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Ultrasound-Based Sensors for Harsh Environment Structural Health Monitoring

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Current generation light water reactors (LWRs), sodium cooled fast reactors (SFRs), small modular reactors (SMRs), and next generation nuclear plants (NGNPs) produce harsh environments in and near the reactor core that can severely tax material performance and limit component operational life. To address this issue, several Department of Energy Office of Nuclear Energy (DOE-NE) research programs are evaluating the long duration irradiation performance of fuel and structural materials used in existing and new reactors. In order to maximize the amount of information obtained from Material Testing Reactor (MTR) irradiations, DOE is also funding development of enhanced instrumentation that will be able to obtain in-situ, real-time data on key material characteristics and properties with unprecedented accuracy and resolution. Such data is required to validate new multi-scale, multi-physics modeling tools under development as part of a science-based, engineering driven approach to reactor development. It is not feasible to obtain high resolution/microscale data with the current state of instrumentation technology. However, ultrasound-based sensors offer the ability to obtain such data if it is demonstrated that these sensors and their associated transducers are resistant to high neutron flux, high gamma radiation, and high temperature. To address this need, the Advanced Test Reactor National Scientific User Facility (ATR-NSUF) have funded an irradiation, led by PSU, at the Massachusetts Institute of Technology Research Reactor to test the survivability of ultrasound transducers. As part of this effort, PSU and collaborators have designed, fabricated, and tested piezoelectric transducers that are optimized to perform in harsh, high flux environments. Four piezoelectric transducers were fabricated with Aluminum Nitride (AlN) (two AlN sensors were fabricated), Zinc Oxide (ZnO), and Bismuth Titanate (BiT) as the active elements.

Several important results are, first and most importantly, the successful operation of the transducers at integrated neutron fluence of approximately 8.68 E+20 n/cm^2 for n >1 MeV, temperatures in excess of 420 °C, and a gamma fluence of 7.23 Gy/cm^2. Although the sensors could perform in such environments, it was not without some troubles including issues with electrical connection and mechanical coupling to the waveguide.

Of the four piezoelectric transducers, only the AlN 2 sensor managed to make it to the end of the irradiation and operate after the capsule had been removed from the reactor. Both the AlN and BiT drop-in samples were operational after they were removed from the test capsule. The ZnO sensor had changed from a milky clear color to an orange color and had delaminated from the substrate. The AlN 2 sensor had changed from a milky clear color to a black color; however, it was securely bonded to the waveguide surface.

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