Advanced Ceramic Materials and Packaging Technologies for Realizing Sensors Operable in Advanced Energy Generation Systems

SPORIAN® MICROSYSTEMS, INC

Small Business Innovation Research (SBIR)

Motivation and Objectives

Needs of Advanced Power Systems:

- Condition monitoring sensors and advanced system controls in harsh environments
- Improve operational efficiency, reduce emissions and lower operating costs
- Protect capital equipment investment and promote safety through prevention of catastrophic failure

Primary Technical Challenge:

- High-temperature: 800-1800°C
- High-pressure: 500-1000 psi
- Irradiation, corrosive or erosive exposures

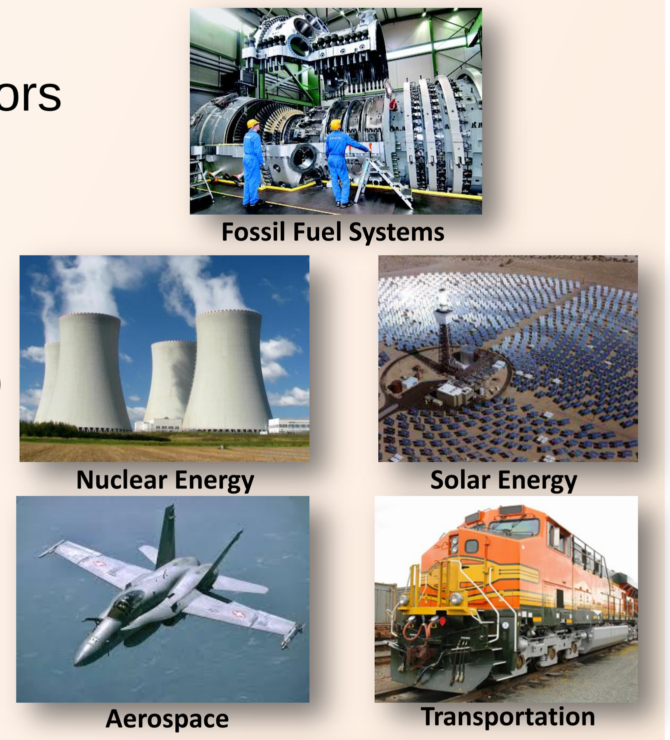
Phase II Objectives:

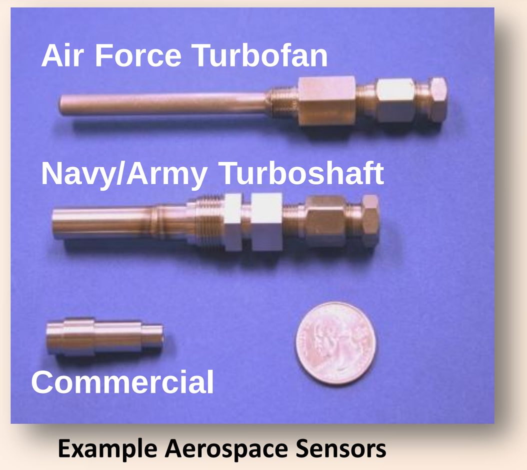
- 1800°C temperature sensor probe
- >1600°C temperature/pressure sensor suite

Approach/Technology Basis

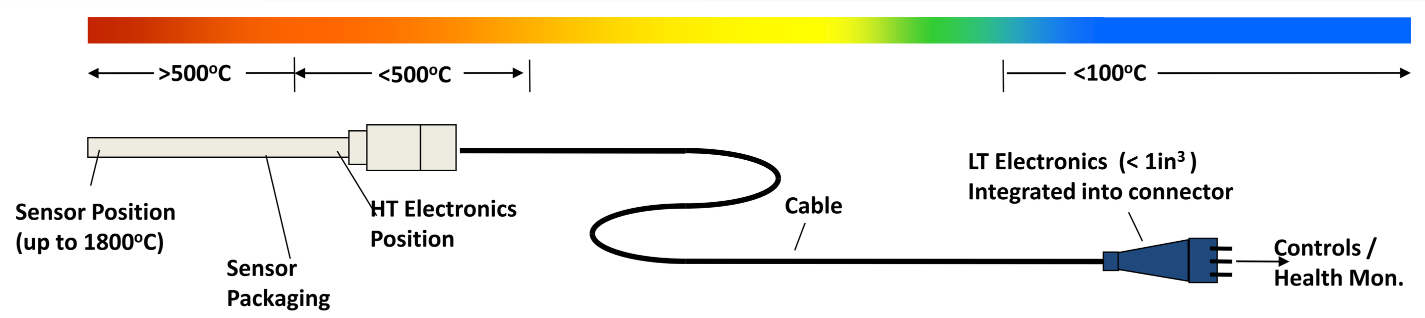
Leverage Sporian's previous experience in high-temperature sensor materials, packaging and design

- Sporian develops and sells high-temperature (1000-1400°C) sensors to directly monitor the most harsh environments and costly components of aerospace and energy generation systems.
- Temperature ▪ Pressure ▪ Flow sensors
  - Energy Generation Applications
    - Fossil fuel systems
    - Nuclear power generation
    - Concentrated solar power (CSP)
  - Aerospace Applications
    - Turbine engine control and monitoring
    - Smart sensor systems for distributed control
    - Space exploration
- "Smart" Sensor Functionalities
  - Analog/digital interface
  - Internal compensation
  - Internal health check
  - Data bus support





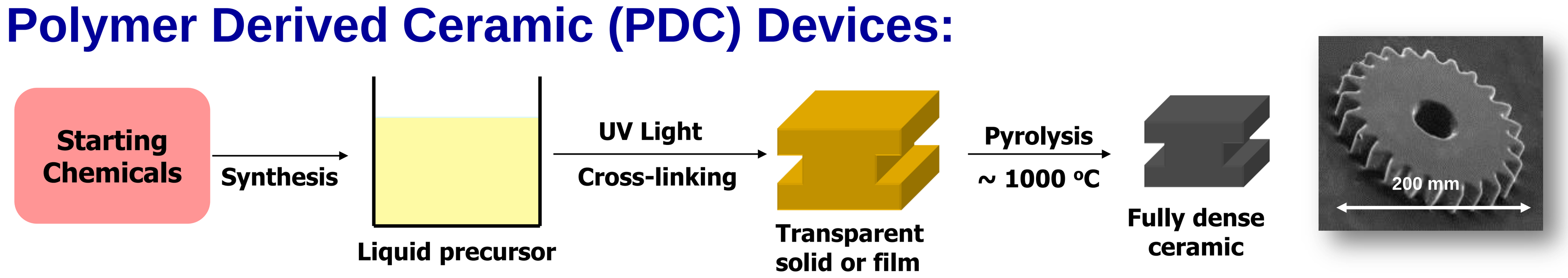
Example Aerospace Sensors



Sporian Core SiCN Sensor Technology

SiCN: A class of high-temperature ceramic materials synthesized by thermal decomposition of polymeric precursors, which possess excellent mechanical properties at high temperatures (up to 1800°C).

Polymer Derived Ceramic (PDC) Devices:

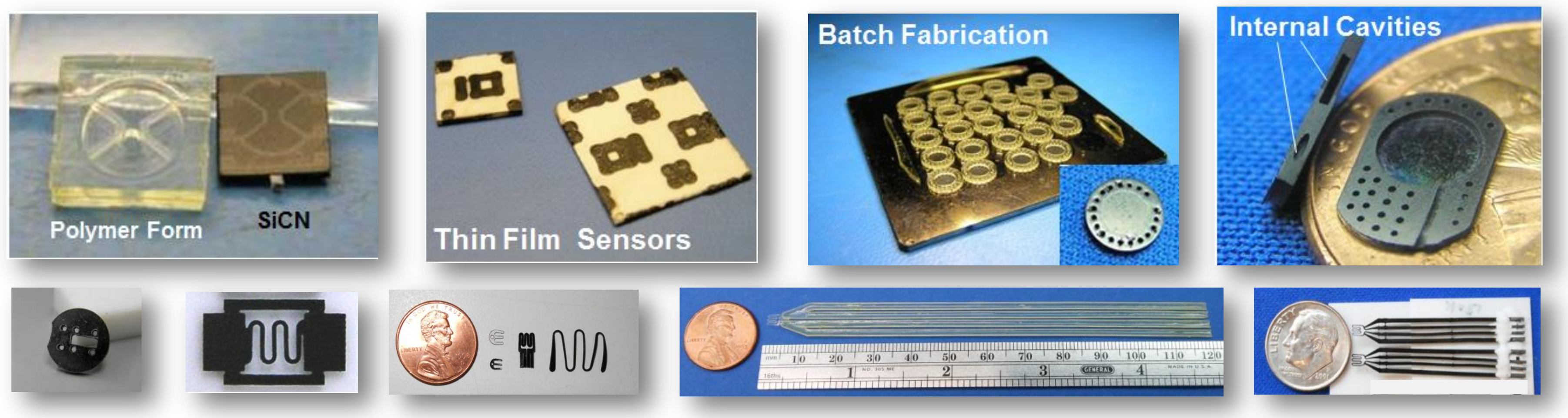


Key Benefits of SiCN as High-Temperature Sensor Materials:

- Doped SiCN can be thermally stable above 1400°C up to 1800°C
- Excellent high-temperature oxidation and corrosion resistance
- Excellent high-temperature thermo-mechanical properties and low creep
- Superior over advanced high purity SiC and Si_3N_4 ceramics
- Facilitate micro-fabrication of multi-layer and multi-material structures
- Take advantage of mature MEMS concepts to create sensor designs
- Tunable electrical properties: Insulator/semiconductor (10^{-8}-10^{4} $\Omega^{-1}cm^{-1}$)

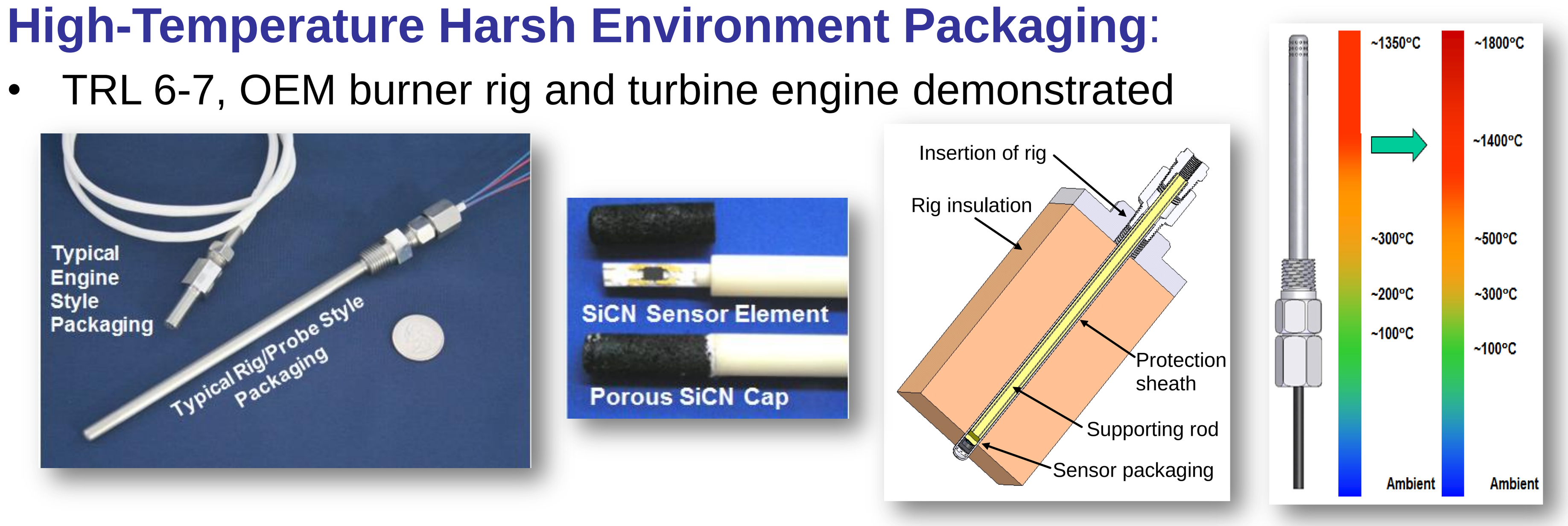
SiCN Based Sensor Elements and Devices:

- Temperature-pressure sensor suites, gas/liquid flow sensors



High-Temperature Harsh Environment Packaging:

- TRL 6-7, OEM burner rig and turbine engine demonstrated



Technology Development Supporters/Partners

Propulsion Instrumentation Working Group (PIWG), Pratt & Whitney (A United Technologies Company), NAVAIR, OAI (Ohio Aerospace Institute), Honeywell, GE, Boeing, Lockheed Martin, Air Force Research Laboratory, Rolls-Royce, Siemens, Williams International

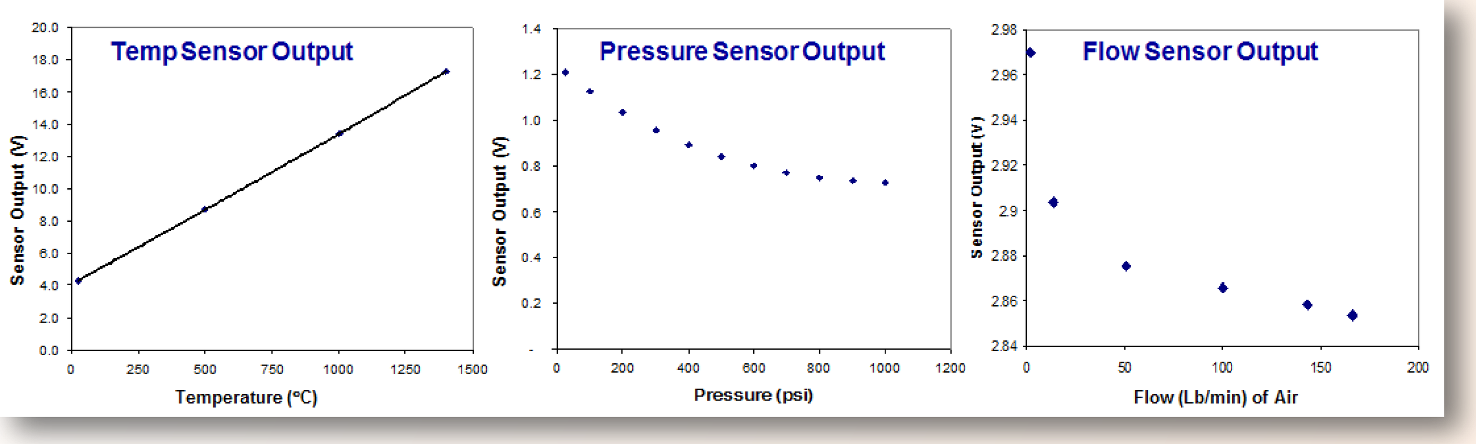
Acknowledgments: This and prior Sporian HT sensor development has been funded by the DOE under Award DOE12-14c

U.S. DEPARTMENT OF ENERGY

NETL

Current HT Sensor Technology

Specification	Target	Note
Pressure Range	25-750 psi	Atmosphere - 1000 psi (briefly 2500 psi)
Operation Temperature	700-1350°C	Air or combustion environment
Natural Frequency	> 100 kHz	Theoretical (Testing TBD)
Probe Length	1.25-3 inch	1-10 inch (Modifiable)
Sheath Diameter	<0.25 inch	≥.25 inch (Modifiable)
Temperature Compensation	Yes	Internal or External
Sensitivity/Combined Uncertainties	≤ 1% FS	Subject to effects of mounting hardware
Temperature Transient Measurement	Yes	Testing TBD



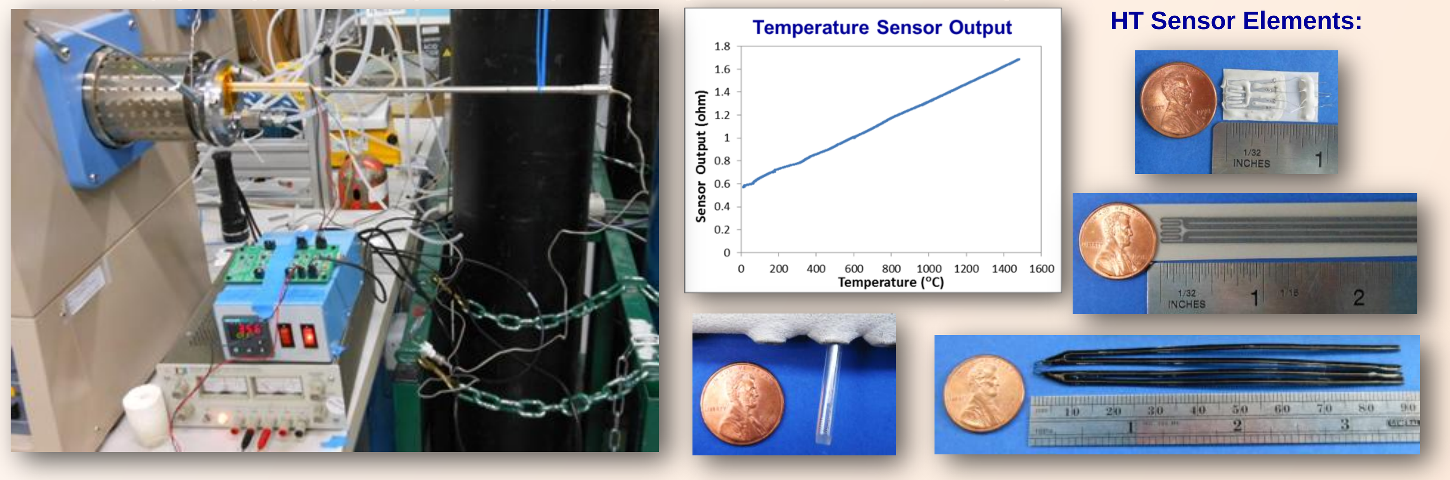
Features	Advantages	Benefits
Polymer derived ceramic materials	• Operating temperature >1000°C w/o liquid cooling or fiber routing • Highly oxidation/corrosion resistant • Thermal shock resistant • Low creep rate & diffusion rate	• Lower weight, smaller size • Lower cost, low-maintenance • Higher durability • Higher operational availability
Temperature/pressure sensor suite	Improved T-compensation of pressure measurements	• Lower weight, smaller size • Higher accuracy
Immersion sensing at source	• Eliminate stand-off tubes • Avoid tube moisture collection	• Lower cost, higher accuracy • Improved dynamic response
Electronics based	• Compatibility	• Lower cost

Recent Results from Project Efforts to Advance Use Temperature to 1800°C

- Optimizing SiBCN formulations for increased operational temperature range (1600-1800°C)

Sporian B-doped SiBCN	Beam	Film	Disk
Thickness	0.5mm	0.5mm	1 mm
Pyrolysis Weight Loss (%)	30%	45%	27%
Pyrolysis Linear Shrinkage (%)	26%	30%	25%
1400-1600°C Weight Loss (%)	4%	5%	2%
1400-1600°C Linear Shrinkage (%)	-4%	-2%	0%

- Development of hardware/packaging and electronics designs for advanced applications
- Prototyping/testing of higher operational temperature sensors



Planned/Future Effort/Activities

- Revise HT sensor and packaging designs, build higher level hardware for lab testing
- Demonstration of final prototypes in application relevant OEM testing systems (NETL, GE)