Novel High Temperature and Radiation Resistant Infrared Glasses and Optical Fibers for Sensing in Advanced Small Modular Reactors

PI: John Ballato- Clemson University

Collaborators: Steve Martin- Iowa State University
Amy Qiao- Pacific Northwest National Laboratory

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ABSTRACT:
Clemson University, in partnership with the Iowa State University (ISU) and the Pacific Northwest National Laboratory (PNNL), proposes an innovative and interdisciplinary research program to develop novel infrared glasses and optical fibers having improved thermal and radiation exposure resistance in order to enable in-vessel fiber optic sensing for advanced Small Modular Reactors (AdvSMR). Advanced Small Modular Reactor (AdvSMR) development is critical to providing the US with a sustainable, economically viable, and carbon-neutral energy supply. AdvSMR designs are economically attractive and should compensate for the economies of scale that have driven large commercial nuclear power plants to date. However, future AdvSMR deployment will require new sensing and monitoring instrumentation, control, and human-machine interface (ICHMI) architectures that accommodate the extreme temperatures, pressures, corrosive environments, and radiation fluxes.

Necessarily, optical materials and sensing technologies will play an important role in future AdvSMR designs. New optical-based ICHMI solutions will need to evolve from commercial off-the-shelf technologies and follow a revolutionary development path. Optical fiber-based sensing approaches have been identified by the DOE as suitable for measuring key AdvSMR process parameters. However high temperature and radiation flux deployment of current silica-based optical fiber is limited intrinsically by the susceptibility of dopants to radiation-induced darkening. Overcoming the current optical fiber limitations would enable in-vessel optical access and optical-based ICHMI systems.

Non-oxide glasses conventionally employed for IR fiber-based sensors are resistant to radiation-induced darkening but their relatively weak chemical bonding also limits their radiation hardness and thermal stability. Accordingly, this proposal will focus on an entirely different family of non-oxide glass compositions that are built upon ionic bonding schemes. Due to their very different bonding, ionic non-oxide compounds can have significantly different properties than their covalent analogues including melting points in excess of 2,000 °C. Their ionic character gives rise to high electronic binding energies which can foster significant radiation hardness.

While such glasses constitute a broad range of compositions, specifically targeted will be the rare-earth chalcogenides, such as La2S3, which have melting points of ~ 2,000 °C and are strongly glass-forming with other refractory sulfides, such as Ga2S3, that produce refractory, fully ionic, and IR transparent glasses that can be drawn into fiber. Compositions will be developed according to two chemical structural models that are based upon charge compensated tetrahedral glass networks. In the first approach, high melting point divalent chalcogenides will be mixed with high melting point trivalent chalcogenides to produce an overall in situ tetrahedral network (ITN) with increased glass stability. The composition MS + G'2S3 + G"2S3, where M is a divalent metal, and G' and G" are two different trivalent metals are typical of this model with specific examples being ZnS + Ga2S3 + La2S3 and BaS + Al2S3 + Gd2S3 glasses. In the second approach, the Tg and the glass forming character of a set of optimized glasses developed using the ITN structural approach will be increased by mixing these ITN compositions with a high melting point tetrahedral ionic chalcogenide, GS2¸ to create modified tetrahedral network (MTN) glass compositions. ITN and MTN glass compositions would be high melting, hence high Tg, and yet still strongly glass forming and therefore amenable to high quality optical fiber fabrication.