U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Clean. Reliable. Nuclear.

Integrated silicon/chalcogenide glass hybrid plasmonic sensor for monitoring of temperature in nuclear facilities

Award # DE-NE0008691

Advanced Sensors and Instrumentation Annual Webinar

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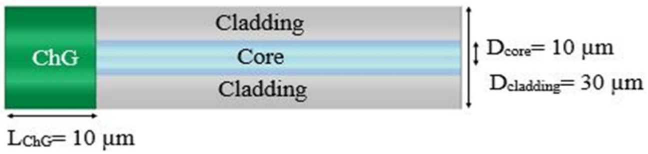
Project Overview

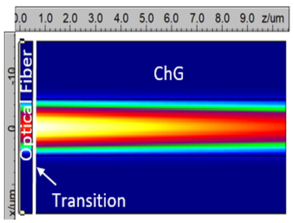
- **Goal and Objective**
  Applying additive technology to develop low power consuming reversible and reusable sensors, which can be deposited directly over the measured surface for real time temperature monitoring.
- **Participants (2020)**
  - Dr. Maria Mitkova – Principal Investigator;
  - Dr. Harish Subbaraman – Co- PI
  - Mr. Al-Amin Ahmed Simon (Graduate Student)
  - Ms. Bahareh Badamchi (Graduate Student)
  - Mr. Henri Kunold (Graduate student)
- **Schedule**
  - Simulation of the sensors' performance based on material's property studies performed in earlier phases of the project
  - Preparation and testing of model devices, based on electrical reading
    (a)Temperature sensors created by vacuum evaporation; electrical testing
    (b)Temperature sensors created by printing; electrical testing
  - Optical testing equipment set up and organization for optical testing
  - Preparation of fiber-based devices and testing
  - Development of temperature reading protocol based on material and devices data

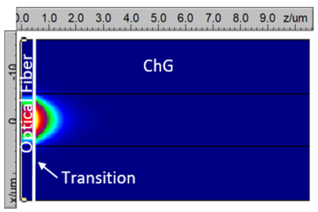
Accomplishments – Proof of concept electrical field devices; Fiber device simulation and fabrication

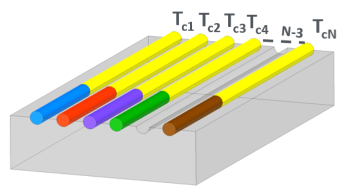
Fiber sensors' performance simulation; Model device fabrication and electrical testing;

- The design is simulated in PhotonDesign software.





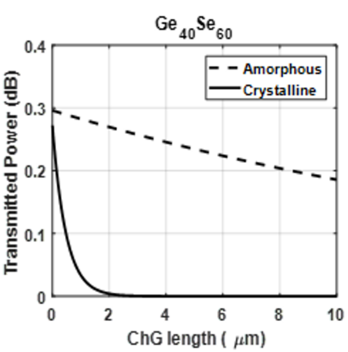




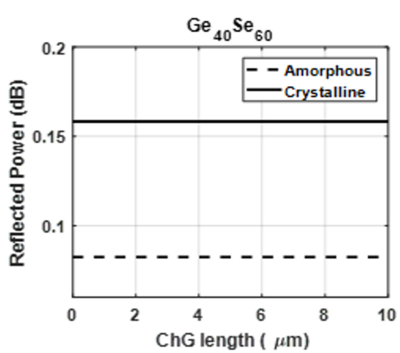
Amorphous phase
Low losses
ChG is transparent

Crystalline phase
High losses
Absorption increase

Optical fiber array; different ChG-capped fiber optics.

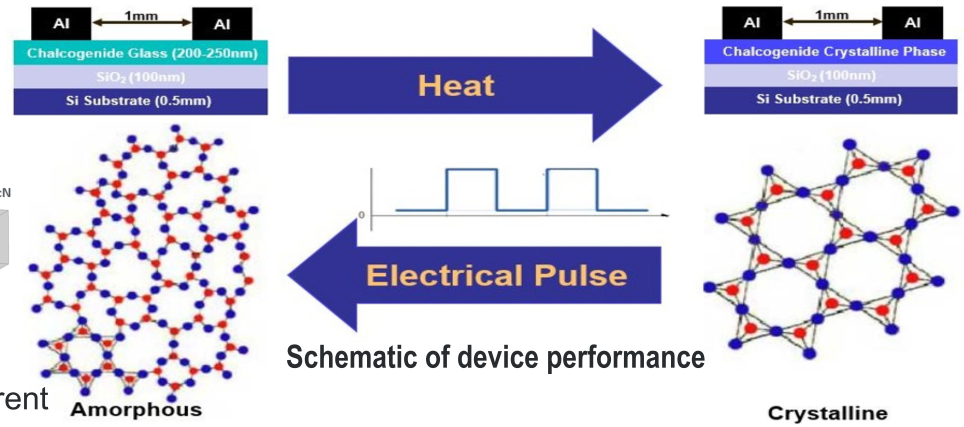


Transmitted power as a function of the length of ChG

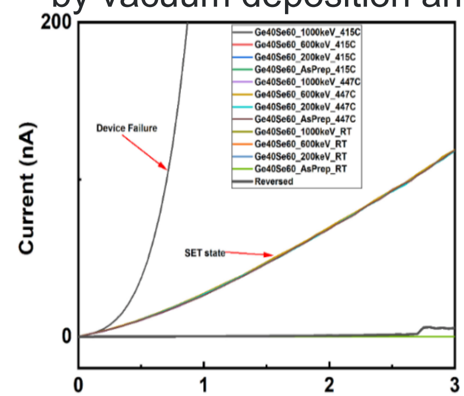


Reflected power as a function of the length of ChG

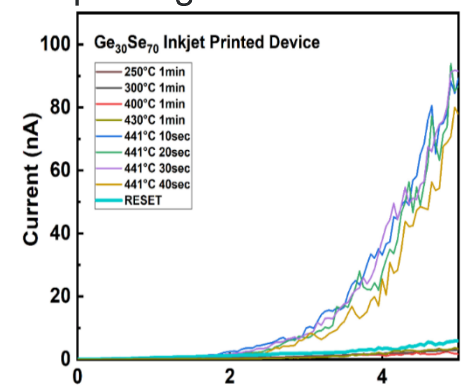
Proof of concept temperature sensing was demonstrated by devices electrical performance



Model devices for electrical field testing were created by vacuum deposition and/or printing



Evaporated film based device

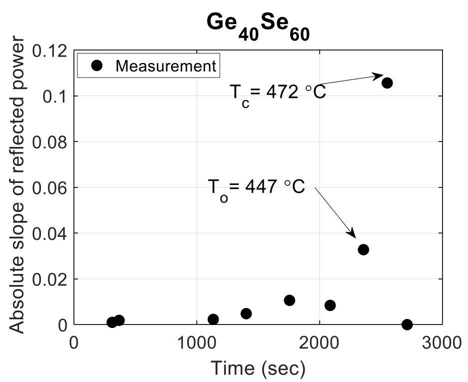


Printed film device

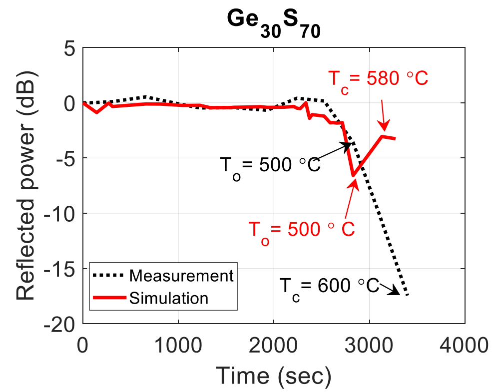
Accomplishments cont. - Fiber tip based temperature sensor

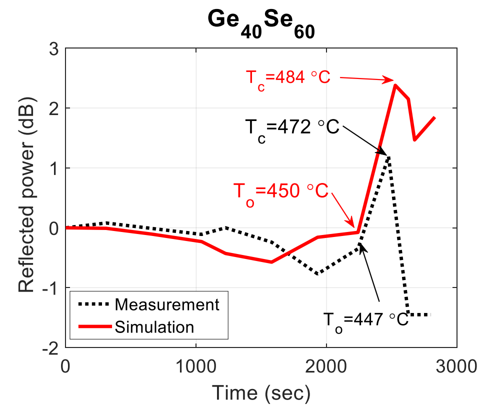
Real time response and temperature profiling of fiber sensors

- Good match between the normalized reflected power as a function of time and the measurement with extracted refractive index profile from studying in-house ChGs.
- The sudden changes in reflected power corresponding to specific temperatures can be efficiently extracted from the sensor data by plotting the slope as a function of time.



Temperature response of evaporated $Ge_{40}Se_{60}$ capped fiber tip based temperature sensor.



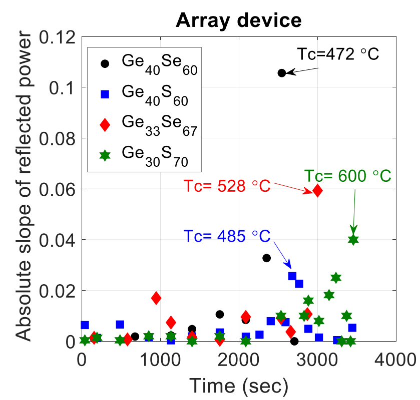


Simulated and measured optical power as a function of time with in-house synthesized capped fiber tip for a) $Ge_{40}Se_{60}$ and, b) $Ge_{30}Se_{70}$

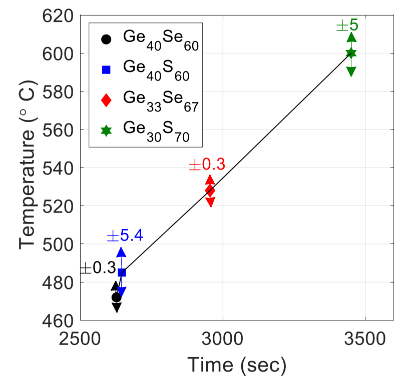
Journal Publications: **1. Phase change in Ge–Se chalcogenide glasses and its implications on optical temperature-sensing devices** AAA Simon. B. Badamchi, Y. Sakaguchi, H. Subbaraman, M. Mitkova J. Mat. Sci.: Mat. Electr. (2020) 31:11211–11226; **2. Silver photodiffusion into amorphous Ge chalcogenides: Excitation photon energy dependence of the kinetics probed by neutron reflectivity.** JP Kleider, E Johnson, R Brüggemann, Y Sakaguchi, T Hanashima, AAA Simon, M. Mitkova Euro. Phys. J.-Appl. Phys.(2020) 89 (6) p. 1-14. **3. Effect of ion irradiation on Amorphous and Crystalline Ge-Se and their application as phase change temperature sensor,** AAA Simon, L. Jones, Y.Sakaguchi, I. Van Rooyen, M. Mitkova, https://doi.org/10.1002/pssb.202000429

Patent application – Nanoparticles ink based on ChG for additive technology

TMS 2020 conference, February 23-27, 2020 contribution talk



Temperature response of array temperature sensor.



Monitored temperature trend as a function of time using array structure.

Technology Impact

- ✓ The state of the art for nuclear application will be advanced by introduction of new type of sensors suitable for:

  - Monitoring LWR, metallic or ceramic SFR reactors where the cladding temperature can reach 650° C.

  - Cohesive temperature monitoring using integration of photonic properties of radiation hard optical waveguides for nuclear application.

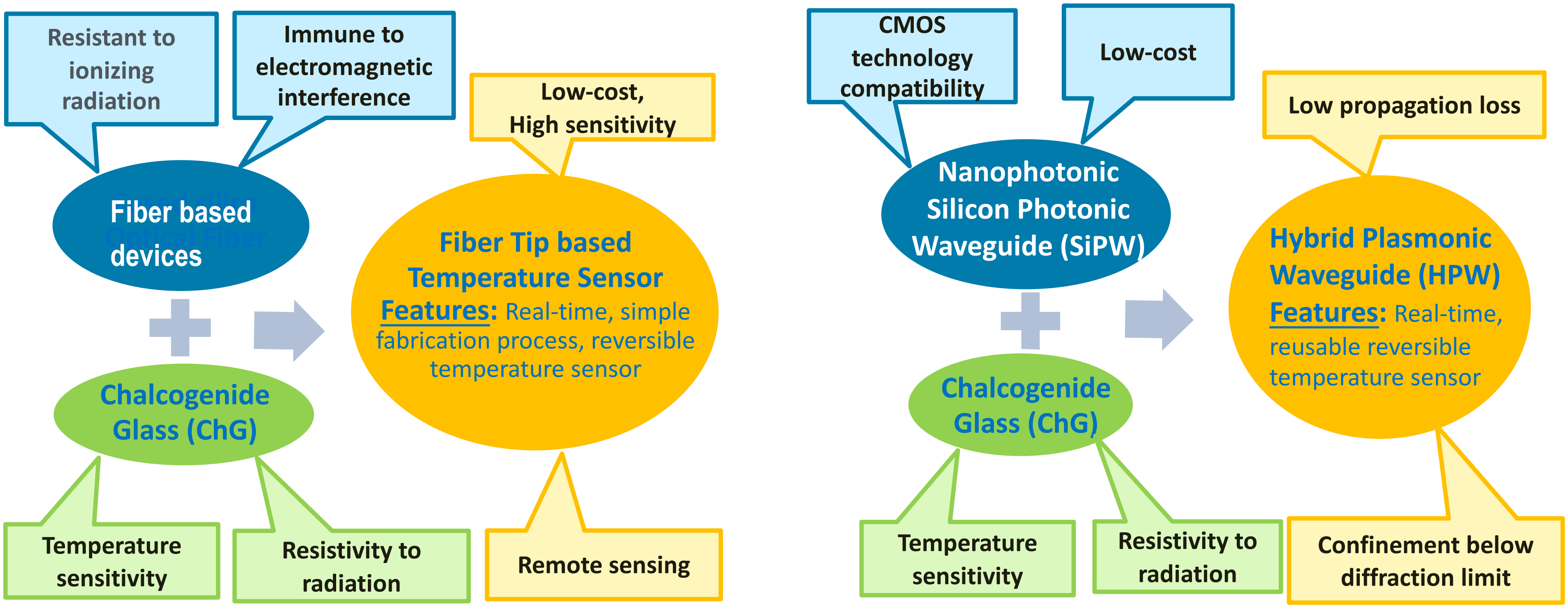
- ✓ The DOE-NE research mission will benefit from generating knowledge about the temperature performance of different components in the reactor environment.

- ✓ Obtaining knowledge about the performance of the radiation hard waveguides in the reactor environment will impact the nuclear industry by extending their application to other important characterization methods such as light transmission for in situ in pile Raman spectroscopy.

- ✓ The project will generate technological documentation which will enable commercialization of this technique

Conclusion

- ✓ Design small size, highly accurate, real-time, reusable and reversible temperature sensor for use within a nuclear facility.
- ✓ Temperature profile data will assist with the development of next-generation accident-tolerant nuclear materials, fuels, and structures.
- ✓ EMI-free operation within the reactor
- ✓ Safe monitoring on the outside
- ✓ Small diameter bundles are compatible with existing feedthroughs
- ✓ Two different device architectures developed.



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