Multi-Layered Avalanche Diamond Detector for Fast Neutron Applications

Project #: NLV-003-20 | Year 3 of 3

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Executive Summary

The primary goal of this project was to design and fabricate a novel multi-layered avalanche diamond (MAD) detector leveraging the intrinsic avalanche and atomic properties of single-crystal chemical vapor deposition (scCVD) diamond to yield a novel fast neutron detector with inherent gain, improved detection efficiency compared to a single layer, and a small footprint. A series of calculations, simulations, and single-layer thin scCVD diamond detector measurements were performed to inform the MAD detector design. The data gleaned from these efforts ultimately led to the design and fabrication of two MAD detectors: one based on the transport of electrons through vertically stacked diamond layers and the other based on the horizontal transport of electrons through the bulk of a single diamond layer.

Description

A significant amount of the third and final year of funding by the NNSS SDRD program for the MAD detector project was spent iterating on the MAD detector design as Applied Diamond, Inc., our collaborator and subcontractor, performing the fabrication of the diamond, was confronted with anticipated challenges. Overcoming these challenges was a huge success in and of itself. The project culminated in the receipt of the very first horizontal and vertical MAD detector prototypes.

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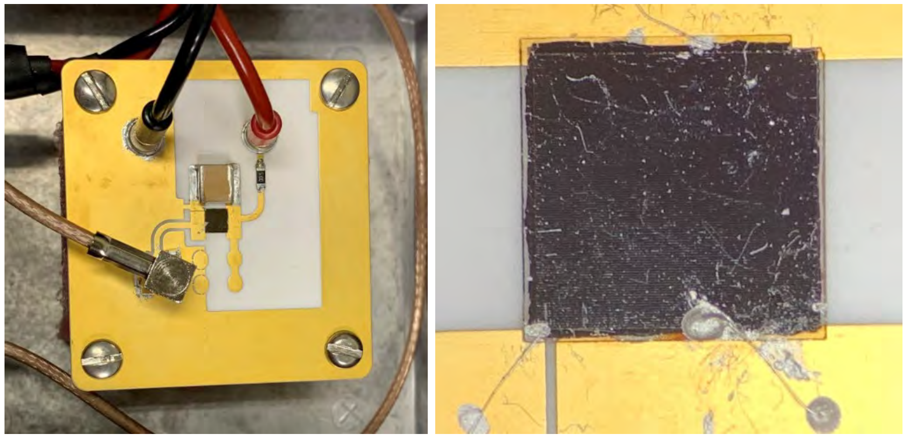

First prototype of the horizontal MAD detector. View of diamond on PCB (*left*) and view zoomed in on diamond (*right*). One significant challenge with the horizontal design was the application of the passivation and resistor material on the diamond wafer. A thick-film resistor was initially chosen for the design, but could not be applied precisely. A thin-film germanium could be applied precisely and meet the target resistivity and so, it was used in this prototype (*dark grey over the diamond*). The passivation successfully adhered to the diamond and the tungsten electrodes and germanium adhered to the passivation and tungsten. The choice of metal was not unanticipated but, necessary for material compatibility.

Conclusion

The prototype MAD detectors were received within the last two weeks of the fiscal year leaving no time to perform characterization measurements to confirm charge multiplication in the devices or to ascertain their gain. Fortunately, the MAD detector work will continue on in FY23 under the funding of the NNSS Detectors and Instrumentation project. The team will be characterizing these prototypes in the first few weeks of FY23 and aims to improve upon the MAD detector design conceived under the SDRD program over the past three years.

Mission Impact/Benefit

The Neutron Diagnosed Subcritical Experiment (NDSE) program at the NNSS requires an in-beam diagnostic to accurately measure a pulse of neutrons from a dense plasma focus (DPF). The MAD detector can be deployed as an in-beam detector and provide improved performance that would drive down the uncertainties of the DPF source term measurement and ultimately the uncertainties in the calculation of Δk_{eff} of the object being interrogated by the DPF neutrons. This is of critical importance to NDSE. The MAD detector will be fielded as part of an NDSE static campaign in FY23.

Publications, Technology Abstracts, Presentations/Posters

Green, J. A., A. Guckes, R. Buckles, D. Constantino, J. Friedman, J. Tabeling, A. Wolverton. 2020. "Geant4 and MCNP6.2 modeling of fast-neutron detectors based on single-crystal chemical vapor deposition diamond." In *Proc. SPIE 11494, Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XXII*, 1149417. Poster presented at SPIE Optical Engineering + Applications Conference, online. https://doi.org/10.1117/12.2567750.

Guckes, A., R. Buckles, A. Wolverton, I. Garza, J. A. Green, J. Tabeling. 2021. “Direct current response of a thin scCVD diamond detector under increased applied field to 14.1 MeV neutrons.” In *Proc. SPIE 11838, Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XXIII*, 1183814. Presentation presented at SPIE Optical Engineering + Applications Conference, San Diego, CA. https://doi.org/10.1117/12.2593455

Guckes, A., R. Buckles, J. A. Green, A. Wolverton. 2020. “Multi-layered avalanche diamond detector for fast neutron applications.” Mission Support & Test Services Technology Abstract (10 June 2020).