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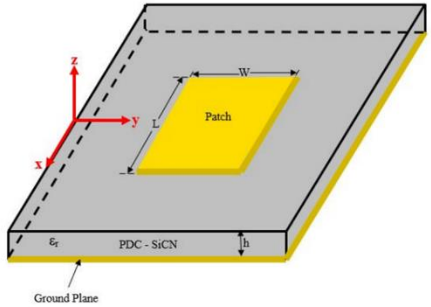
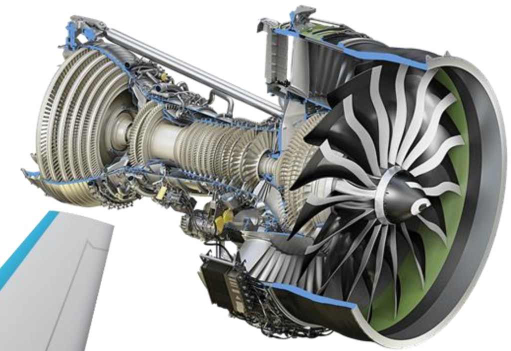
Wireless Passive Microstrip Patch Antenna Temperature Sensor in High-Temperature Applications

Dr. Cheryl Xu
Department of Mechanical and Aerospace Engineering
North Carolina State University
Raleigh, NC 27695



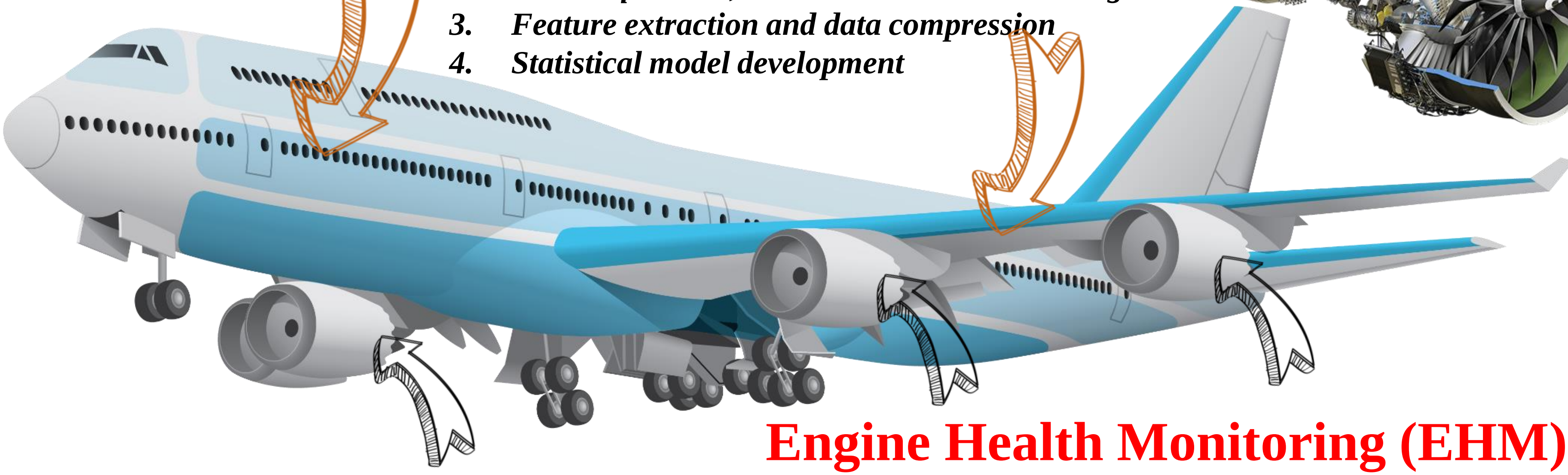
2019 Passive Wireless Sensor Technology (PWST) Workshop
Ottawa, Canada
October 16-18, 2019

Engine Health Monitoring (EHM)



Structural Health Monitoring (SHM)

1. *Operational evaluation*
2. *Data acquisition, normalization and cleansing*
3. *Feature extraction and data compression*
4. *Statistical model development*



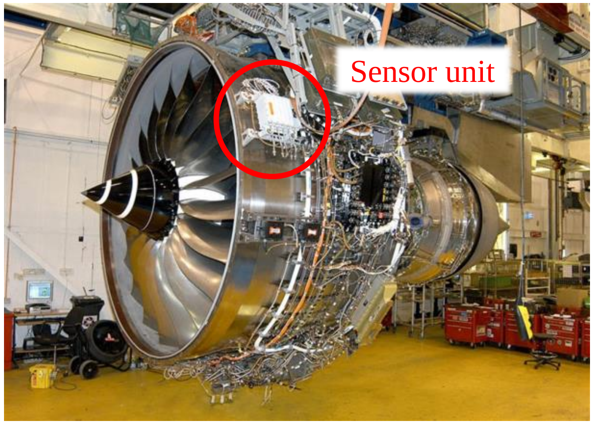
Engine Health Monitoring (EHM)

1. *APM (aircraft performance monitoring)*
2. *ECM (engine condition monitoring)*
3. *AHMS (auxiliary power unit APU health monitoring)*

Engine Accidents

Air France 380

Engine Health Monitoring (EHM)

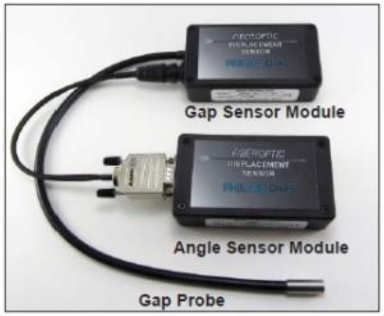


Engine Monitoring Unit on Trent 900 Engine

GE dynamic piezo Pressure sensor

Temperature sensor 1200C, Meggit SA.

750F accelerometer Endevco



Blade tip clearance sensor

Fuel flow sensor

Oil debris sensor

Wireless Passive High Temperature Sensors for Engine Health Monitoring

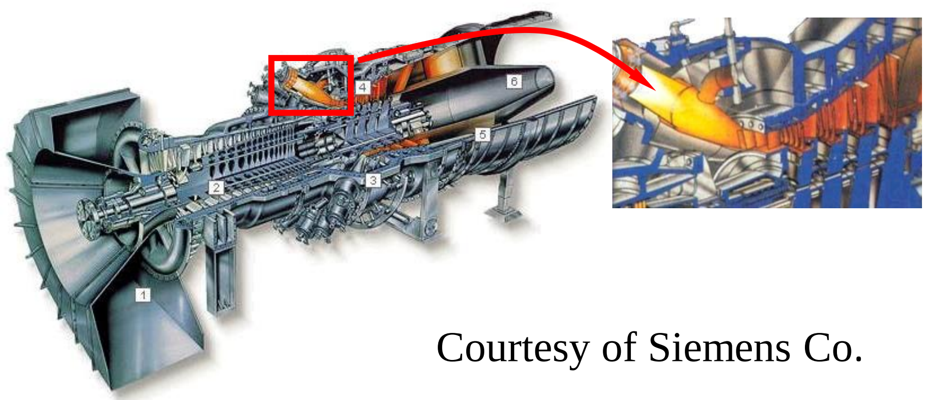
○ Extreme Environments:

- High temperature (> 1600^{o}C)
- High pressure (mechanical, gas, etc.)
- With oxidation, corrosion and/or radiation

Nozzle guide vane burned out

○ Applications:

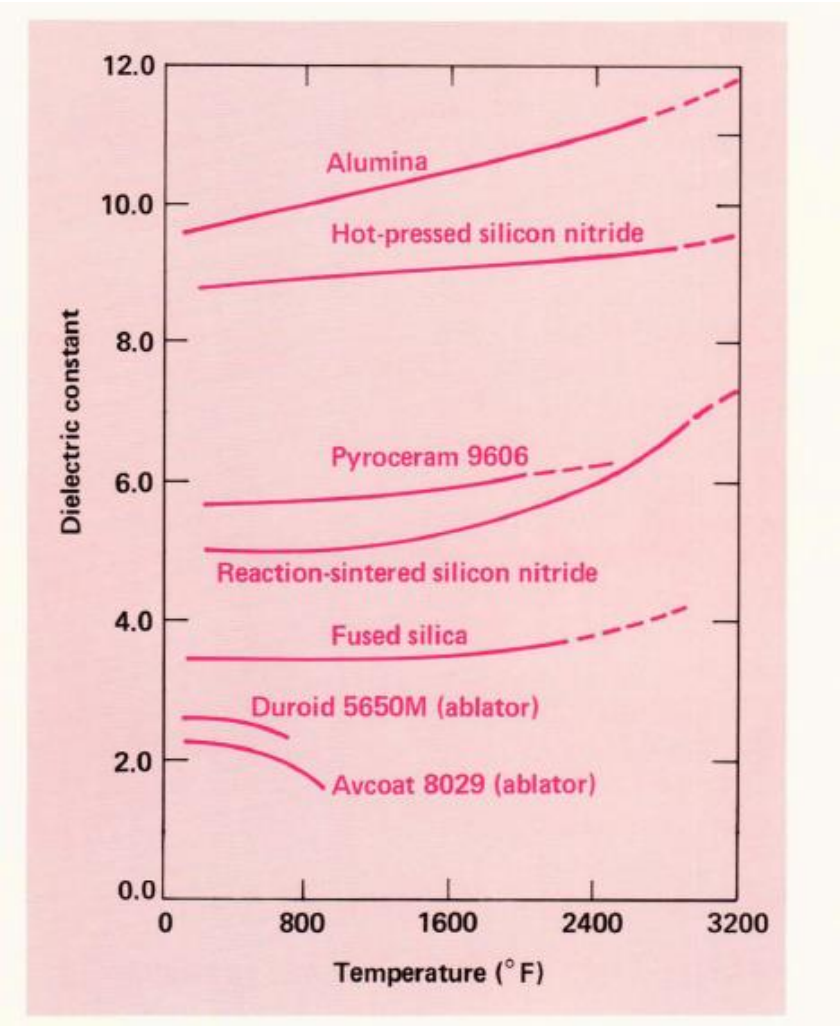
- Turbine engine: power generation; aerospace propulsion
- Nuclear reactors
- Hypersonic vehicles



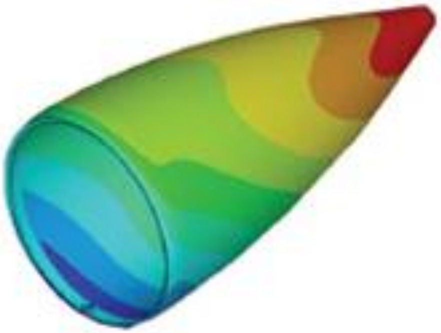
Courtesy of Siemens Co.

Thermal hotspot melt out

Technical Review: Typical High-Temp Dielectric Materials



"Tactical Missile Structures and Materials Technology" William C. Caywood, Robert M. Rivello, and Louis B. Weckesser

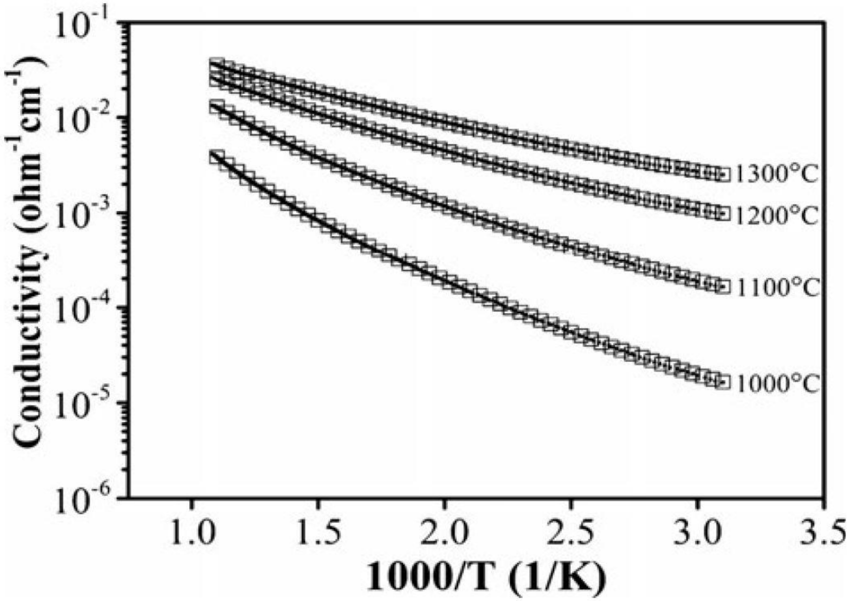


Representative CMC Radome Temperature Distribution

Materials Research & Design, Inc.

Effect of Processing Condition on Electrical/Dielectric Property

- Motivation:
  - Traditional manufacturing method – form crystal structure of SiC at about 1700°C.
  - Effect of processing temperature (e.g., 1000°C-2000°C) on its structural information and electrical/dielectric property has not been investigated.
- Effect of processing temperature on material properties:
  - Microstructural property
  - DC/AC conductivity
  - Permittivity, loss tangent
  - etc.



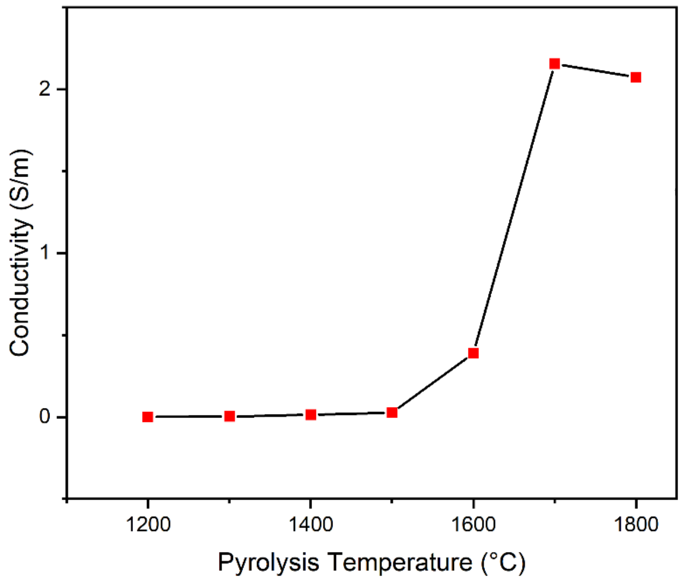
Temperature-dependent DC conductivity of the SiC processed at different pyrolysis temperatures

Wang, K., et. al., Journal of the American Ceramic Society, 98(7), 2153-2158, 2015.

- **Funded project**:
  - ARO - Effect of Pyrolysis Temperature on Electrical Properties of Polymer-Derived SiC Ceramics

Electrical Property

DC conductivity measured at room temperature

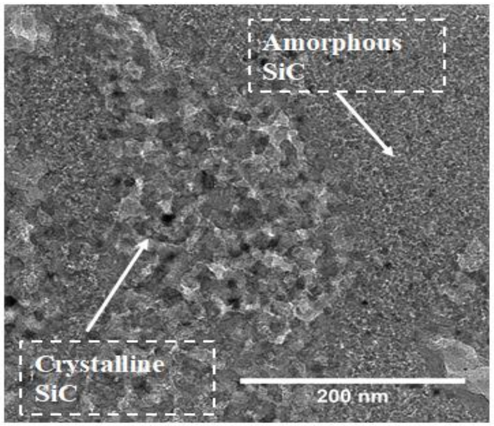


Pyrolysis Temperature (°C)	DC Conductivity ($S.cm^{-1}$) at 25°C
1200	1.9E-05
1300	2.53E-05
1400	1.34E-04
1500	2.65E-04
1600	3.89E-03
1700	2.1E-02
1800	2.0E-02

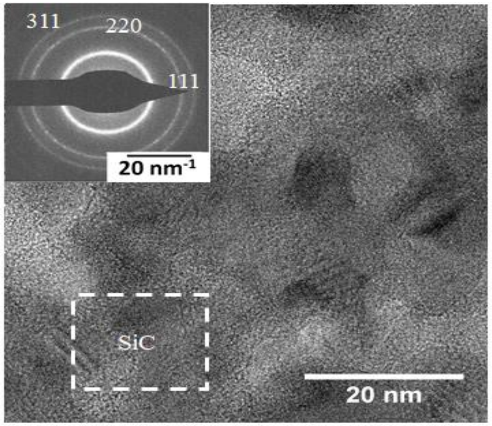
- The room temperature DC conductivity of PDC SiC increases **3 orders** of magnitude with increasing **pyrolysis temperature**.
- The jump in conductivity is observed above the pyrolysis temperature of **1500°C**

Structural Information

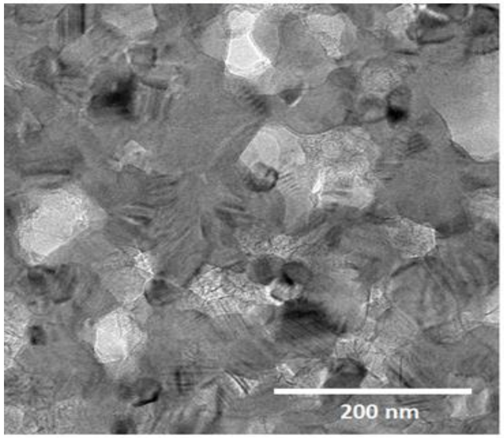
- Verification of formation of Turbostratic Carbon with TEM



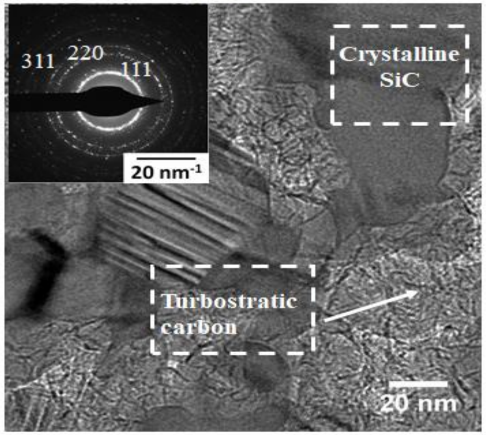
(a) 1500°C



(b) 1500°C



(c) 1700°C



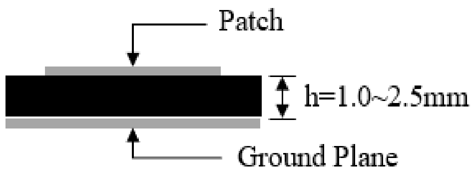
(d) 1700°C

- In the 1500°C pyrolyzed sample, both isolated crystalline grains, the amorphous phase of SiC is observed
- The carbon cluster is still very small to be detected in the matrix
- The excessive grain growth observed at 1700°C shows the concentration of the network of carbon is high near the grain boundary of SiC

Wireless Sensing Mechanisms (Microstrip Antenna)

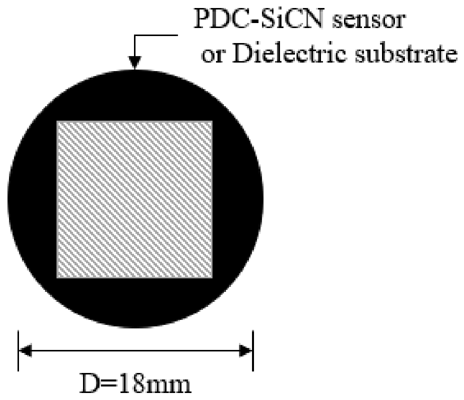
○ Sensor Components:

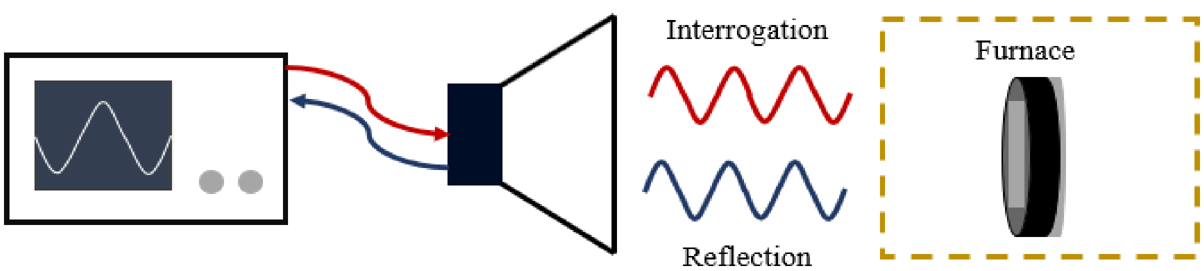
- Sensing material: PDC-SiCN or PDC-SiC
- Patch and ground plane: carbon paste; platinum paste, etc.

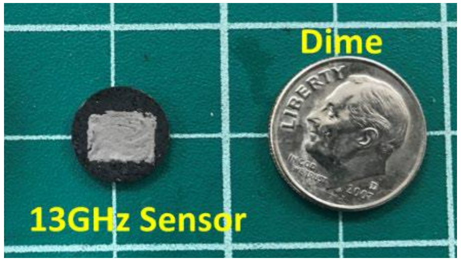


○ Sensing Mechanisms:

- Monotonic relationship between substrate's dielectric constant with ambient testing temperature/pressure.
- At different testing temperatures/pressures, resonant frequency shifts.





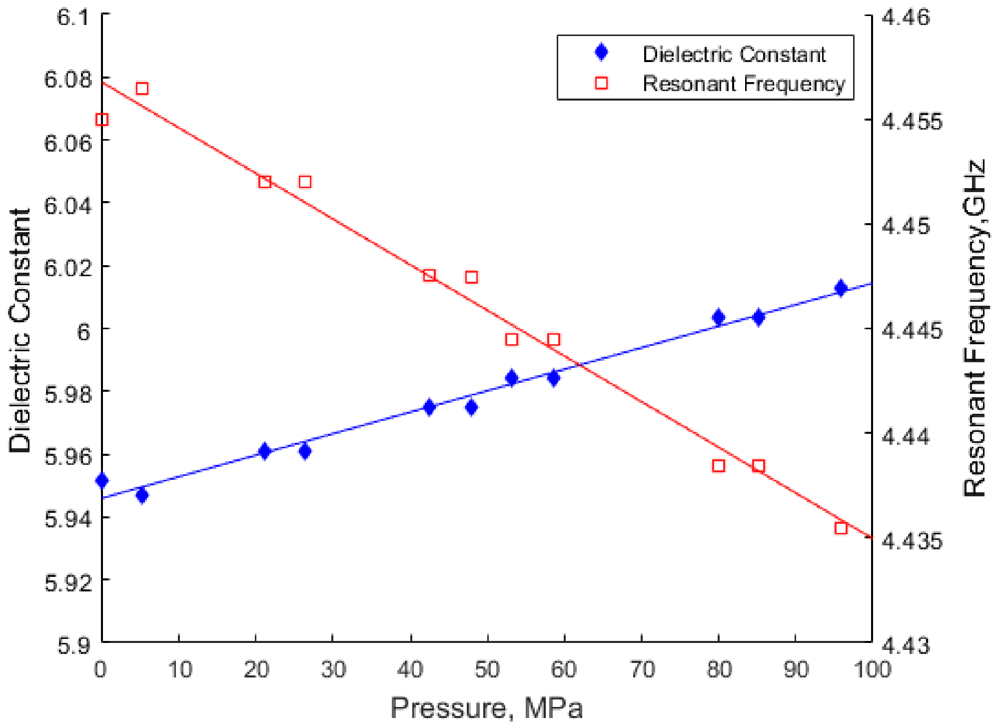


Vector Network Analyzer **Horn Antenna** **Patch Antenna Sensor**

Measurement Results for Wireless Pressure Sensing

○ Amorphous Polymer-derived Ceramics (PDCs):

- Remarkable thermal stability
- High oxidation resistance
- Thermal shock resistance
- Zero creep behavior (up to 2000^{o}C)

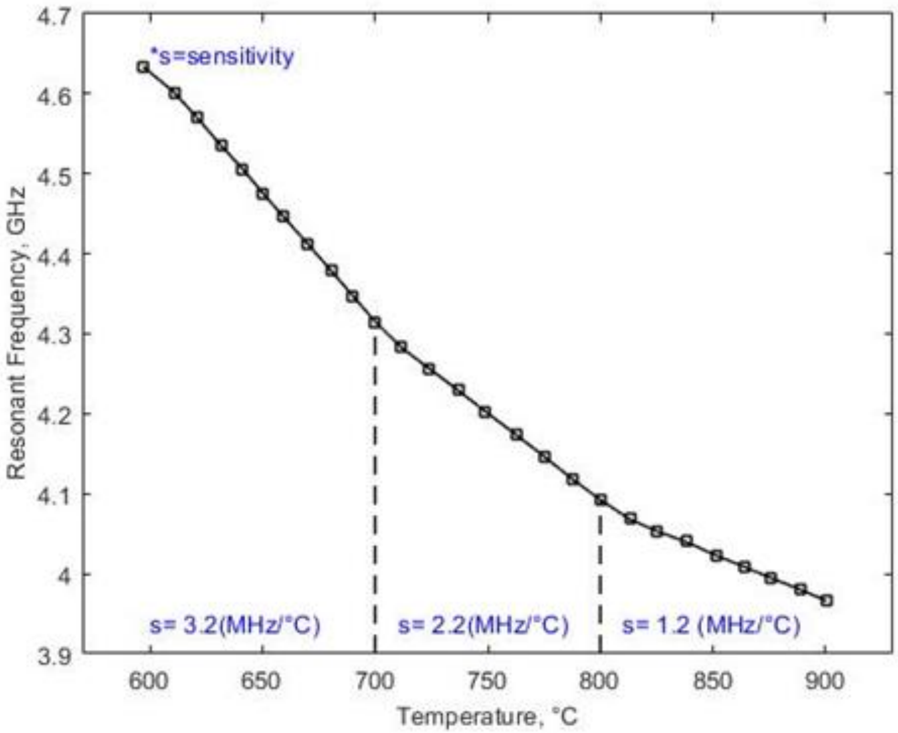


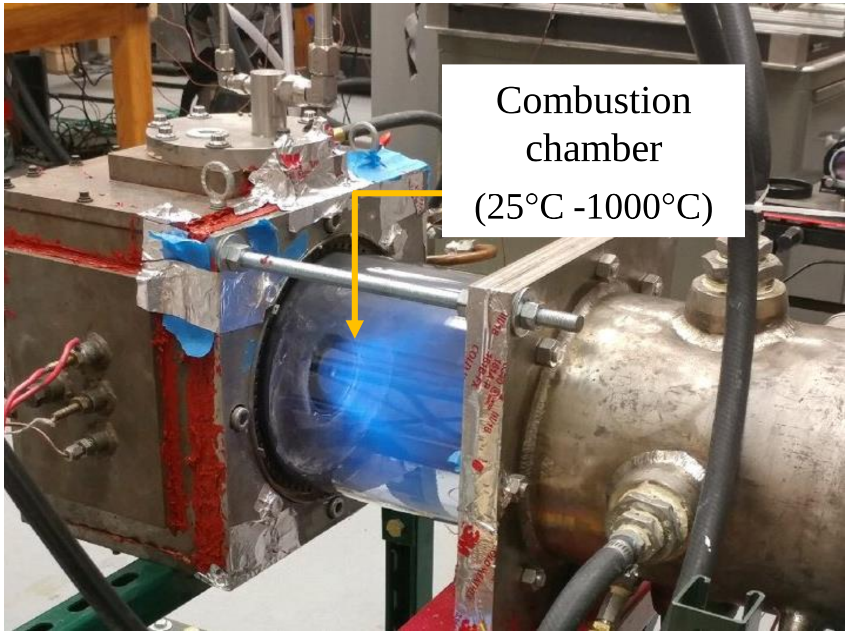
○ Multi-functional Properties:

- Semiconductor property
- Piezo-dielectricity
- photoluminescence

- Zhao, R., Shao, G., Li, N., Xu, C. and An, L. (2016). Development of A Wireless Temperature Sensor Using Polymer-Derived Ceramics. Journal of Sensors, Article ID 8624817.
- Cheng, H., Shao, G., Ebadi, S., Ren, X., Harris, K., Liu, J., Xu, C., An, L. and Gong, X. (2014). Evanescent-Mode-Resonator-Based and Antenna-Integrated Wireless Passive Pressure Sensors for Harsh-Environment Applications. Sensors and Actuators: A. Physical, 220, 22-33.
- Xun, G., An, L. and Xu, C., (2012). Wireless passive sensor development for harsh environment applications. IEEE International Workshop on Antenna Technology, 140-143.

Measurement Results for Wireless Temperature Sensing



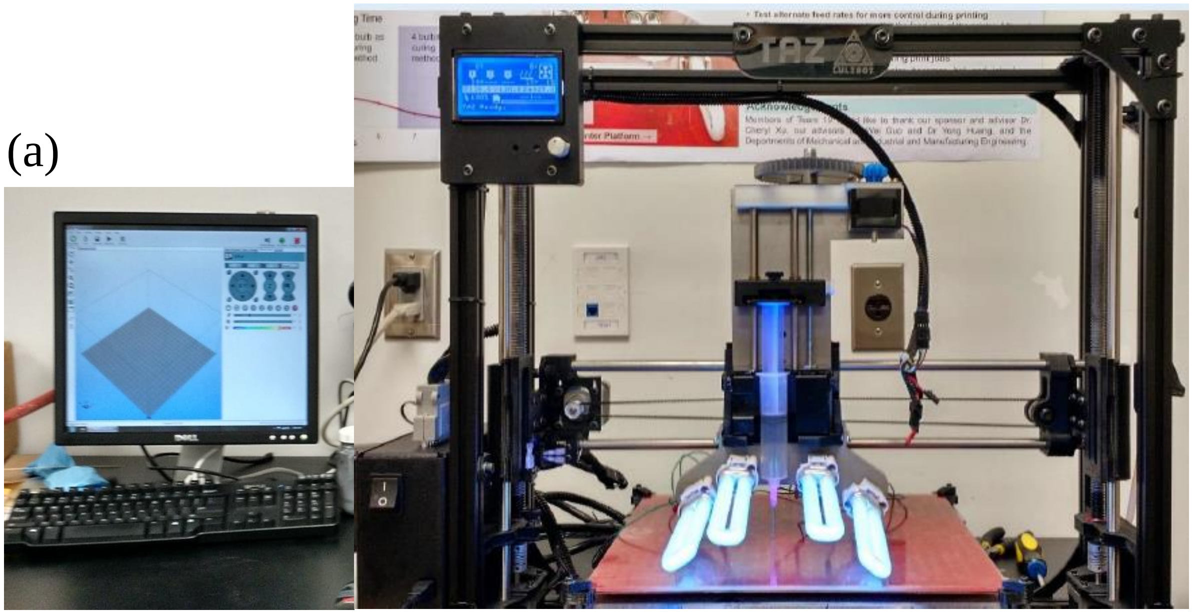


○ Achieved Experimental Results:

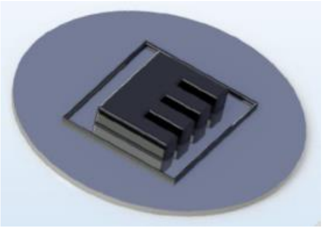
- Maximum temperature measured: 1000°C
- Maximum pressure measured: 135 MPa
- Wireless sensing distance: 0.5 meters

Additive Manufacturing of PDC Wireless Sensors

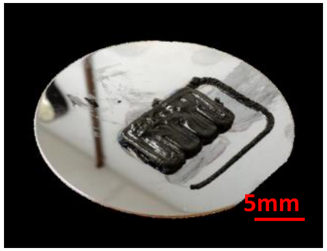
(a)



(b)



(c)



(d)

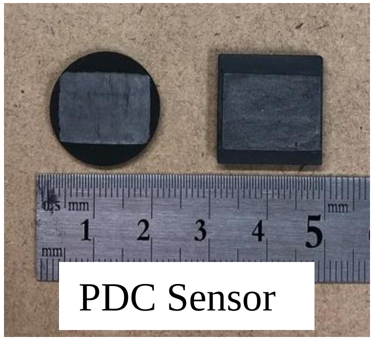


Figure. (a) Experimental setup; (b) CAD model of a sample part; (c) Actual 3D-printed part. (d) Manufactured wireless passive sensors.

Summary

- Wireless Temperature Sensor:
  - Wireless measurement distance: 0.5 meter
  - Temperature measurement range: 25°C - 1000°C
  - Resonant frequency range: 2.6 – 5.2 GHz
  - Temperature measurement sensitivity: 2.67 MHz/°C

- Wireless Pressure Sensor:
  - Wireless measurement distance: 0.5 meter
  - Current maximum pressure measured: 135 MPa

- Next step plan:
  - Test performance on a metallic surface, such as metallic turbine blade/vane
  - Conformal antenna design
  - Simultaneous measurement of temperate and pressure

Thank you for your attention!