Study of Transport Behavior and Conversion Efficiency in Pillar Structured Neutron Devices

Rebecca J. Nikolić
(925) 423-7389
nikolic1@llnl.gov

A radiation detection device that can be easily fielded and offers high detection efficiency is vital to national security efforts. In this project, we will demonstrate technology that could lead to a device with over 70% thermal neutron detection efficiency. By applying microtechnology methods to neutron detection, we expect to make revolutionary improvements in device efficiency and field usability. We will take advantage of recent advancements in material science, charged carrier transport, and neutron-to-alpha conversion dynamics to fabricate semiconductor pillars in a 3-D matrix in which the neutron-to-alpha conversion material has adequate density to capture the full neutron flux.

Project Goals

With this project, we intend to develop and demonstrate a proof-of-principle device, and we will devise a roadmap for scaling the device to optimal efficiency. This is significant because current technology suffers from poor efficiency and adaptability to field use, high voltage, sensitivity to microphonics, a large device footprint, and high pressure, resulting in significant complications in air transport and deployments. The advances we propose in micro- and nanofabrication methods are applicable to many other fields, including biochemical detection, communications, and computations.

Relevance to LLNL Mission

Our project supports the Laboratory's national security mission by advancing technology for detection of special nuclear materials and radiological dispersal devices. If our demonstration device meets the requirements for high efficiency and demonstrates suitability for field use, it will pave the way to manufacturing field-ready devices in partnership with an industrial collaborator.

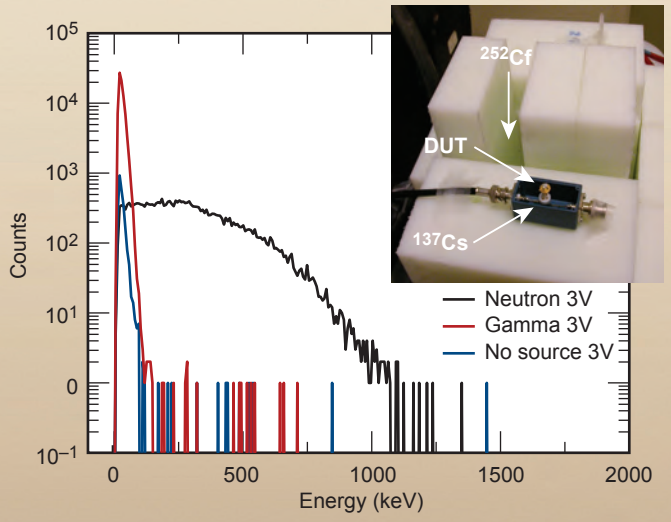

Figure 1. Neutron efficiency for LLNL's 3-D Pillar Structured Thermal Neutron Detector, currently at 20% thermal neutron detector efficiency, at 3 V, and 10^5 neutron to gamma discrimination. The inset shows the test configuration for the device under test (DUT). Both Cf and Cs are present for testing of both neutrons and gammas.

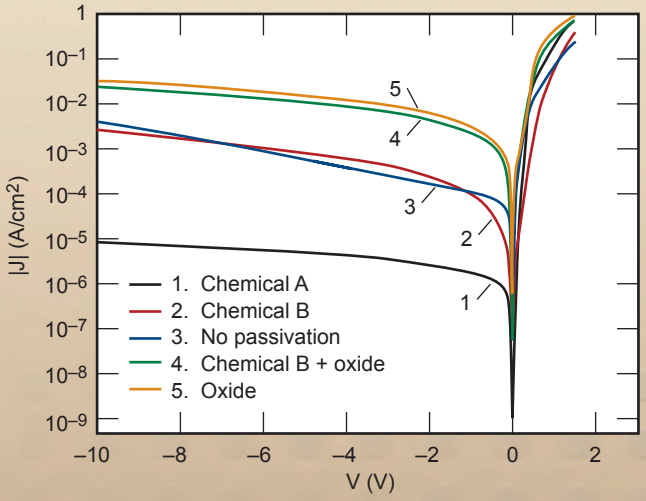

Figure 2. Current-voltage characteristics of Si pillar diodes with various passivation methods. An ideal diode would show very low current for negative voltages. Treatment with Chemical A produces diodes that come the closest to ideal in this case.

FY2009 Accomplishments and Results

Our primary milestones for FY2009 that came to full completion included:

1. Fabrication and characterization of 26-µm tall pillar detector with a 20% thermal neutron detection efficiency, 3-V reverse bias and a neutron to gamma discrimination of 10^5 (Fig. 1).
2. Reduction in pillar sidewall leakage current by understanding the relationship between chemical sidewall treatments and the electron-hole pair recombination lifetime. Decreased recombination rates (longer minority-carrier lifetimes) lead to less leakage current and to improved device performance (See table and Figs. 2 and 3).
3. We continued to publish material in both conference and journal papers.

In summary, we have designed a high efficiency thermal neutron detector by understanding the transport dynamics of neutrons, their interaction by-products and ultimately electron-hole pairs. By optimizing our 3-D detector structure we have defined a pathway to achieve a thermal neutron detection efficiency greater than 50% (Fig. 4).

Related References

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2. Conway, A. M., L. F. Voss, C. E. Reinhardt, R. T. Graff, T. F. Wang, R. J. Nikolic, N. Deo, and C. L. Cheung, "Si Based Pillar Structured Thermal Neutron Detectors," *IEEE Nuclear Science Symposium*, October 2009.
3. Conway, A. M., T. F. Wang, N. Deo, and C. L. Cheung, "Numerical Simulations of Pillar Structured Solid State Thermal Neutron Detector Efficiency and Gamma Discrimination," *IEEE Transactions on Nuclear Science (TNS)*, October 2009.
4. Voss, L. F., C. E. Reinhardt, R. T. Graff, A. M. Conway, R. J. Nikolic, N. Deo, C. L. Cheung, "Comparison of CF_4 and SF_6 Plasmas for ECR Etching of Isotopically Enriched ^{10}boron Films," *Nuclear Instruments and Methods in Physics Research A*, **606**, pp. 821–823, 2009.
5. Nikolic, R. J., A. M. Conway, C. E. Reinhardt, R. T. Graff and T. F. Wang, N. Deo and C. L. Cheung, "Pillar Structured Thermal Neutron Detectors," *International Conference on Solid State and Integrated Circuit Technology (ICSICT)*, Beijing, China, October 20–23, 2008.

Passivation methods applied to Si pillars.

Passivation method	Preparation
Chemical A	1. RCA II, 80 °C, 10 min 2. HF (1%) 120 s 3. H_2SO_4:H_2O_2, 1:1, 120 °C, 10 min 4. HF (1%) 180 s
Chemical B	HNO_3:H_2:NH_4F, 126 ml: 60 ml: 5 ml, 1 min
Thermal oxidation	Dry O_2, 1150 °C, 40 min

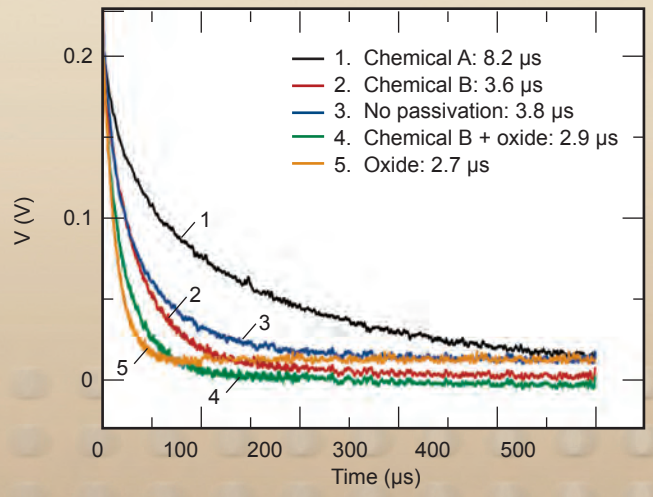

Figure 3. Open-circuit voltage decay waveforms of Si pillar diodes with various passivation methods. The extracted minority carrier lifetimes are listed. Longer lifetimes mean better performance of the diode.

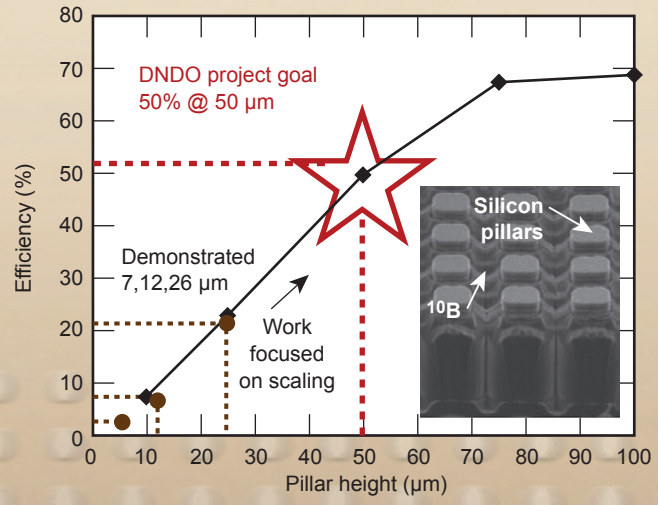

Figure 4. Roadmap of detector efficiency.