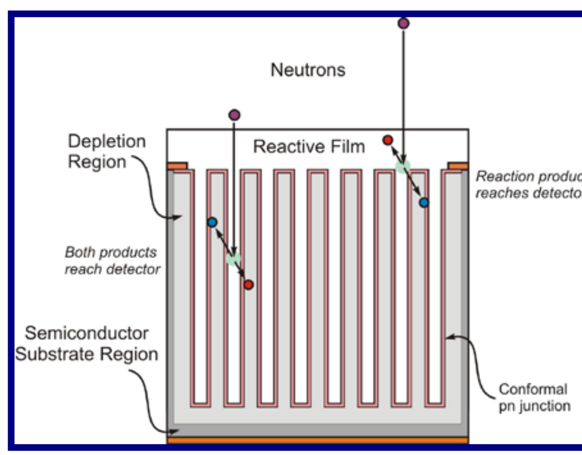

Fig. 2. The deep microstructures backfilled with neutron reactive material increase *both* neutron absorption efficiency and the reaction production detection efficiency for MSND®s.

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‡*US Patents 6,545,281 and 7,164,138*

MSND® Technology Introduction

Microstructured Semiconductor Neutron Detectors (MSND®)

MSND®s have high neutron detection efficiency, excellent neutron to gamma ray selectivity, operate on low power (1-3 volts) and are inexpensive to manufacture compared to ^{3}He detectors. The devices are fabricated in Si using typical VLSI methods. Cavities are etched deep into the Si substrate (Fig. 3), and subsequently backfilled with neutron reactive material ^{6}LiF.

Neutrons absorbed in the neutron reactive material undergo a reaction that releases energetic charged particles. These particles intersect the Si fins (Fig. 2), thereby, being detected in the Si diode structure. The high ratio of neutron reactive material to Si allows for excellent neutron absorption and detection efficiency as well as excellent n/γ discrimination ratios (>10^{7}) for normally incident photons less than 1.3 MeV.

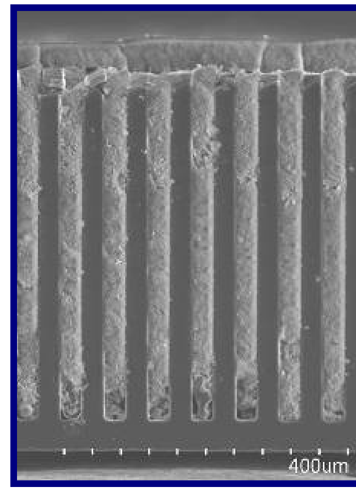

Fig. 3. MSND®side profile showing 490 micron deep microstructures backfilled with compacted ^{6}LiF.

RDT has manufactured and tested MSND®s backfilled with ^{10}B or ^{6}LiF, and it has been learned that the best performance is achieved with ^{6}LiF as the backfill material. The reasons for the better performance with LiF-backfilled devices are multiple, including: (1) ^{6}LiF reaction products have longer ranges (*t* 32-μm, ^{4}He 7-μm) than ^{10}B reaction products (α 4.2-μm, ^{7}Li 2.1-μm). As a result, feature dimensions can be approximately 10 times larger for LiF devices than ^{10}B devices while retaining high efficiency. (2) The energies for ^{6}LiF reaction products are much higher than that of ^{10}B, thereby, allowing for easier discrimination of background radiations. (3) The spectral features for ^{6}LiF reaction products have a natural low energy valley, thereby, allowing for easy allocation of the lower level discriminator. The salient "wall effect" with ^{10}B does not allow for this important advantage. (4) The *pn* junction depths can be diffused deeper. Because the reaction products from ^{10}B have such short ranges, dopant diffusion depths (dead region) must be kept small, typically less than 500 nm. Devices backfilled with ^{6}LiF can have diffused junctions up to 2 microns deep without adversely affecting the ε_{th}. (5) Although the features must be etched much deeper for ^{6}LiF backfilled materials than for ^{10}B, the consequent reduction of semiconductor volume further improves the n/γ discrimination ratio.

‡ *US Patents 6,545,281 and 7,164,138*

[1] McGregor et alii, Nucl. Instr. Meth. ***A500*** *(2003) 272.*
[2] Bellinger et alii, Proc. MRS, ***1164*** *(2009) L06-01.*
[3] Shultis et alii, Nucl. Instr. Meth., ***A606*** *(2009) 608.*

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