Understanding irradiation behaviors of ultrawide bandgap Ga_2O_3 high temperature sensor materials for advanced nuclear reactor systems

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ABSTRACT:

The objective of the project is to understand fundamental irradiation behaviors of emerging ultrawide bandgap Ga_2O_3 high temperature sensor materials through a series of well-designed irradiation experiments and post-irradiation examination (PIE) tests. Due to its unique physical properties, especially intrinsic high radiation resistance and excellent temperature tolerance, Ga_2O_3 has been considered as a promising candidate material for several key nuclear sensing and radiation hardened electronics applications for nuclear instrumentation of next-generation nuclear reactor systems and strategic fuel cycle technologies. The proposed work fully leverages the expertise of North Carolina State University (NCSU) in nuclear sensor materials development, neutron irradiation and positron measurements with the post irradiation examination capabilities of Idaho National Laboratory (INL) and Center for Advanced Energy Studies (CAES). The success of the project will generate crucial scientific insights into the deployment of the innovative Ga_2O_3 sensors in advanced nuclear energy systems.

The proposed research will focus on two key parts to achieve the project objective: (1) performing systematic neutron irradiation and positron annihilation lifetime spectroscopy (PALS) and Doppler broadening spectroscopy (DBS) analysis at NCSU's PULSTAR Nuclear Reactor; and (2) conducting targeted post irradiation examination (PIE) at CAES to measure the changes of microstructures, compositions and functional properties of Ga_2O_3 sensor materials. Special emphasis will be put on the evaluation of the impact of irradiation and temperature on Ga_2O_3, i.e., clarifying the neutron influence-rate dependence of Ga_2O_3 performance at different working temperature. We will utilize the state of the art positron facility at NCSU's PULSTAR Nuclear Reactor to take positron annihilation lifetime and Doppler broadening spectroscopy measurements of Ga_2O_3 sensors materials before and after neutron irradiation. Such efforts will help understand the formation and evolution of radiation-induced materials defects, especially vacancy-related ones, and clarify their effects on the sensing performance of Ga_2O_3, thus providing key information regarding Ga_2O_3 sensors' use in intense irradiation and high temperature environment. After neutron irradiation and positron measurements at the NCSU PULSTAR reactor, the samples will be sent to the CAES facility for PIE using several dedicated PIE characterization instruments. The nature and evolution of defects, compositions and microstructures of Ga_2O_3 sensor materials will be systematically investigated before and after irradiation. Through these well-designed irradiation experiments and PIE analysis, we anticipate to achieve a deep understanding of irradiation behaviors of Ga_2O_3 sensor materials when these materials are exposed to harsh nuclear environment, especially intense radiation and high temperature fields. The scientific output of this project will provide key fundamental knowledge to promote Ga_2O_3's nuclear instrumentation applications for next-generation nuclear energy systems.