Embedded Sensors for Extreme Temperatures and Harsh Environments

Paul R. Ohodnicki, Jr.
Materials Scientist / Team Leader (Acting)
Electrochemical and Magnetic Materials Team
Functional Materials Development Division

NETL-RUA
Regional University Alliance
the ENERGY lab

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

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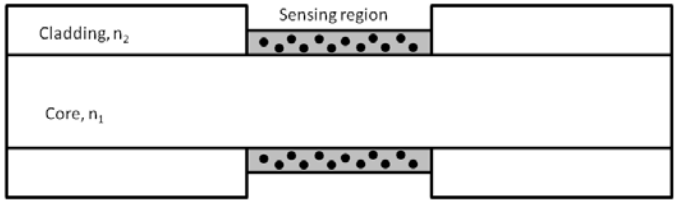
The Technology Summary

Technology: Optical and Magnetic Sensors Enabled by Advanced Sensing Materials for Embedded Sensing of Temperature, Gas Composition, or Magnetic Field in Extreme High Temperature Environments

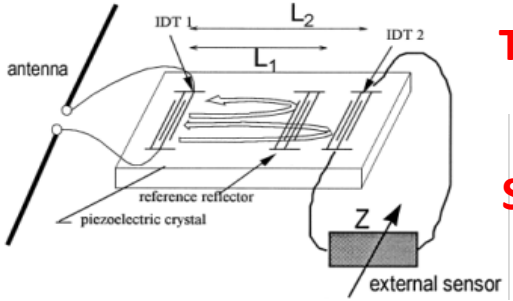
Optical Sensors



Temp. up to 1000°C

Gas / Temperature Sensitive Materials

Magnetic Sensors



Temp. up to 300°C

Magnetic Field Sensitive Materials

Advantages: Minimize Wires, Electrical Contacts, and Complex Electronics for Embedded Stable, Reliable, Safe and Cost-Effective Sensor Devices

Development Stage: Packaging and Prototype Sensor Development

Funding Sources: DOE FE Cross-Cutting Technology Program (Optical)
DOE ARPA-E Solar Adept Program (Magnetic)
URS Incorporated Grant, NETL-RUA (Magnetic)

Research and Development Team

Dr. Paul R. Ohodnicki, Jr., Optical Sensor Project PI

- Bachelor's, Engineering Physics and Economics, U. Pitt. (2005)
- M.S. and PhD in Materials Science and Engineering, Carnegie Mellon (2008)
- Sr. Research Engineer, PPG Industries (2008-2010)
- Project Manager, Material Scientist, Acting Team Leader, DOE NETL (Current)
- Adjunct Faculty, Materials Science and Eng., Carnegie Mellon (Current)

In-House Sensor Project Team

6 MS or PhD-level Engineers / Scientists
(Materials, Electrical, Mechanical, Chemists)

NETL-RUA
Regional University Alliance

NETL - RUA Collaborators

Prof. Kevin Chen, Optical Sensor Devices, Univ. of Pittsburgh
Prof. David Greve, Microwave Sensor Devices, Carnegie Mellon
Prof. Michael McHenry, Magnetic Materials, Carnegie Mellon

A Team of World-Renowned Experts in Materials and Sensor Devices!

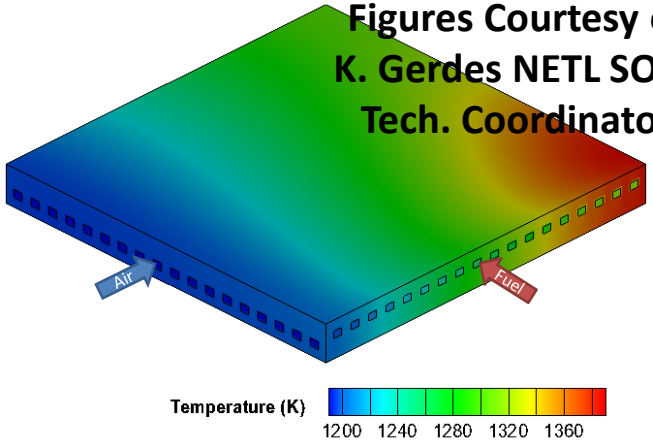
Technology Proposition Example

Optical Sensing Materials to Enable Simple, High Temperature Stable Embedded Sensors

Power Generation Technology Needs

	Coal Gasifiers	Combustion Turbines	Solid Oxide Fuel Cells	Advanced Boiler Systems
Temperatures	Up to 1600°C	Up to 1300°C	Up to 900°C	Up to 1000°C
Pressures	Up to 1000psi	Pressure Ratios 30:1	Atmospheric	Atmospheric
Atmosphere(s)	Highly Reducing, Erosive, Corrosive	Oxidizing	Oxidizing and Reducing	Oxidizing
Examples of Important Gas Species	H_2, O_2, CO, CO_2, H_2O, H_2S, CH_4	O_2, Gaseous Fuels (Natural Gas to High Hydrogen), CO, CO_2, NO_x, SO_x	Hydrogen from Gaseous Fuels and Oxygen from Air	Steam, CO, CO_2, NO_x, SO_x

Example : Solid Oxide Fuel Cells Internal Gas and Temperature Distribution



Figures Courtesy of K. Gerdes NETL SOFC Tech. Coordinator

Traditional Electrical Sensors

Prohibitively Costly and Intrusive

Require Stable Wiring, Insulation, Electronic Components

Complex Optical Sensors

Expensive and

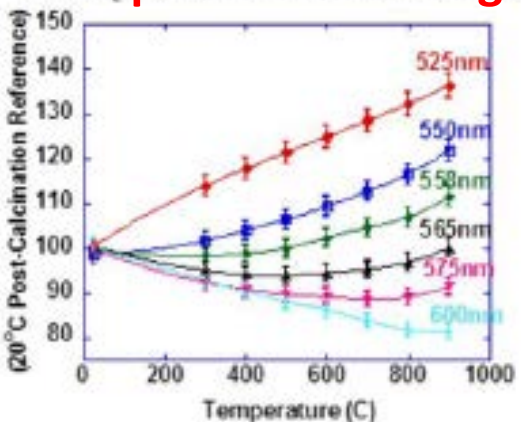
Inherent Temperature Instability Issues

Pakalapati, S. R., 'A New Reduced Order Model for Solid Oxide Fuel Cells,' Ph.D Thesis, Department of Mechanical and Aerospace Engineering, West Virginia University, Morgantown, WV

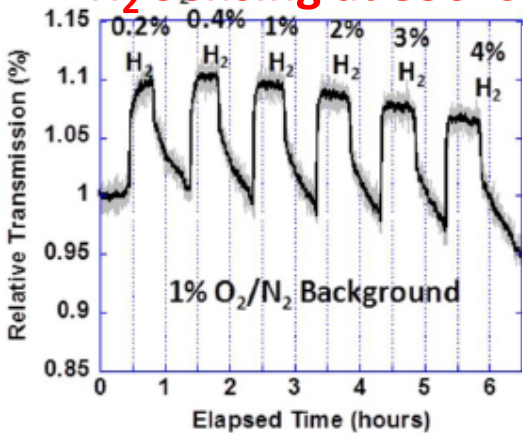
Technology Proposition Example

Fabricated Prototype Sensor

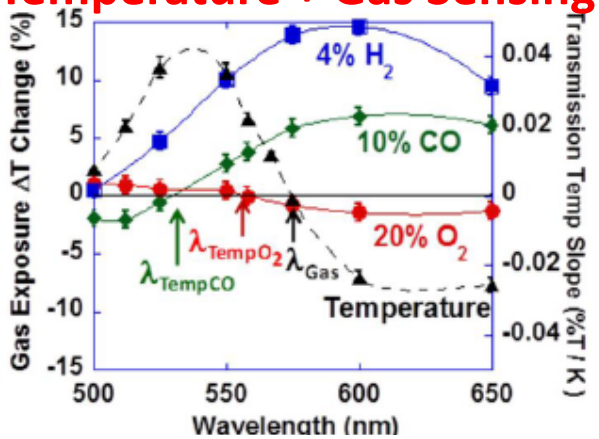
Temperature Sensing



H_2 Sensing at 850°C

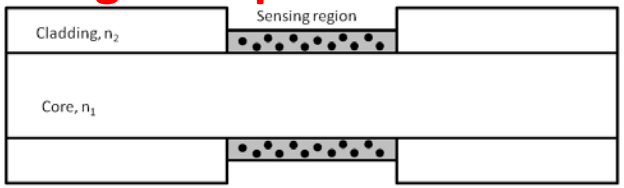


Temperature + Gas Sensing



Simple, Inexpensive,

High Temperature Stable



P. R. Ohodnicki et al., Nanoscale, 2013, Advance Article, DOI: 10.103/C3NR02891G

Advanced Optical Materials + Broadband Interrogation = Multi-Function Capability

No Comparable Commercial Sensor on Market!

The Market Opportunity

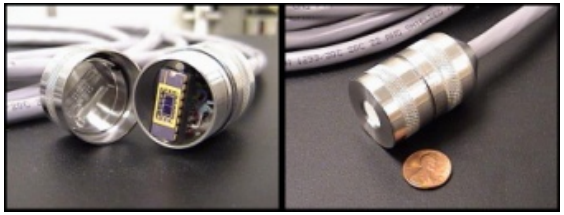
Markets: **Fossil and Nuclear Power Generation, Oil & Gas, Industrial Manufacturing, Aviation, Aerospace, Automotive, Military**

Potential Customers: **GE, Pratt & Whitney, Westinghouse, Siemens, etc.**

Potential Competitors: **Standard Products from Honeywell, Allegro Microsystems, Omega, Many Small Sensor Companies**

Traditional Sensors: Thermocouples, RTDs, Chemi-resistive Sensors, Fluxgate Magnetometers Employing Conventional Magnetics

Thermocouples



Chemi-resistive Sensors

RTDs

A Broad Range of Developed Markets Exist Along with a Number of Potential Customers and Competitor Technologies.

The Market Opportunity

Creation of New Markets:

No Commercial Solution for Embedded Gas and Temp. Sensing at T>500°C

No Commercial Magnetic Sensors Rated at T>175°C

Would Enable Unprecedented Access to New Information in Real Time!

Drivers for Market Growth:

Regulations: Energy Efficiency, Reduced Emissions, Safety

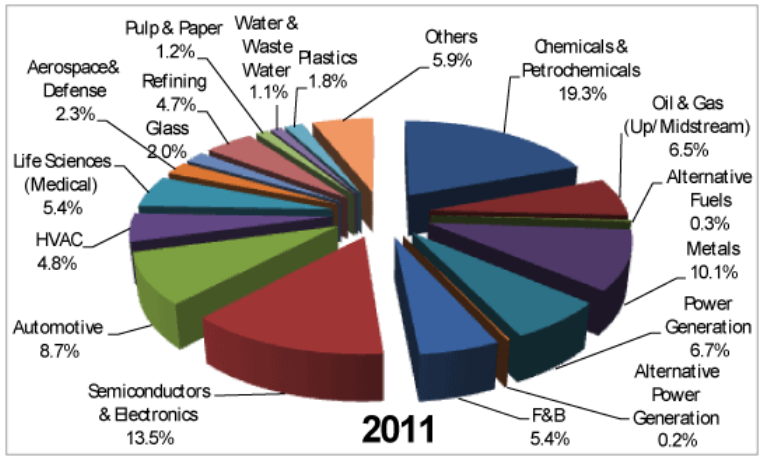
Global Trends: Increased Complexity of Systems and Processes

(Power Generation, Manufacturing, Transmission & Distribution)

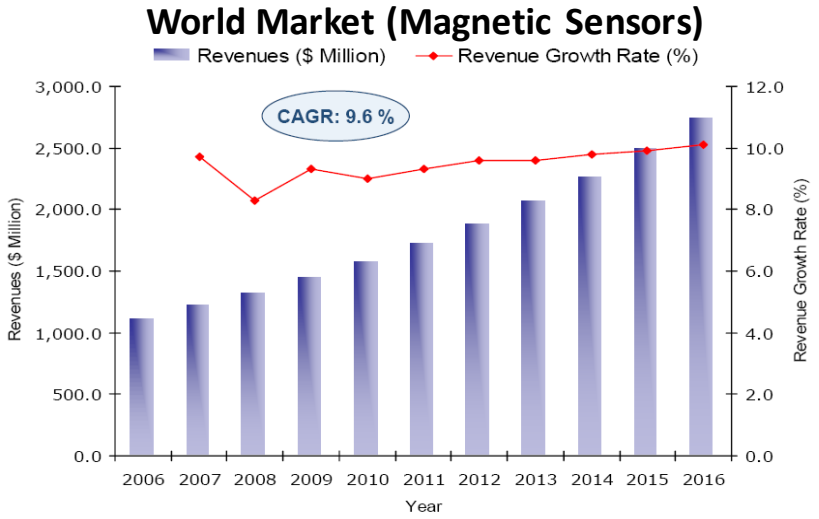
We are Trying to Create New Markets, Not Penetrate Mature Ones!

Quantitative Market Research is Difficult…

The Market Opportunity



www.sensormag.com



Frost & Sullivan

Temperature Sensor Market

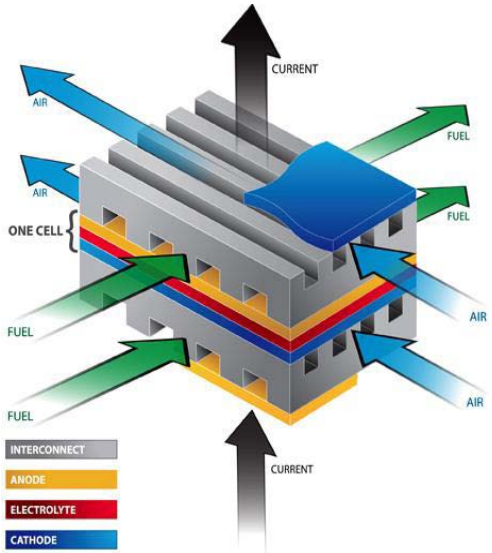
Asia-Pacific Represents Fastest Growing Region with Compound Annual Growth Rates >9% Estimated Global Market for Temperature Sensors is Projected to Reach $4.5 Billion by 2018

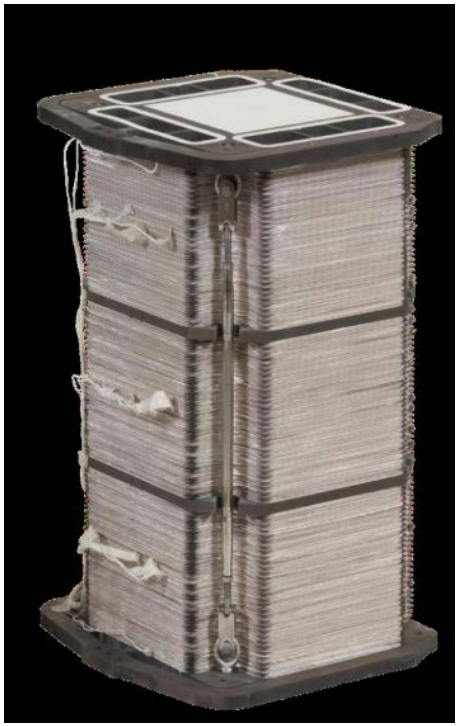
Magnetic Field Sensor Market

Compound Annual Growth Rates of 8-10% Predicted by Frost & Sullivan Global Revenues Estimated at $1.5 Billion in 2012

No Identified Commercial Sensor Rated at T > 175°C

The Market Opportunity
(Concrete Example : SOFC Temperature Sensors)





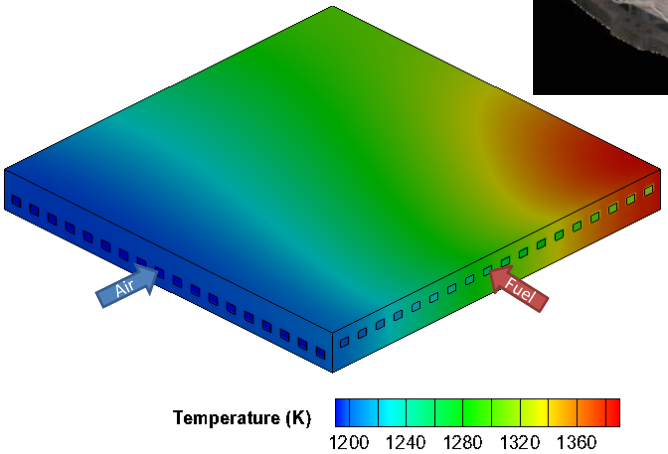
Total Market for Solid Oxide Fuel Cells:

2011 - $380 million

Projected for 2016 - $530 million

(6.9% compounded annual growth rate)

Source: www.environmental-expert.com,
Solid Oxide Fuel Cells Market,
Transparency Market Research

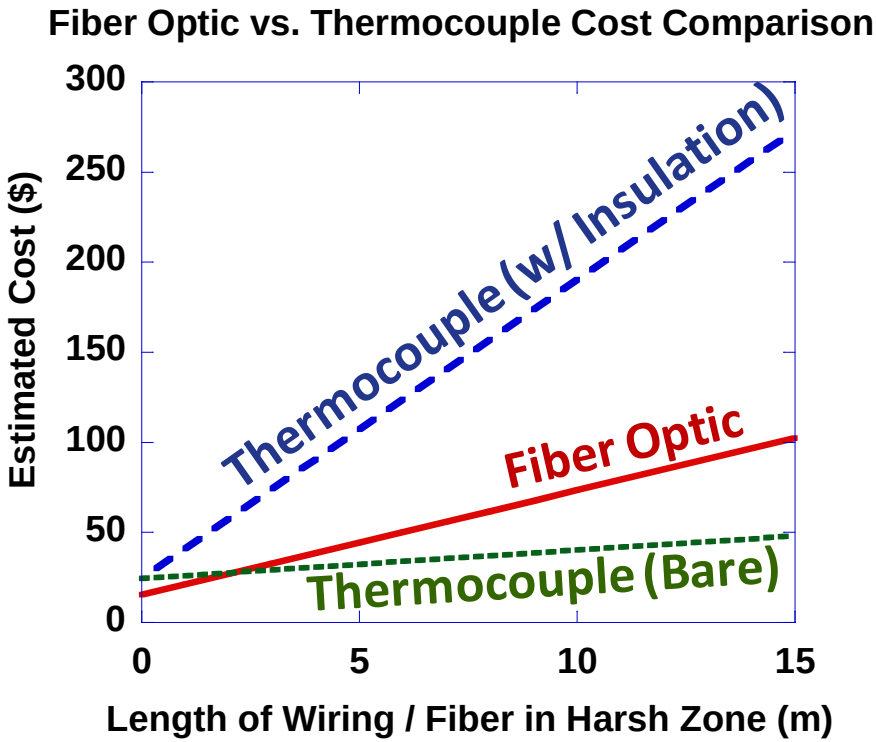


Spatial Variation in Temperature and Gas Composition within a Cell.

Traditional Thermocouples are Not Suitable

100's of Sensors Could Be Deployed!

The Market Opportunity
(Early Stage Cost Estimates of Temperature Sensors)



Insulating Property of Fiber Optic Cables Makes Them Potentially Competitive...

Packaging Cost Not Yet Included

Distributed Sensing Capability is a Key Advantage

Exploitation of Dual Sensing Capability (Gas and Temperature) Would Be a Game-Changer

The Commercialization Plan

- **The Combination of New Technologies Developed and Patented are Well Suited for a New Startup Company to Bridge the Gap from Novel Sensor Materials to Commercial Sensors!**
- **Key tests and trials**
  - Completed / Ongoing Lab-Scale Prototype Tests (Several Publications / Patents)
  - Pilot Scale Prototype Tests Currently in Progress w/ NETL SOFC Team
  - Pilot Scale Tests in Realistic Environments Anticipated in Future
- **Strong IP Position in High Temp. Optical Gas / Temp Sensors**
  - 3 Full Patent Applications Submitted or Awarded
  - 2 Provisional Patent Applications Pending Full Application
- **Solid IP Position in High Temp. Magnetic Field Sensors**
  - 1 Provisional Patent Application Pending Full Application

Our University Partners are Currently Seeking Parties Interested in Covering Patent Costs for 2 Technologies Jointly Developed with NETL.

Opportunity Summary

Thank you for the time and attention!

Technology: Embedded Gas, Temperature, and Magnetic Field Sensors for Applications in High T, Harsh Environments

Unique IP Position: Focus on Novel Sensor Materials as Enabling Technologies for Advanced Sensors

Gas and Temperature Sensing Materials

3 Full Patent Applications and 2 Provisional Patent Applications

Magnetic Field Sensing Materials

1 Provisional Patent Application on Magnetic Field Sensing Materials

Markets: Significant, Growing Markets Exist… We are Targeting New Market Creation Through Unique Functionality Imparted by Advanced Sensing Materials

Come Talk to Me About How You Can Work With our World Class Team to Make New Sensor Technologies a Commercial Reality!