Project 90256

Multipurpose Radiation Resistant Semiconductor Detectors for Alpha, Neutron & Low Energy Gamma Ray Measurements at High Temperatures in High-Intensity Gamma Ray

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RESULTS TO DATE: PROGRESS REPORT

1.0 Summary

Work scheduled under year one of DOE Grant DE-FG02-04ER63734 is on schedule and all year-one milestones have or will be met. A new class of multipurpose, radiation-resistant semiconductor detectors that can be used in elevated-temperature and high-radiation environments is being developed under this grant. These detectors, based on silicon carbide (SiC) semiconductor are designed to have larger active volumes than previously available SiC detectors, and are being tested for their response to alpha particles, X-rays and low energy gamma rays, and fast neutrons. Specifically, SiC radiation detectors with larger areas and 100-micrometer thick active regions have been designed and manufactured according to the design specifications. Detectors based on a Schottky diode design were specified in order to minimize the effects of the detector entrance window on alpha particle measurements. During manufacture of the Schottky diodes, the manufacturer provided an advance set of SiC p-i-n diodes for testing. Initial fast-neutron response measurements were carried out with these detectors. Extensive alpha particle measurements are being carried out to test and quantify the response of the SiC Schottky diodes. Exposures to 148Gd, 213Bi, 213Po, 217At, 221Fr, 225Ac, 237Np, 238Pu, 239Pu, and 242Pu sources were used to obtain detailed alpha response data in the alpha energy range from 3.183 MeV to 8.376 MeV. The 148Gd, 213Po, 217At, and 221Fr sources provide energy-separated, mono-energetic alpha particle peaks which can be analyzed to provide detailed information on the energy response characteristics of the detectors. The full width at half maximum (FWHM) is being measured for each of six mono-energetic peaks in the 3.183 MeV to 8.376 MeV range, and details of the energy deposition process that contribute to the FWHM are being modeled with calculations using the SRIM-2003.26 code developed by Zeigler and Beirsack. Electronic broadening of the FWHM is also being evaluated in order to isolate the component of the FWHM that is inherent to SiC semiconductor. Initial evaluations indicate that this FWHM component may be less than 20 keV, which is comparable to the best available silicon alpha particle detectors, which have typical FWHMs of 20 keV. Irradiations are under way in the Westinghouse Gamma Hot Cell to assess the performance of SiC radiation detectors after intense gamma irradiation. To date, only negligible changes in detector response have been observed following cumulative 137Cs gamma-ray doses of 6.0E(06) Rad and 2.4E(07) Rad. Conventional silicon detectors suffer severe response deterioration at about 1E(06) Rad. Therefore, SiC detectors have already been shown to be far more resistant to gamma radiation effects than silicon detectors. These measurements will be continued over the three-year duration of the program resulting in cumulative gamma ray exposures up to 4E(09) Rad. Initial neutron exposures using p-i-n diodes with 4-mm x 4-mm x 70-micrometer active volumes have led to excellent fast neutron response results. Exposures to 14-MeV neutrons from an electronic D-T source show prominent and well-resolved reaction peaks from 12C(n,alpha)9Be and 28Si(n,alpha)25Mg reactions in the SiC detector. Ten peaks are observed for the latter reaction corresponding to branches to the ground state and excited states of 25Mg. The energy of these peaks can be used to accurately determine the energy of fusion neutrons from a D-T plasma, and the widths of the peaks can be used to determine the ion plasma temperature. Additional exposures of these p-i-n detectors to 252Cf and 241Am-Be isotopic neutron sources have also been carried out in preparation for the neutron spectrometry tasks scheduled for year two of the program.

2.0 Status of Schedule & Milestones

The status of the tasks and milestones that were scheduled for year one are summarized in the following sections.

Task 1. Design of SiC Radiation Detectors. Following a meeting with the manufacturer, Cree, Inc., the design of the SiC multi-purpose radiation detectors was finalized in late December, 2003. The first milestone, which was to specify the design parameters and issue the purchase order for the manufacture of the detectors, was completed on schedule in late December using internal funding prior to issue of DOE Grant Number DE-FG02-04ER63734 by DOE Chicago Operations in early February. Task 1 has been completed.

Task 2. Fabrication of the Multipurpose SiC Detectors. Fabrication of large-volume SiC Schottky diodes was begun by the vendor, Cree, Inc., in late December 2003 and completed in mid-June 2004. Because manufacturing delays were encountered by Cree, four additional large-volume SiC p-i-n diodes were shipped free of charge for testing. Following receipt of the Schottky diodes, testing was accelerated by Westinghouse to recover the time lost in the manufacture of the diodes. Task 2 has been completed.

Task 3. SiC Detector Testing. Subtask 3.1 Gamma-ray radiation effects testing. Following initial response testing with alpha particle sources, selected SiC Schottky diodes are being subjected to long-term gamma-ray exposures in the Westinghouse Gamma Hot Cell. These diodes will be subjected to periodic response testing as gamma-ray doses up to 4E(09) Rad are being accumulated in order to assess any effects of gamma ray exposure on detector performance.

Subtask 3.2 Charged-Particle Response Testing. 3.2.1 Alpha Response Testing. Testing of the SiC Schottky diodes with 148Gd, 213Bi, 213Po, 217At, 221Fr, 225Ac, 237Np 238Pu, 239Pu, and 242Pu alpha particles is in progress. Excellent energy resolution results have been obtained in the testing. Measured peak shapes for the mono-energetic peaks from 148Gd, 213Po, 217At, and 221Fr are being analyzed to determine the components of the peak full width at half maximum (FWHM) that are due to the detector entrance window, electronic noise, charge carrier statistics, and processes inherent to SiC semiconductor. The milestone, “Complete SiC Detector Alpha-Response Testing”, scheduled for November 2004 is expected to be completed ahead of schedule.

3.2.2 Alpha Response Modeling. Detailed range-energy calculations are being carried out to assess the effects of the SiC contact layers and counting geometry on the energy deposition process in the SiC detectors. Range straggling is a major contributor to the broadening of the observed alpha particle peaks in SiC, because gold, platinum, and titanium metallic layers are required to ensure good bonding of electrical leads to the SiC Schottky contact. These calculations coupled with measurements of the noise broadening of the peaks will enable the peak resolution component inherent to the properties of SiC to be isolated and evaluated.

Subtask 3.3 X-Ray and Low-Energy Gamma-Ray Response Testing. Initial X-ray response tests have been carried out using 241Am and 237Np sources. Evaluation of these tests is in progress.

Subtask 3.4 X-Ray and Low-Energy Gamma-Ray Response Modeling. This task is scheduled to begin in October.

Subtask 3.5 High-Energy Neutron Response Testing. 3.1.1 D-T (14 MeV) Tests. This task was started early due to the availability of the high-volume SiC p-i-n diodes that were supplied by Cree, Inc. as a result of delays in the manufacture of the SiC Schottky diodes. A dramatic improvement was observed over results reported previously with smaller-volume Schottky diodes. In addition to the 12C(n,alpha)9Be peak observed previously, multiple peaks corresponding to the 28Si(n,alpha)25Mg ground state and excited state branches were observed. Peak broadening resulting from pulse-height defect effects was observed and is being modeled using SRIM calculations. These modeling results will be useful for development of the recoil-spectrum de-convolution methodology under task Task 3.6, which is scheduled to begin during the second year of the program. Initial 252Cf and 241Am-Be neutron response spectra were taken with the SiC p-i-n diodes in anticipation of Tasks 3.5.3 and 3.5.4, also scheduled to begin next year.

All tasks and subtasks under Task 3 are on or ahead of schedule.

In summary, the first scheduled milestone for year one was completed on schedule and the second milestone is expected to be completed on schedule. All scheduled tasks for year one are on schedule and several tasks are ahead of schedule.

3.0 Highlights of Progress During Year-One

A new class of large-volume SiC detectors has been designed and manufactured for testing. - The alpha-particle energy resolution for these SiC detectors has been shown to be comparable to the best obtainable with conventional silicon detectors. - Only negligible SiC detector response changes have been observed after a cumulative gamma-ray exposure of 2.4E(07) Rad. Silicon detectors show significant performance degradation at 1E(06) Rad. - Initial fast-neutron response spectra show detailed information from neutron-induced reactions in both silicon and carbon.

DELIVERABLES: The following paper will be presented at the 2004 IEEE Nuclear Science Symposium and Medical Imaging Conference in October, 2004: "The Fast Neutron Response of Silicon Carbide Semiconductor Radiation Detectors" , F. H. Ruddy, A. R. Dulloo, J. G. Seidel, M. K. Das, S-H Ryu, and A Agarwal.