Robust Heat-Flux Sensors for Coal-Fired Boiler Extreme Environments

Prof. Oded Rabin
Materials Science and Engineering

Prof. Peter Sunderland
Fire Protection Engineering

University of Maryland, College Park

Project Manager: Maria Reidpath
NETL, Crosscutting Research – Sensors and Controls

2021 DOE/FE R&D Project Review Meeting

Project Objectives

- **Develop robust heat-flux measurement systems** capable of operating in the challenging high-temperature, corrosive environments of the boilers of coal-fired power plants.

- Support the **training of graduate and undergraduate students** in STEM disciplines, preparing them to apply science and engineering principles to solve real-life problems.

Technical Approach

- **Prototyping the wire-wound Schimdt-Boelter-style sensor head**
- **Prototyping the Transverse Seebeck Effect sensor head**

- **Modeling of the Thermo-Mechanical Properties of the sensor head**

- **System design**
- **Testing and Calibration**

Project Participants

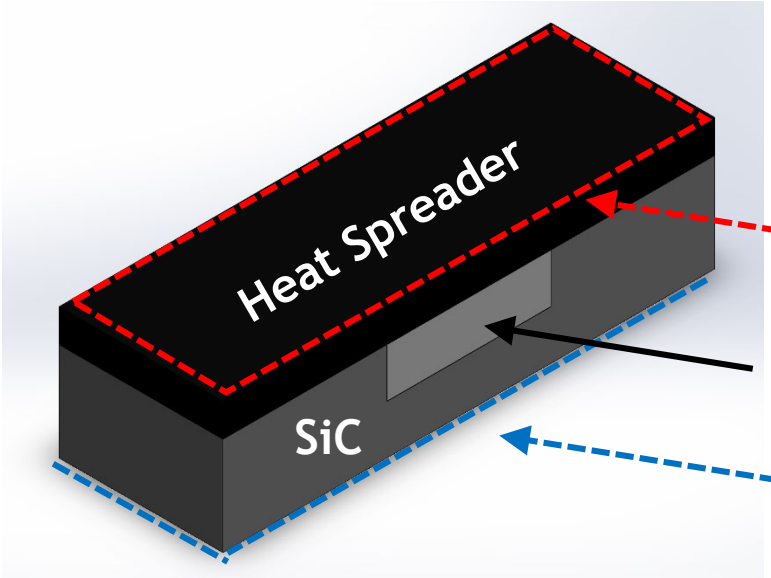
- PI: Oded Rabin, Materials Science and Engineering
- Co-PI: Peter Sunderland, Fire Protection Engineering
- Graduate students
  - K. M., 1st year graduate student in Aerospace Engineering
- Undergraduate students
  - A. L., Sophomore in Mechanical Engineering
- Technical staff (PT)
  - Machining and rig construction

Project Timeline

		Lead Person	FY 2021				FY 2022				FY 2023			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TASKS			1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36
1.0	Project Management and Planning	PD												
1.1	Project Management Plan	PD												
1.2	Technology Maturation Plan	PD												
2.0	Prototyping the Wire-Wound Schmidt-Boelter-Style Sensor Head	PD												
2.1	Materials Procurement	Staff												
2.2	Ceramic Machining	Staff												
2.3	Thermopile Wire Fabrication	PD				X								
2.4	Sensor Head Assembly	All												
3.0	Prototyping the Transverse Seebeck Effect Sensor Head	PD												
3.1	Materials Procurement	Staff												
3.2	Ceramic Machining	Staff												
3.3	Single Crystal Preparation	PD					X							
3.4	Sensor Head Assembly	All												
4.0	Modeling of the Thermo-Mechanical Properties of the Sensor Heads	co-PI				X								
5.0	System Design	PD						X						
6.0	Testing and Calibration	co-PI												
6.1	Design and Set-Up of Test Facilities	staff												
6.2	Low-Temperature Heat Flux Signal Testing	co-PI												
6.3	High-Temperature Resilience Testing	co-PI									X			
6.4	High-Temperature Heat Flux Signal Testing	co-PI												
6.5	Heat Flux-to-Electrical Signal Transfer-Function Analysis	PD												
6.6	High-Temperature Heat Flux Measurement: Testing against Commercial Sensor	co-PI												X
7.0	Presentations, Intellectual Property, and Partnerships	All	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Thermo-electrical Modeling

- **Sensor head consists of thermoelectric unit (voltage generating), blackbody absorber (heat spreader) and ceramic casing.**



FEA MODEL

Cross-sectional view of sensor head

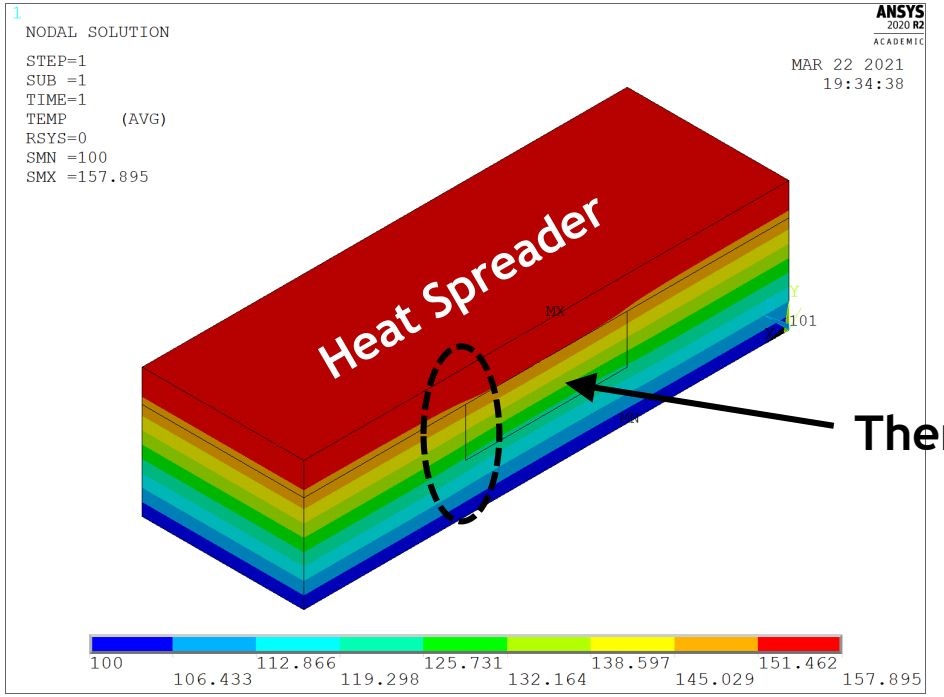
Constant Heat Flux boundary plane

Thermoelectric Element

Constant Temperature boundary plane

Thermo-electrical Modeling

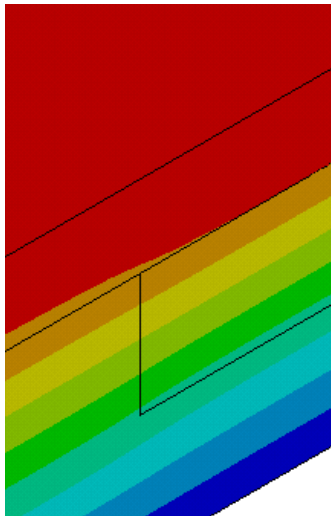
- **A one dimensional heat flow through the thermoelectric element is desired for the most linear sensor response.**



Thermoelectric Element

FEA RESULTS

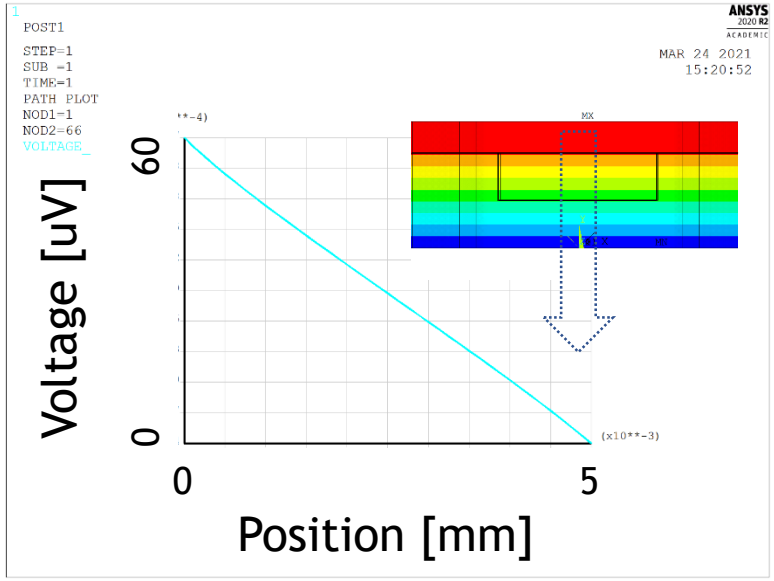
Temperature Distribution in Sensor Head



Thermo-electrical Modeling

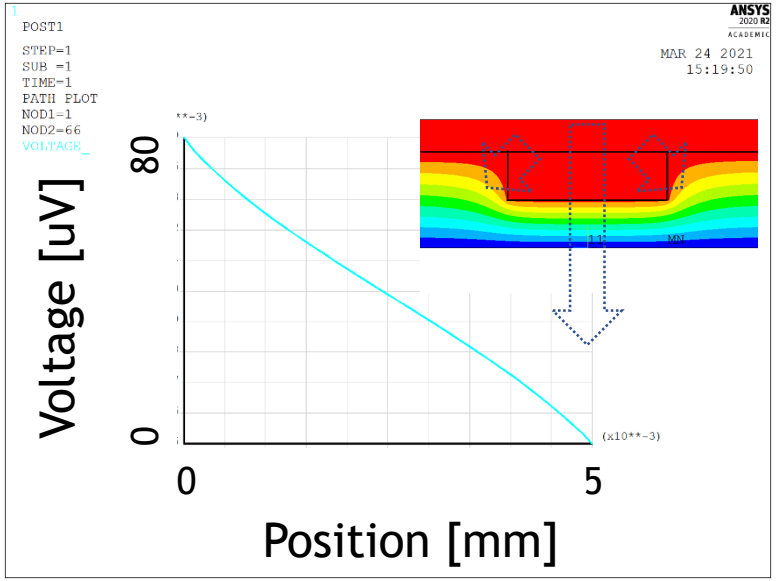
- **Voltage profile in thermoelectric element**

One-dimensional Heat Flow



Linear voltage profile (constant $\frac{\partial V}{\partial x}$)

Three-dimensional Heat Flow



Deviations from constant $\frac{\partial V}{\partial x}$ at the edges of the sample

Conclusions

- One dimensional heat flow through the thermoelectric sensor produces a linear voltage response to heat flux. Deviations from a one-dimensional heat flow reduce linearity and complicate deployment.
- The thermo-electrical FEA simulations helped us determine the range of acceptable values of materials parameters, for materials selection and system design.

Acknowledgment: This material is based upon work supported by the Department of Energy Award Number DE-FE0031902.