Project ID: **65015**

Project Title: **Three-Dimensional Position-Sensitive Germanium Detectors**

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Annual Report for EMSP Project Number 65015
"Three-Dimensional Position-Sensitive Germanium Detectors

Research Objective

A critical component of the DOE decontamination and decommissioning effort is the characterization of radioactively contaminated equipment and structures. Gamma-ray spectroscopy and imaging with germanium (Ge) based detectors are powerful techniques that allow for the quick and accurate in-situ identification, spatial mapping, and quantification of radioactive contaminants. However, the image resolution obtained with a Ge detector can be limited by the accuracy to which the gamma-ray interaction events are spatially detected within the detector itself. Our primary objective is to develop the technologies necessary to produce Ge gamma-ray detectors with enhanced accuracy in locating gamma-ray interaction events thereby resulting in improved image resolution. Our approach is to locate the gamma-ray interaction events within the detector in all three dimensions rather than just two. Additionally, we will base the detectors on known and tested LBNL fabrication technologies and utilize the simplest possible detector geometries and signal-readout electrode structures in order to reduce the system complexity and difficulties in fabrication. The technologies developed as a result of this research will form the basis for the design and construction of future high-performance gamma-ray imaging systems. These instruments will greatly facilitate DOE's radioactive materials characterization process.

Research Progress and Implications

This section summarizes the work from the initial 8 months of our three-year project. During this period, we have concentrated our efforts on three separate task areas: detector fabrication development, orthogonal-strip detector fabrication and testing, and detector modeling. Though much of the detector fabrication is based on previously developed LBNL technologies, some detector processing development of particular importance to detectors with highly segmented signal-readout electrodes is necessary for this project to succeed. In our detectors, the electrical contacts to the bulk single-crystal Ge are made through an RF sputtered amorphous semiconductor (normally Ge or silicon) layer deposited onto the bulk Ge. These contacts allow for the application of the high voltages necessary to fully collect the electrons and holes generated by gamma-ray interaction events within the bulk Ge and for the measurement of the electrical signals produced by this charge collection. These electrical signals form the basis for the determination of each gamma ray's energy and interaction location thereby allowing spectroscopy and imaging to be performed. The properties of the amorphous contact layer are key to the proper performance of the detector. In particular, a large electrical barrier to charge carrier injection is necessary. We have and continue to systematically study the injection barrier properties of amorphous Ge and amorphous silicon films deposited under various conditions onto bulk Ge. From this work we know that amorphous Ge sputtered in pure argon produces a contact that works nearly equally well as a barrier for hole and electron injection and can therefore be used for either a positively or negatively biased electrical connection. Also, if necessary, a greater hole barrier to injection can be obtained (with a correspondingly reduced electron injection barrier) from amorphous Ge sputtered in a hydrogen-argon mixture. Similarly, a greater electron barrier is obtained from silicon sputtered in pure argon.

Another fabrication issue that needed to be addressed was the method of electrically connecting the amorphous semiconductor contacts on the Ge detector to the measurement electronics. The amorphous semiconductor contacts typically consist of an amorphous semiconductor layer that covers much of the detector surface. On top of this layer is deposited a metal electrode layer to which an electrical connection can be made. To produce a detector capable of imaging, the metal layer is segmented (divided into a number of pieces) and an electrical connection is made to each segment. For high spatial resolution, these electrodes will be finely spaced. Consequently, we have developed a metallization/wire bonding process that allows us to make contact to closely spaced (< 1 mm) electrodes on Ge detectors without damaging the detector.

With the aid of the above fabrication process development, we have produced a small Ge detector for studying spatial localization of gamma-ray interaction events within the detector in three dimensions. The objectives of this task have been to test and refine the fabrication processes, study the physics of charge collection and signal formation in highly segmented Ge detectors, and investigate depth-of-interaction sensing. An orthogonal-strip type geometry was chosen for this detector because of its simplicity. In this geometry the electrodes on one side of a planar detector are segmented into a set of linear strips. On the opposing detector surface is another set of strips that run perpendicular to the first set. The location of a gamma-ray interaction event within this detector is determined by measuring the induced charge signals from each strip of both sets of electrodes. For a simple gamma-ray interaction event, a single strip on one side of the detector will collect the generated holes and a single strip from the opposing detector surface will collect the electrons. Therefore for such an event, only one strip on each side of the detector will produce a net charge signal thereby localizing the interaction event in two dimensions. We have tested the operation of our detector in this respect by scanning a highly collimated gamma-ray source along the electrode surface of the detector. From these tests we see evidence of a loss of photopeak efficiency when an interaction event occurs in the region between two adjacent strips. Based on these measurements and modeling results, it appears that this is caused by slow charge collection in a weak field region between adjacent strips. This loss of efficiency would degrade detector performance. One simple method to reduce this effect is to reduce the gap between the strips. The amount that this can be done however will be limited by the fabrication process used to define the strips and by the decreased signal-to-noise ratio as a result of the increased inter-strip capacitance. Another method to solve this poor charge collection problem is to increase the field between adjacent strips. This can be accomplished by using only every other strip for signal measurement. The remaining strips are used as field-shaping electrodes to which a voltage can be applied thereby increasing the field between adjacent strips and improving the charge collection to the signal measurement strips. We have successfully used this technique to improve the photopeak efficiency of our orthogonal-strip detector, though more work remains to be done in this area.

As previously described, the orthogonal-strip detector geometry can be used to locate a gamma-ray interaction event within the detector in two dimensions. To more precisely locate the interaction event, we desire to also determine the depth at which the gamma ray has interacted within the detector thereby producing a three-dimensional position-sensitive detector. This can be accomplished by measuring the difference between the arrival time of the holes at a strip on one side of the detector and the arrival time of the electrons at a strip on the opposing detector side. We have tested this idea by measuring the induced charge signals on two opposing sensing strips resulting from gamma rays interacting at various depths between the two strips. Because of the fine-pitched strip geometry of our detector, the shape of the induced charge signals is such that the charge arrival times at each strip can be readily extracted.

The spectroscopy and imaging performance of the Ge detectors depends on the detector and electrode geometry and the readout electronics configuration. Numerical modeling is an efficient means to optimize the detector and readout electronics design for the best possible system performance. We have begun to model the response of our orthogonal-strip detector in order to refine the detector design and to allow us to design the most effective readout electronics. This has initially consisted of calculating the induced charge signals on the detector strips as a result of gamma-ray interaction events at various depths within the detector. These calculations combined with our induced charge signal measurements will be used to determine the best method to electronically extract the gamma-ray depth of interaction from the measured induced charge signals.

Planned Activities

In the short term we plan to continue the investigation with the small orthogonal-strip detector concentrating on the use of field-shaping electrodes to improve the photopeak efficiency and depth-of-interaction sensing. The depth-of-interaction sensing requires the development of specialized electronics for the readout of the signals. This task, to be started shortly, will include the design, modeling, and construction of the necessary electronics.

To this point in the project, the characterization of the orthogonal-strip detector has been done in a general-purpose cryostat. This cryostat is not ideal for the types of measurements necessary to fully test the detector. We will therefore, within the year, design and build a cryostat specifically for many channels of electronics readout, ease of gamma-ray scanning, and quick temperature cycling.

In both the short term and long term our efforts will continue to be directed at refinements in the fabrication processes. The development and use of modeling tools to better understand the physics of our detectors and to optimize their performance will also continue throughout the project.

Once a good understanding has been gained from modeling and measurements made with small detectors, we will design, fabricate, and test larger area detectors more suitable for imaging applications.