

Non-Destructive Spent Fuel Characterization with Semiconducting GaAs Neutron Imaging Arrays

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The project involves the use of integrated GaAs chips for thermal and epithermal neutron imaging. The detectors use a neutron reactive film coating that enables the GaAs detection chips to sense the interaction location. These GaAs detectors will be used to image fuel burn up on spent fuel elements. The project is funded by the DOE through the NEER program.

Several years ago, it was discovered at the University of Michigan that Schottky barrier detector diodes fabricated from semi-insulating bulk GaAs have very odd characteristics. Under reverse bias, the devices have a distinctive two-zone electric field distribution, in which a *constant* high field region is present at the reverse biased contact, and a very low field region extends across the remainder of the device. The high field region electric field is approximately 10^4 V/cm, whereas the low field region is generally less than a volt per cm. Additionally, the high field region expands linearly at the rate of approximately 1 volt per micron. Hundreds of volts are required to fully activate a device that is 1 mm thick, an excessive amount for a gamma ray detector so thin. Consequently, bulk GaAs detectors are generally very inefficient for gamma rays exceeding energies over 100 keV.

The devices were instead found to be excellent for neutron detection. When coated with ^{10}B , the GaAs devices were capable of easily detecting the charged particle reaction products from the $^{10}\text{B}(n,\alpha)^7\text{Li}$ reaction, in which 1.47 MeV alpha particles and ^7Li ions are ejected in opposite directions. The range of an 1.47 MeV alpha particle is only 4.2 microns in GaAs, hence the operating voltage of the device is 10 volts or less. Additionally, the thin active region of only a few microns is an ineffective gamma ray absorber. The device naturally discriminates background gamma ray interference from the high-energy charged particle pulses. Additionally, GaAs is a material that circuitry can be easily integrated upon, and Schottky barrier technology is radiation hard.



Figure 1: Jeff Sanders, a Nuclear Engineering graduate student, puts the finishing touches on the electronic circuitry for a radiation-hardened bulk GaAs neutron-imaging array (lower right). The GaAs neutron imaging chip and electronics was later placed in a radiation hot cave to measure the neutron sensitivity from epithermal neutron sources.

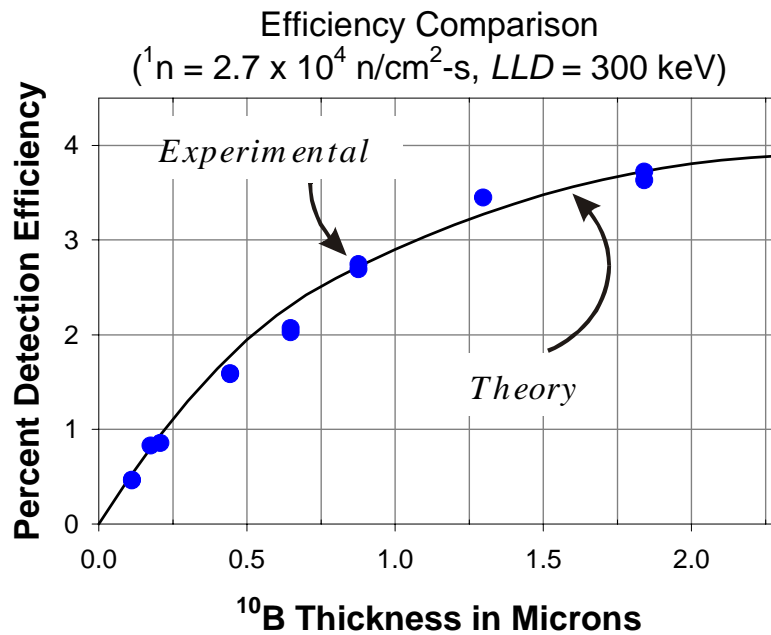


Figure 2: Experimentally measured thermal neutron detection efficiency for ^{10}B -coated bulk GaAs detectors as a function of the boron thickness. Also shown is a comparison to the theoretical (calculated) efficiency. Stacking the devices can increase the detection efficiency.

The present work involves the use of radiation-hardened, ^{10}B -coated, bulk GaAs-based, Schottky barrier, pixellated imaging arrays for spent nuclear fuel measurements. Spent nuclear fuel is very radioactive and the device used in the investigation should be radiation hard and insensitive to the high gamma ray background. Tests have shown that neutron induced events can be easily discriminated from background gamma rays, and the device can be operated in a mixed gamma ray and neutron field.

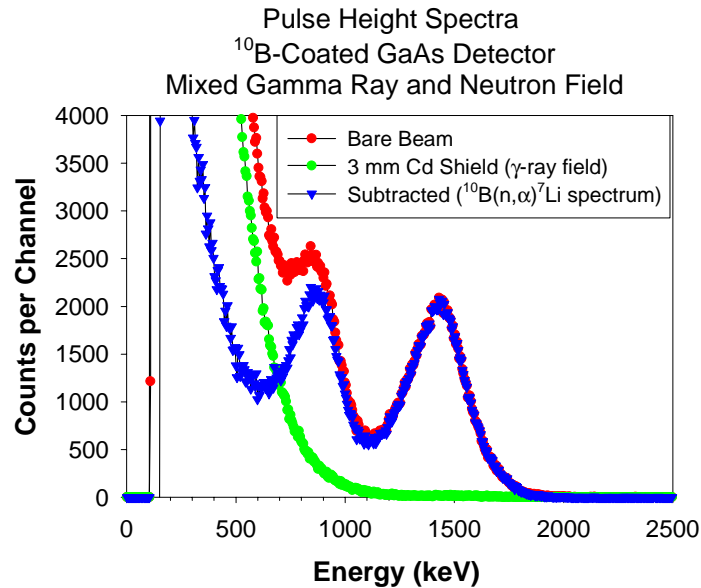


Figure 3: In a mixed beam of gamma rays and neutrons, the neutron-induced events are easy to discriminated from background gamma rays. The measurement was taken at the from a neutron beam port that directly faces the reactor core. The detector was exposed to both gamma rays (1.1 R/hr) and thermalized neutrons (10^6 n/cm²-s) from the reactor core.

The overall measurement configuration involves the use of a Sb/Be 24 keV neutron source. The Sb/Be source is a photo-neutron emitter. The Sb and Be materials can be separated for transport, in which only the gamma rays from the activated Sb need be shielded. The use of 24 keV neutrons is also unique, in that a Fe filter can be used to reduce neutron scattering noise. Natural iron has a large ^{56}Fe component, and ^{56}Fe has a large dip in the neutron interaction cross-section exactly at 24 keV. Hence, ^{56}Fe appears as a vacuum to 24 keV neutrons. Coupled together, the ^{56}Fe -Sb/Be configuration is a good portable mono-energetic neutron source.

The cross section is much lower in uranium for 24 keV neutrons than thermal neutrons. The Sb/Be source will be used to transmit 24 keV neutrons

directly through the nuclear fuel, which will be imaged by a ^{10}B -coated GaAs imaging array. Probing measurements of spent nuclear fuel may allow for tomographic mapping of burnup in nuclear fuel bundles. Pixellated arrays of ^{10}B -coated GaAs detectors have been fabricated and tested for such measurements. The electronics and configurations are designed to withstand the harsh radiation environment expected near spent fuel.

Refereed Publications:

1. D. S. McGregor, R. T. Klann, J. D. Sanders, J.T. Lindsay, K.J. Linden, H.K. Gersch, P.M. De Lurgio, C.L. Fink, and Elsa Ariesanti, "Recent Results From Thin-Film-Coated Semiconductor Neutron Detectors," Proc. of SPIE, (2002) in press.
2. D.S. McGregor, M.D. Hammig, H.K. Gersch, Yong Hong Yang, and R.T. Klann, "Design Considerations for Thin Film Coated Semiconductor Thermal Neutron Detectors, Part I: Basics Regarding Alpha Particle Emitting Neutron Reactive Films," Nuclear Instruments and Methods (2002) in press.
3. D.S. McGregor, H.K. Gersch, J.D. Sanders, R.T. Klann, and J.T. Lindsay, "Thin-Film-Coated Detectors for Neutron Detection," Journal of the Korean Association for Radiation Protection, 26 (2001) pp. 167-175.
4. D.S. McGregor, R.T. Klann, H.K. Gersch, and Y-H. Yang, "Thin-Film-Coated Bulk GaAs Detectors for Thermal and Fast Neutron Measurements," Nuclear Instruments and Methods, A466 (2001) pp. 126-141.

Conference Presentations:

1. J.D. Sanders, J.T. Lindsay, and D.S. McGregor, "Development of a GaAs-Based Neutron Tomography System for the Assay of Nuclear Fuel," Conference Record of the IEEE Nuclear Science Symposium, San Diego, California, Nov. 4-9, 2001.
2. D.S. McGregor, R.T. Klann, H.K. Gersch, and Y-H. Yang, "Thin-Film-Coated Bulk GaAs Detectors for Thermal and Fast Neutron Measurements," 2nd International Workshop on Radiation Imaging Detectors, 2000, July 2-6, Freiburg, Germany.
3. D.S. McGregor, J.T. Lindsay, Y-H. Yang, and J.C. Lee, "Bulk GaAs Based Neutron Detectors for Spent Fuel Analysis", Conference Record of ICONE-8, No. 8827, 8th International Conference on Nuclear Engineering, April 2-6, 2000, Baltimore, MD USA.

