Single-Mode Sapphire Fiber Optic Distributed Sensing for Extreme Environments

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Introduction

- LUNA and Ohio State University have developed a distributed temperature sensor based on **single-mode sapphire optical fiber**
- The sapphire is made single-mode through an internal cladding created by irradiation with triton and alpha particles in a nuclear reactor
- The sensor is intended to **measure distributed temperature, velocity, and deposit buildup along the length of the sensor (Figure 1)**
- The goal for **max operation temperature is 1700 °C**

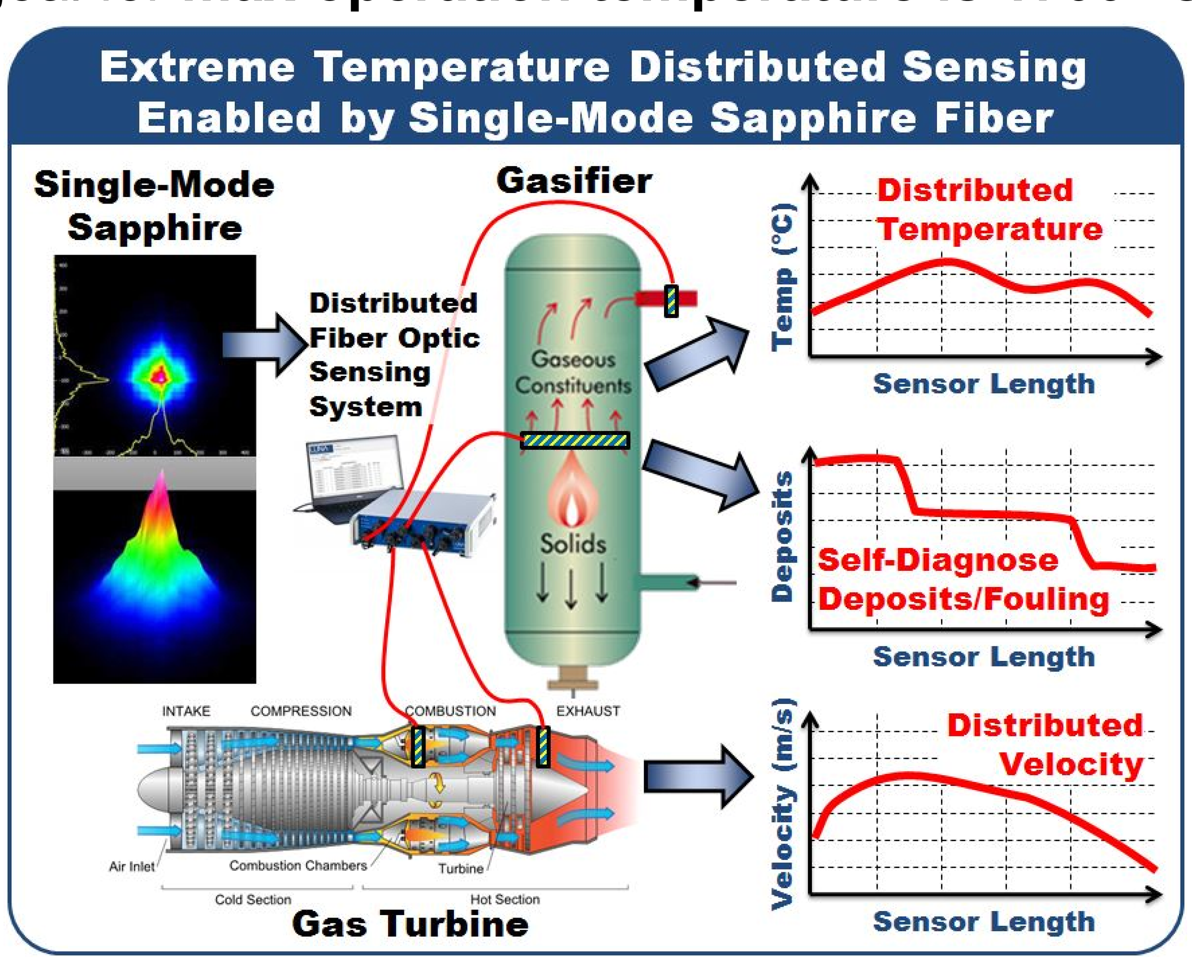

Figure 1: Distributed Sensing for Fossil Energy Applications with Single Mode Sapphire Fiber

Need

- Fossil Energy (FE) based modular power systems are a growing market
- Gasification of coal or biomass to produce energy in remote/isolated areas
- Feed-forward control can optimize performance mapping for variations in feed stock and environmental conditions
- Real-time sensing of flow properties is needed for these systems that reach 900°C - 1500°C

Approach

- Leverage Dr. Tom Blue's newly developed single-mode sapphire optical fiber that is created with $Li^6(n,\alpha)^3H$ reaction
- Use high-definition fiber optic sensing (HD-FOS) based on optical frequency domain reflectometry (OFDR) to enable distributed measurements with data spacing of 0.65 mm
- Employed 50 fiber Bragg gratings (FBG) written with femtosecond laser in sapphire fiber over 0.55 m to produce high signal-to-noise distributed data
- Used steady and dynamic cooling flow to assess flow velocity and deposit/fouling buildup along length of sensor
- Experiments performed in a box furnace with cooling flow and simulated deposits (Figure 2)

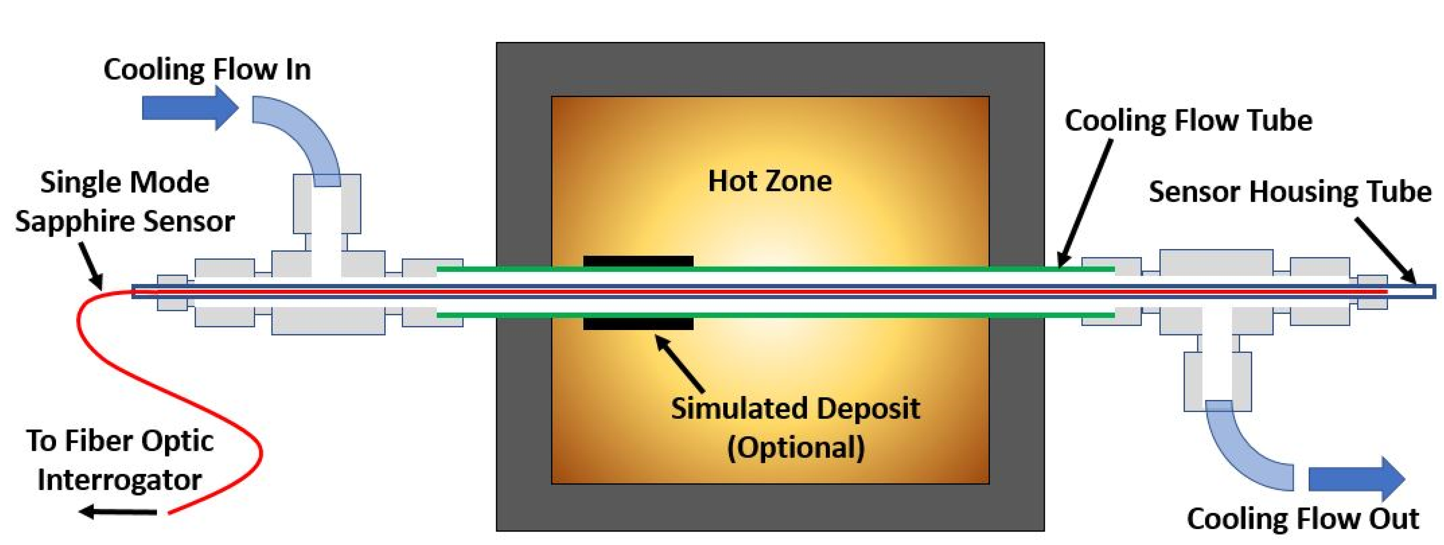

Figure 2: Experimental Setup

Results

- Calibration data was collected in 100 °C increments up to 1000 °C and back
- Spectral shift in the scatter pattern from the distributed gratings was measured versus length and averaged over the center region of the furnace
- A **cubic polynomial fit provided an excellent correlation (R^2 = 0.9999)** to mean temperature (Figure 3) and was used in all subsequent measurements to convert the raw data to temperature
- Distributed temperature profiles (Figure 4) demonstrate the match with thermocouple validation points, but also **visualize the temperature gradients within the furnace and through the insulating walls**

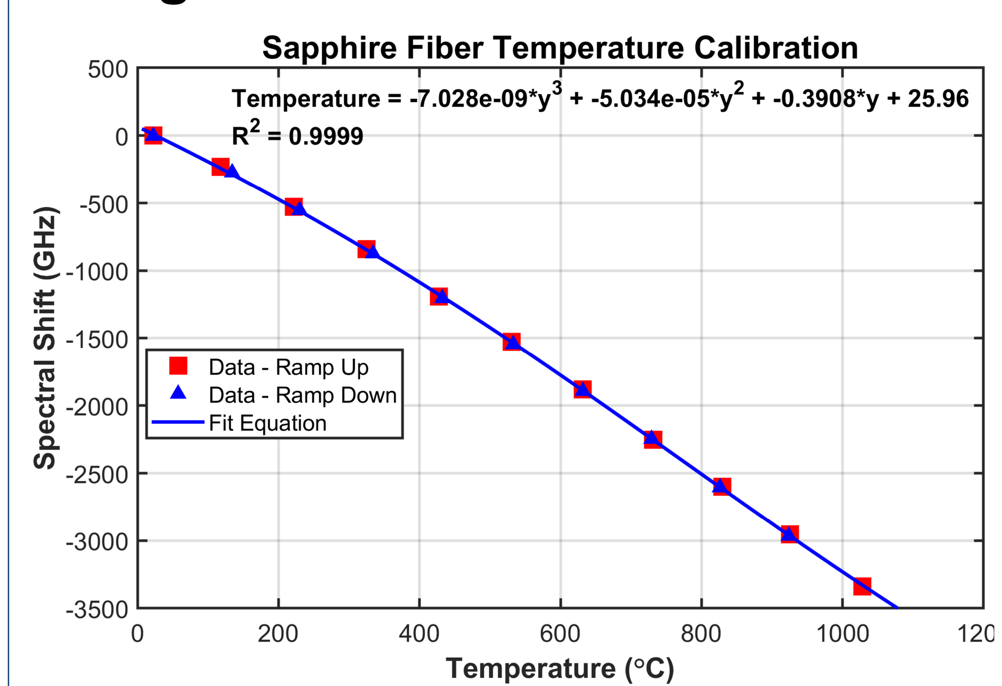

Figure 3: Calibration from Spectral Shift to Temperature

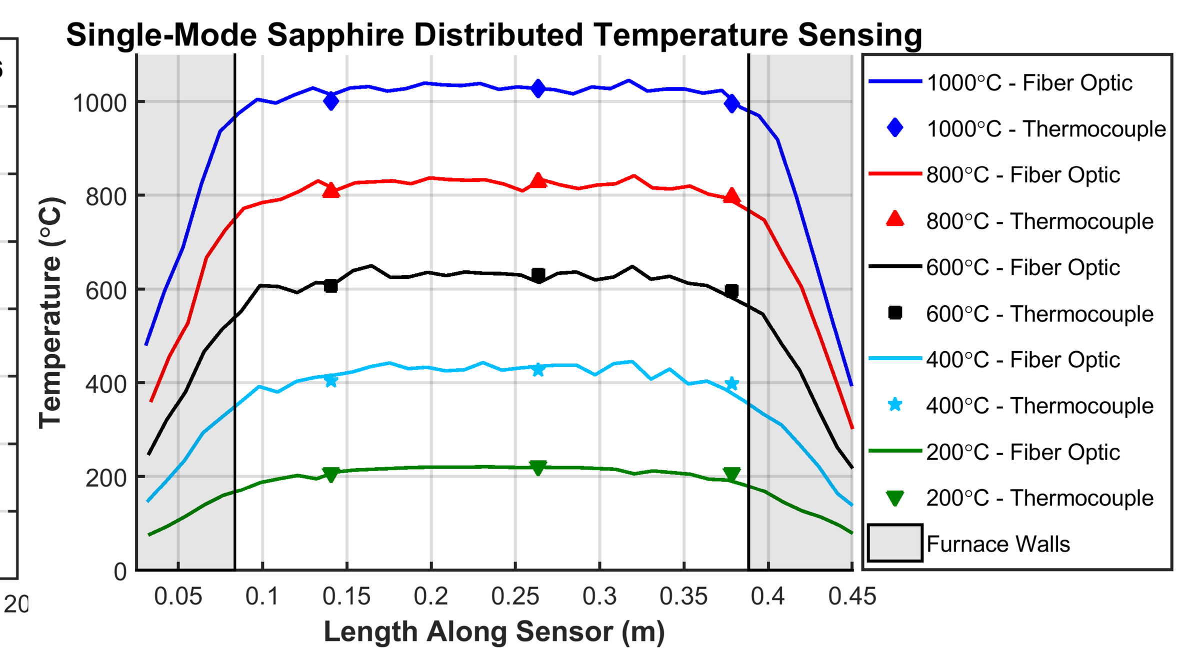

Figure 4: Distributed Temperature Measurements in Excess of 1000°C

- The steady effects of cooling flow (from left to right) can be seen in Figure 5
- There is a negative temperature delta along the length of the fiber in the furnace that diminishes in magnitude as the flow is heated, while the temperature of the sensor exiting the furnace is elevate do to the heat transport out of the furnace
- Simulated deposits (ceramic and metal tubing sections) show negligible effects in the steady condition, however the transient results in Figure 6 indicate **that deposits should be detectible based on the measured time constant when flow is toggled on and off**

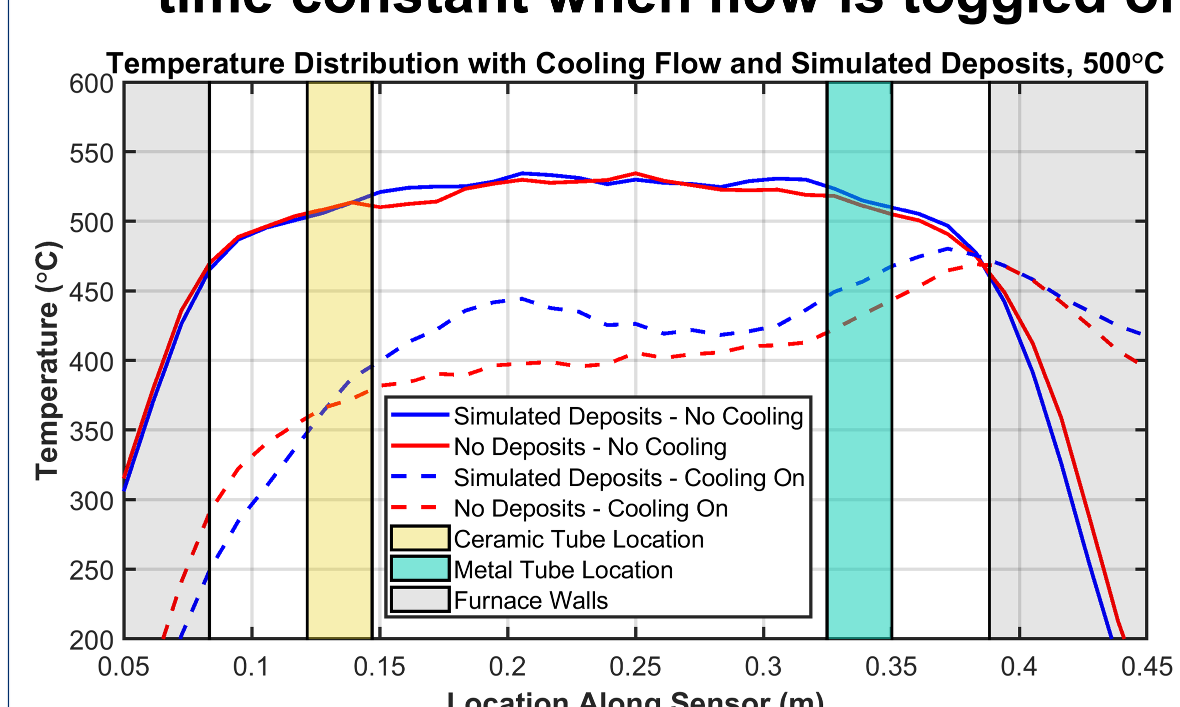

Figure 5: Steady Cooling Flow Effect with Simulated Deposits

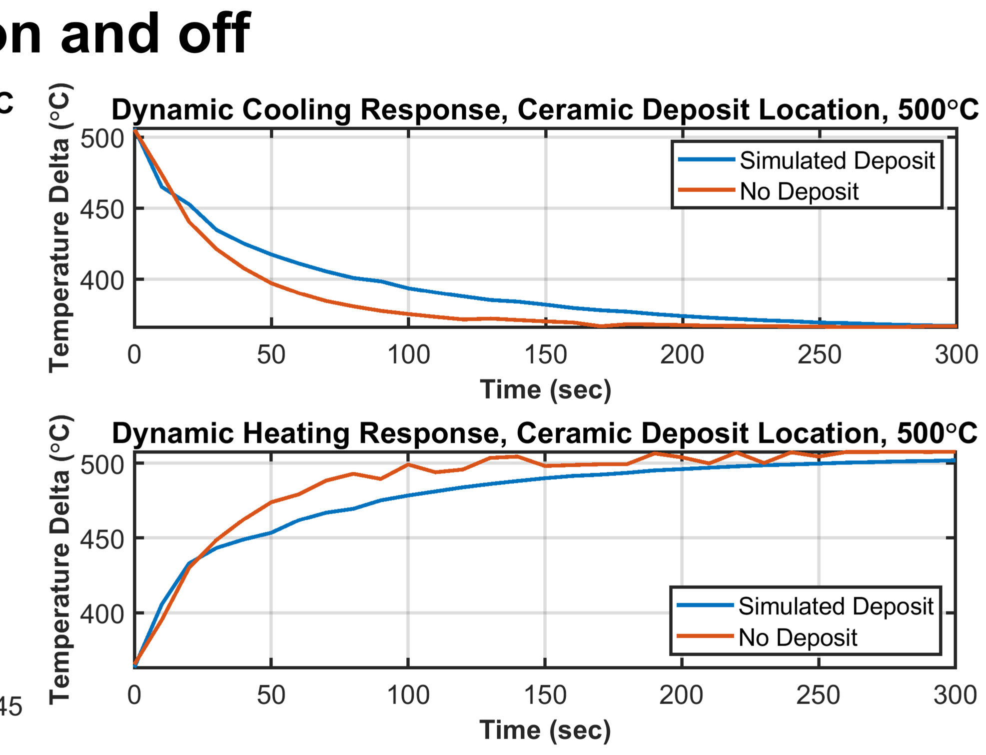

Figure 6: Transient Effect of Simulated Deposits

Benefits and Future Work

- **This is the first demonstration of distributed temperature sensing with semi-continuous femtosecond FBGs in excess of 1000 °C using OFDR**
- Single mode sapphire fiber combined with OFDR sensing will allow **thousands of data points to be measured with a single sensor**
- **Self diagnosis of deposit and fouling buildup** will be valuable for maintenance and health sensing in FE power systems
- Future tests will prove the **viability of the sensor up to 1700°C** and the possibility of **distributed velocity measurements**

Acknowledgements

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