TCAD modeling of SiC alpha-particle radiation detectors

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While radiation detection at ambient conditions has become a mature technology, detectors that work at the most extreme conditions in a nuclear environment in terms of temperature and radiation are still a challenge to be mastered.

Among the most extreme conditions are those found in pyroprocessing, where high-temperature molten salts and electric fields are used to separate and collect fuel isotopes. For this technology, on-line techniques for measuring U and Pu concentrations are needed. One possible technique would use an alpha-particle radiation detector that operates inside of the reprocessing tank, if the detector's output has sufficient resolution to allow decays of U and Pu to be distinguished.

4H-SiC Schottky diode detectors in contact with the molten salt can potentially fulfill this need. Concentrations would be determined via alpha-particle spectroscopy, taking into account the absorption of alpha particle energy in the molten salt. Because of the complexity of the pyroprocessing environment, an initial feasibility study was performed to investigate if the resolution of the detector was sufficient to distinguish and quantify the alpha particle emissions of U and Pu in the molten salt mix.

SRIM 2010 was used to estimate the energy loss of α particles in the molten salt. SRIM 2010 was also coupled with Sentaurus Device, a tool in the Sentaurus TCAD suite. Together these codes simulated the charge transport of alpha particle tracks in a 4H-SiC Schottky diode detector, and predicted the detector's output signal. Initially, default and best-guess values have been used for the parameters describing charge transport in the diode. As the work progresses, these values will be improved, where necessary, by concurrent atomistic ab-initio modeling work.

The TCAD simulations were performed using different meshes to describe different phenomena of the detectors. To simulate I-V curves, a low-density 3D cylindrical mesh was used. For the alpha particle collection events, 2D meshes were chosen over 3D meshes in order to reduce computational demands. For the 2D simulations, the angle of incidence of the alpha particle onto the detector was varied from normal to near-parallel to the window of the detector. The simulations using normal incidence were also compared to a 3D simulation in cylindrical geometry.

Room temperature results predict that there is recombination of charge carriers in the ionization tracks of the alpha particles prior to the charge cloud exiting the depletion region. As a consequence, the collected charge is dependent on the angle of incidence of the alpha particles on the detector (Fig. 1). Also, as the temperature of the detector is increased to 600 °C, the predicted rise time of the pulse increases due to decreases in the carrier mobility, resulting in increased intra-track recombination and thus reduced output pulse heights (Fig. 2). This adversely affects the resolution of the detector. Considering all these effects in our model, we will discuss our results in comparison to first experimental results in detectors built by our collaboration and answer the question: "Is the resolution of the detector sufficient to distinguish and quantify the alpha particle emissions of U and Pu in the molten salt mix?"

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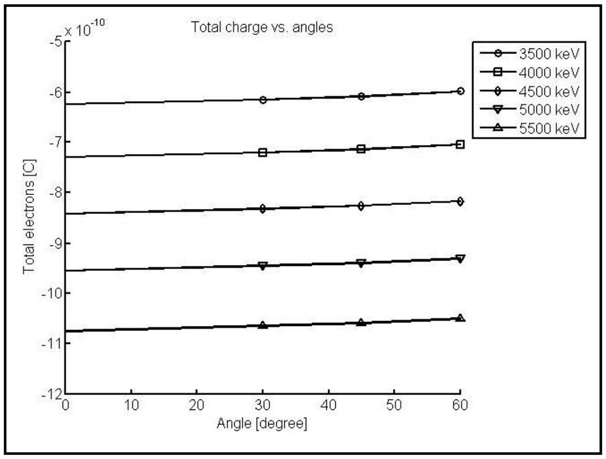

Fig. 1. Collected charge for 5 different alpha particle energies, with varying angles of incidence.

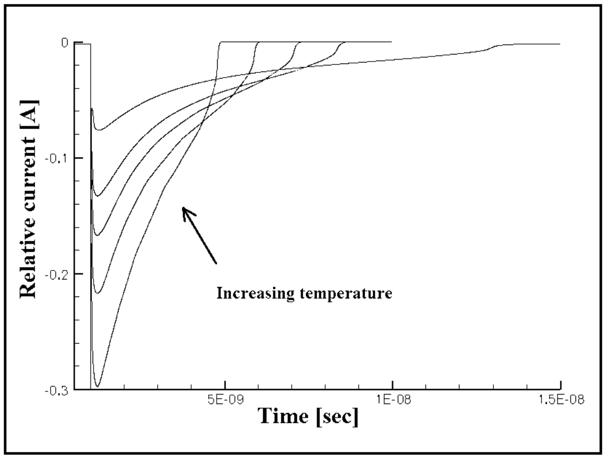

Fig. 2. Collected charge for 3,500 keV alpha particle energies, normal incidence, and increasing temperature.