Wireless, Passive Ceramic Strain Sensors for Turbine Engine Applications

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Outline

- Motivation
- Strain Sensors - State of the Art
- Objectives
- Schedule and timelines
- Accomplishment
- Future Work
- Summary

Motivation – applications of turbines

- Turbine engines – key for energy generation and propulsion

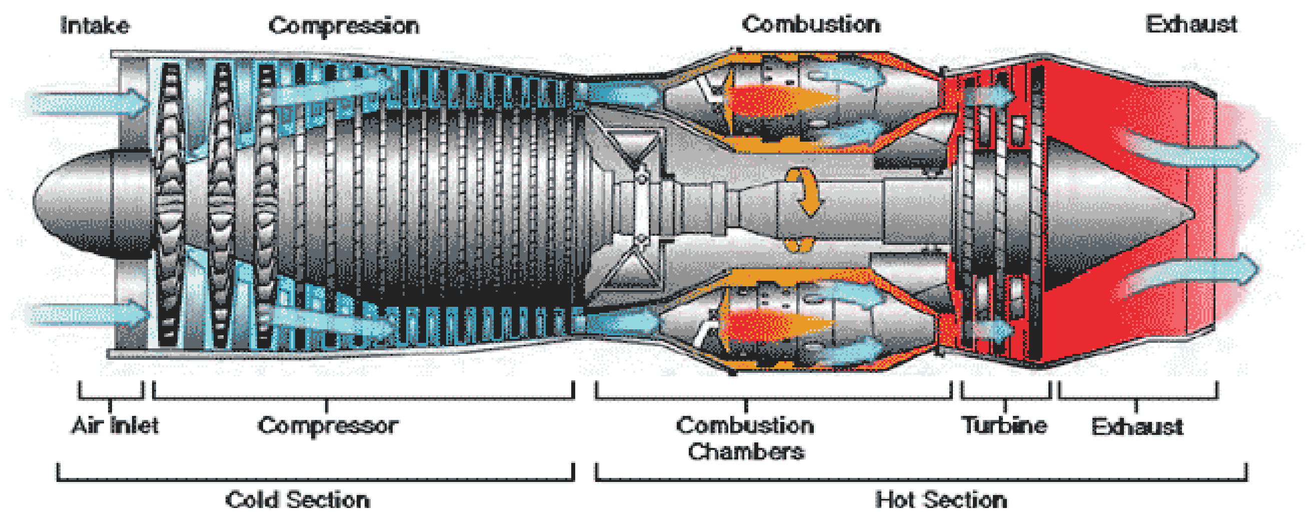
Description	2007
Net Generation (thousand megawatthours)	
Coal[1]	2,016,456
Petroleum[2]	65,739
Natural Gas	896,590
Other Gases[3]	13,453
Nuclear	806,425
Hydroelectric Conventional[4]	247,510
Other Renewables[5]	105,238
Wind	34,450
Solar Thermal and Photovoltaic	612
Wood and Wood Derived Fuels[6]	39,014
Geothermal	14,637
Other Biomass[7]	16,525
Pumped Storage[8]	-6,896
Other[9]	12,231
All Energy Sources	**4,156,745**

>70%

2007 Energy Generation Statistics (DOE)

Motivation – need for wireless strain sensors

- Parts subjected to severe strain/stress in extreme environments
- Moving parts/hidden areas – need wireless
- High temperatures – need passive
- Predict the failure
- Reduce unnecessary out-of-service examination and replacement



Strain sensors-State of the Art

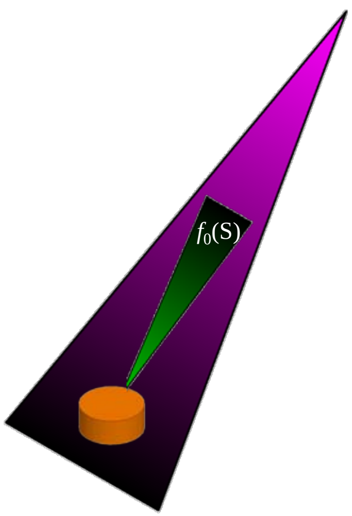
- Optical-Based Non-Contact Sensors
  - Lack of necessary accuracy
  - Not robust in harsh environments
- Strain gage
  - Piezoresistivity – changes in resistivity with strain/stress
  - Cannot be wireless
- Piezoelectric based load cell
  - Can be wireless
  - Piezoelectric materials cannot be used to high temperatures
  - Need power source
- Capacitive based pressure sensor
  - Can measure pressure induced strain/stress
  - Cannot measure parts strain/stress

Objectives

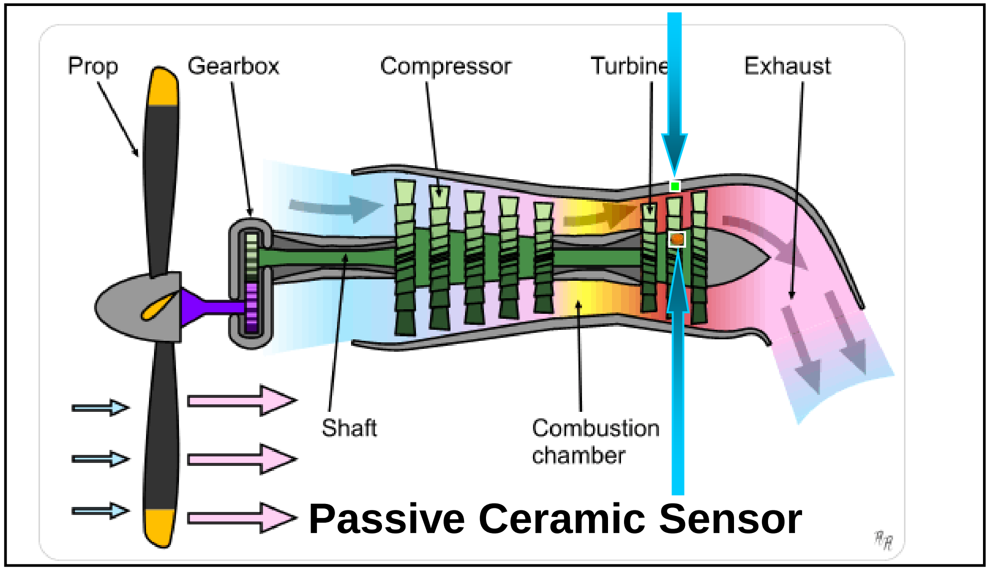
- Overall Objective

  Develop RF resonator-based wireless passive polymer-derived ceramic strain/stress sensors

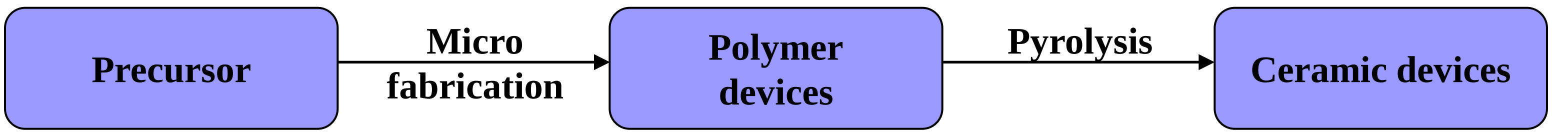
- Scientific Goals
  - Develop piezo-dielectric polymer-derived ceramics (p-PDCs)
  - Design and fabricate resonator sensors
  - Characterize the sensors in extreme environments



Passive Ceramic Sensor



Background – polymer-derived ceramics

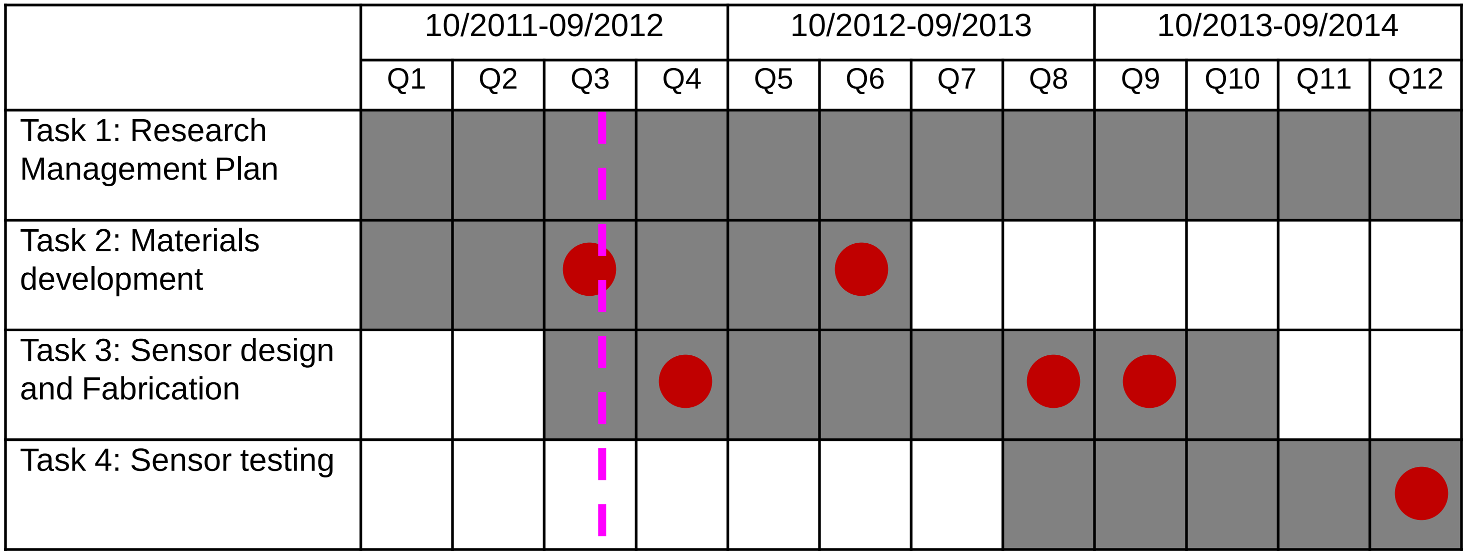


- Excellent high-temperature resistance
  - High thermal stability
  - High oxidation/corrosion resistance

- Microfabrication capability

- Unique electric/dielectric behavior
  - Resistivity varied in a large range
  - High piezoresistivity
  - High piezo-dielectricity

Schedule and Timeline



Milestone	Planned Completion Date	Verification Method
1: Finish room temperature material selection	06/30/2012	
2: Finish first run of sensor design	09/31/2012	
3: Finish final material selection	03/31/2013	
4: Finish final sensor design	09/31/2013	
5: Sensor fabrication	12/31/2013	
6: Sensor characterization	09/30/2014	

Accomplishments

- Material synthesis
  - Precursor synthesis

Name	MA	ASB	819	VL20	PVN
S-1	2 wt%	5 wt%	5 wt%	78 wt%	10 wt%
S-2	2 wt%	5 wt%	5 wt%	68 wt%	20 wt%
S-3	2 wt%	5 wt%	5 wt%	58 wt%	30 wt%
S-4	2 wt%	10 wt%	5 wt%	53 wt%	30 wt%
S-5	2 wt%	20 wt%	5 wt%	43 wt%	30 wt%

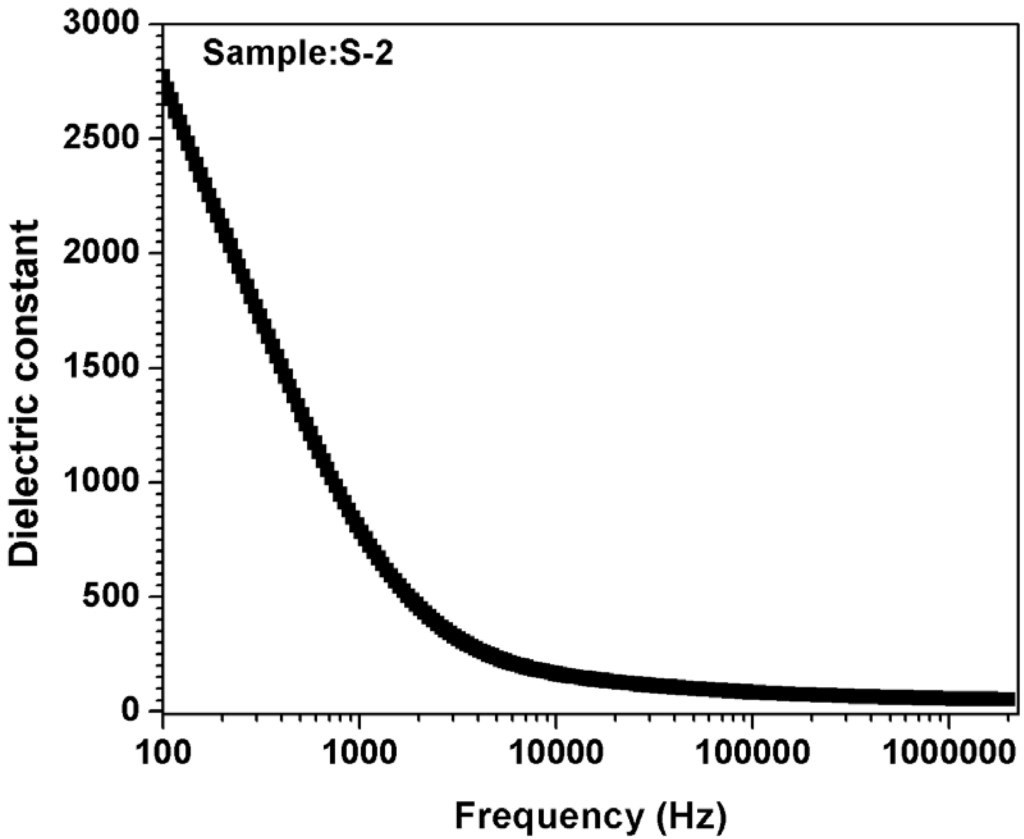
- **Polysilazane (VL20) – main precursor**
- **Phenylbis (2, 4, 6-trimethylbenzoyl) phosphine oxide (819) -- photo initiator**
- **Methacrylic Acid (MA) – photo enhancer**
- **Aluminum-tri-sec-butoxide (ASB) – precursor for aluminum)**
- **Poly (melamine-co-formaldehyde) acrylated solution (PVN) – precursor for nitrogen)**

  - Precursor synthesis

Samples obtained at 1000, 1100, 1200 and 1300°C for each composition

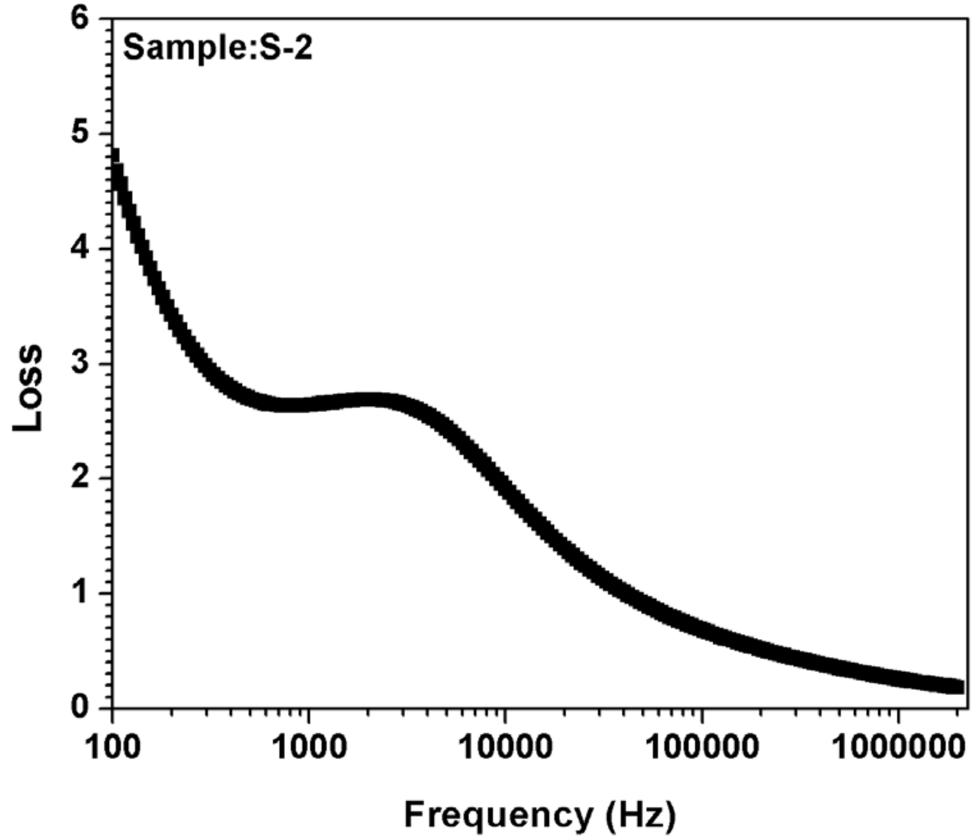
Accomplishments

- Property characterization
  - Frequency-dependent dielectric constant



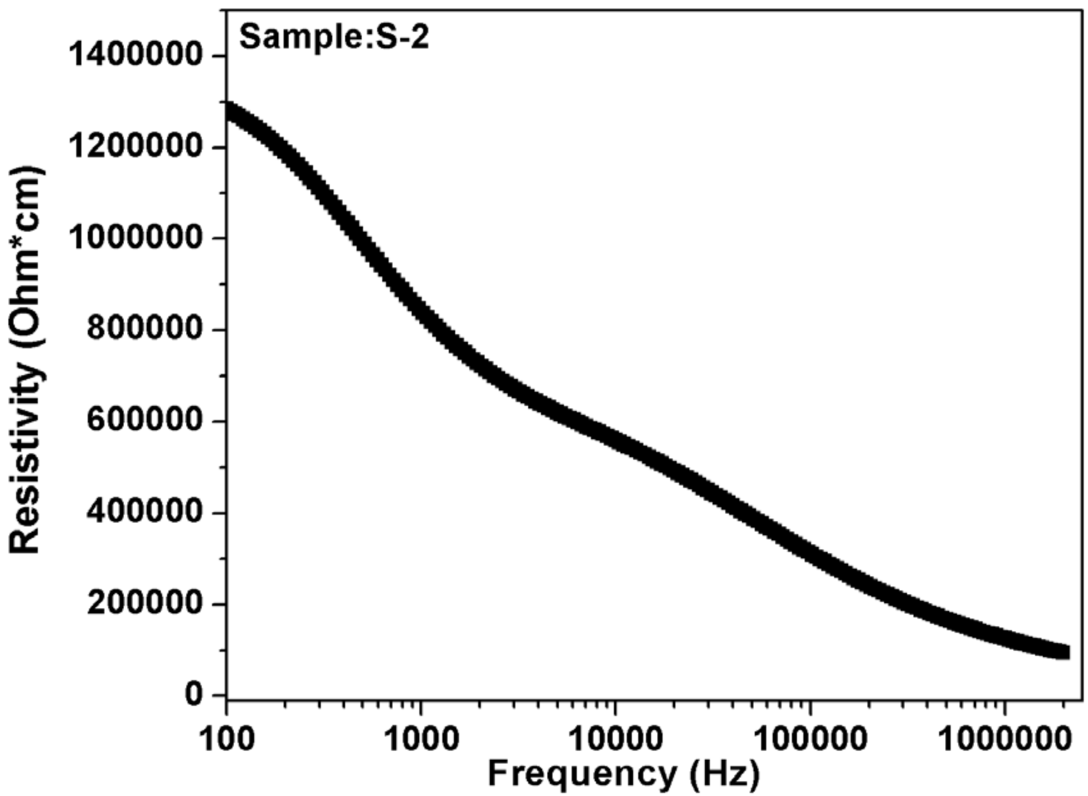
Accomplishments

- Property characterization
  - Frequency-dependent dielectric loss



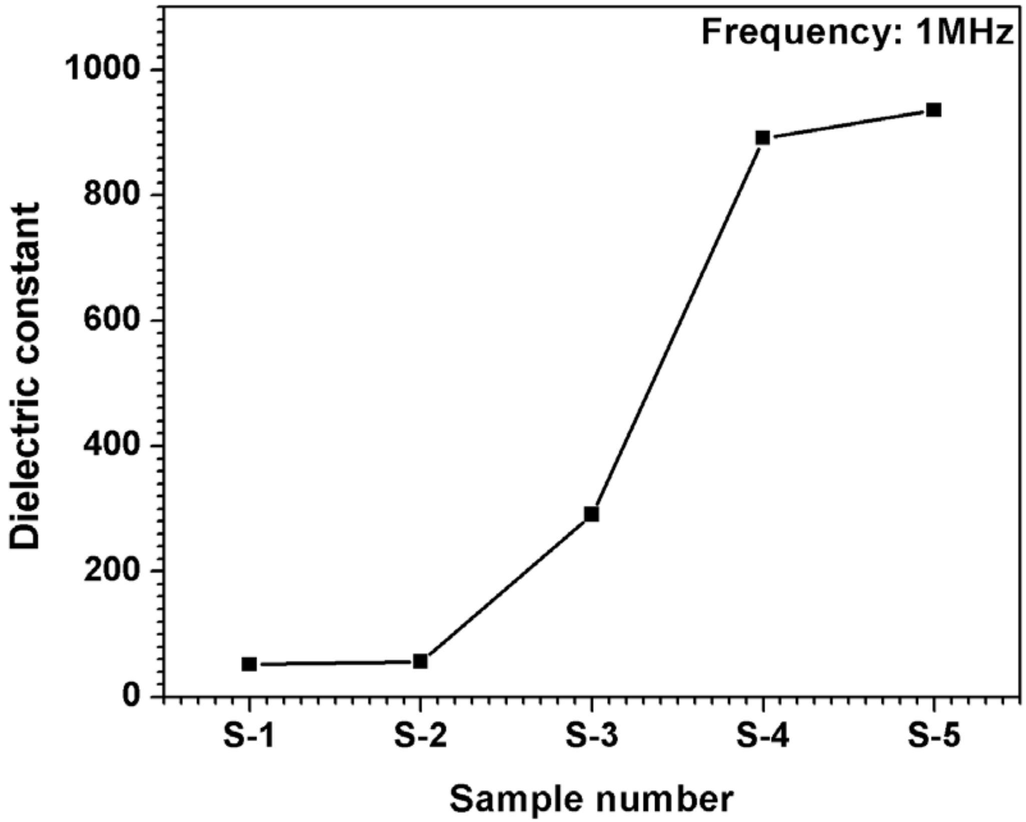
Accomplishments

- Property characterization
  - Frequency-dependent resistivity



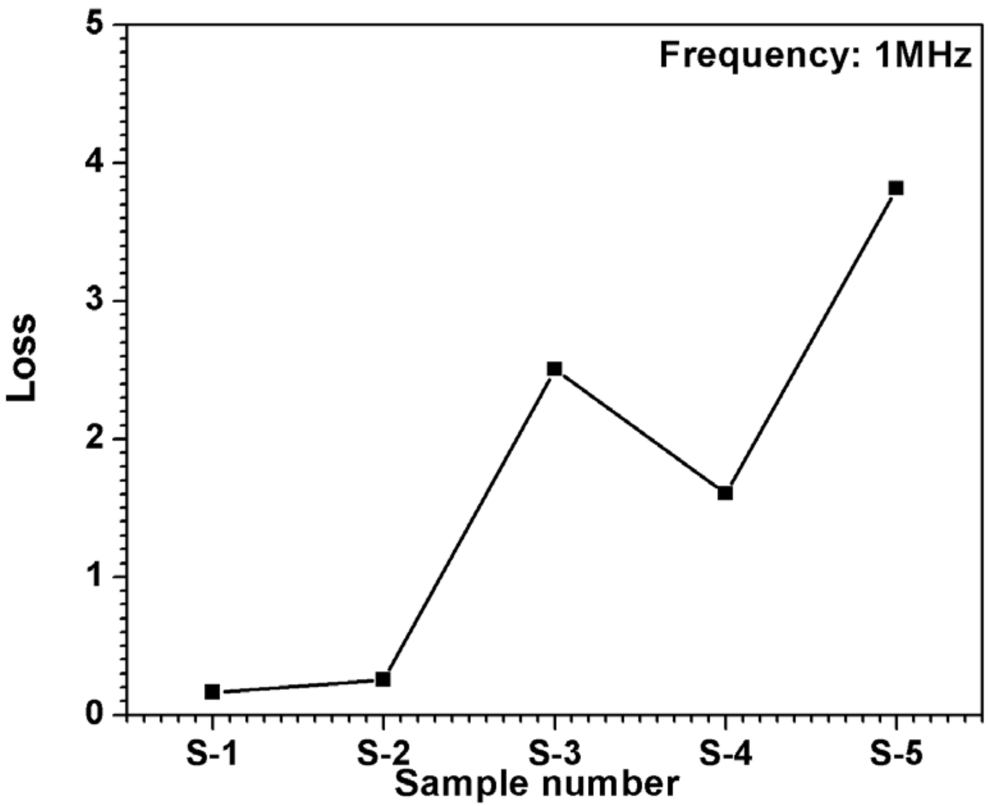
Accomplishments

- Property characterization
  - Comparison of dielectric constant



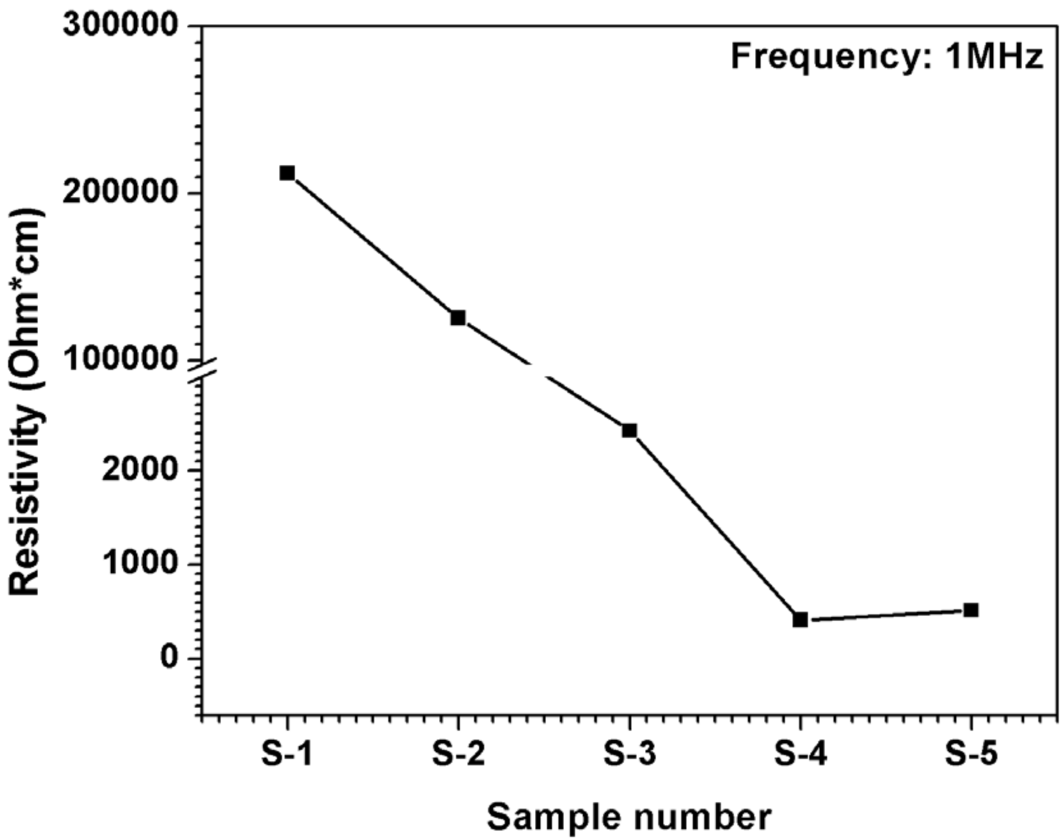
Accomplishments

- Property characterization
  - Comparison of dielectric loss



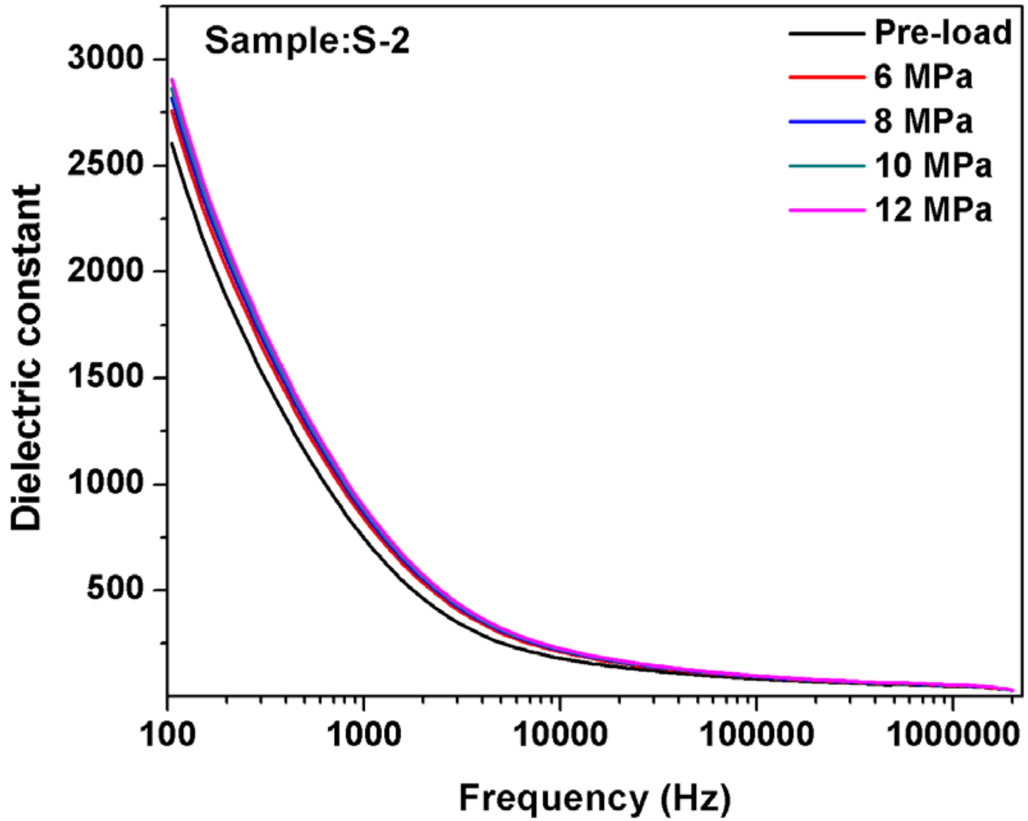
Accomplishments

- Property characterization
  - Comparison of resistivity



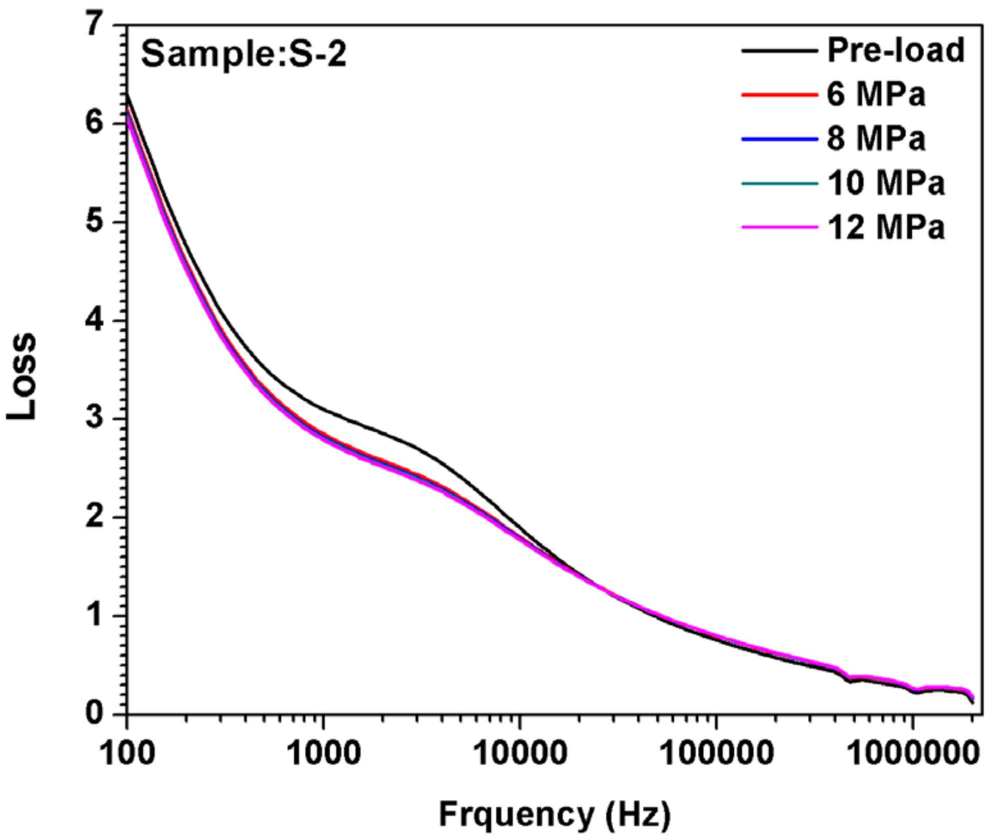
Accomplishments

- Property characterization
  - Pressure-dependent dielectric constant



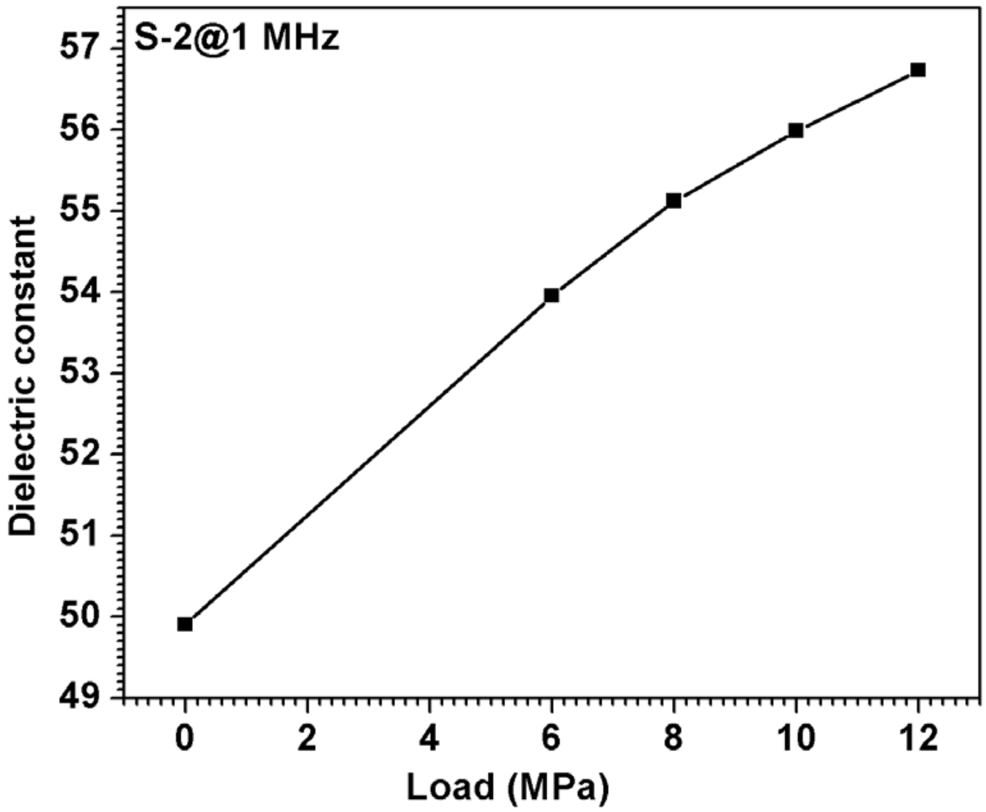
Accomplishments

- Property characterization
  - Pressure-dependent dielectric loss



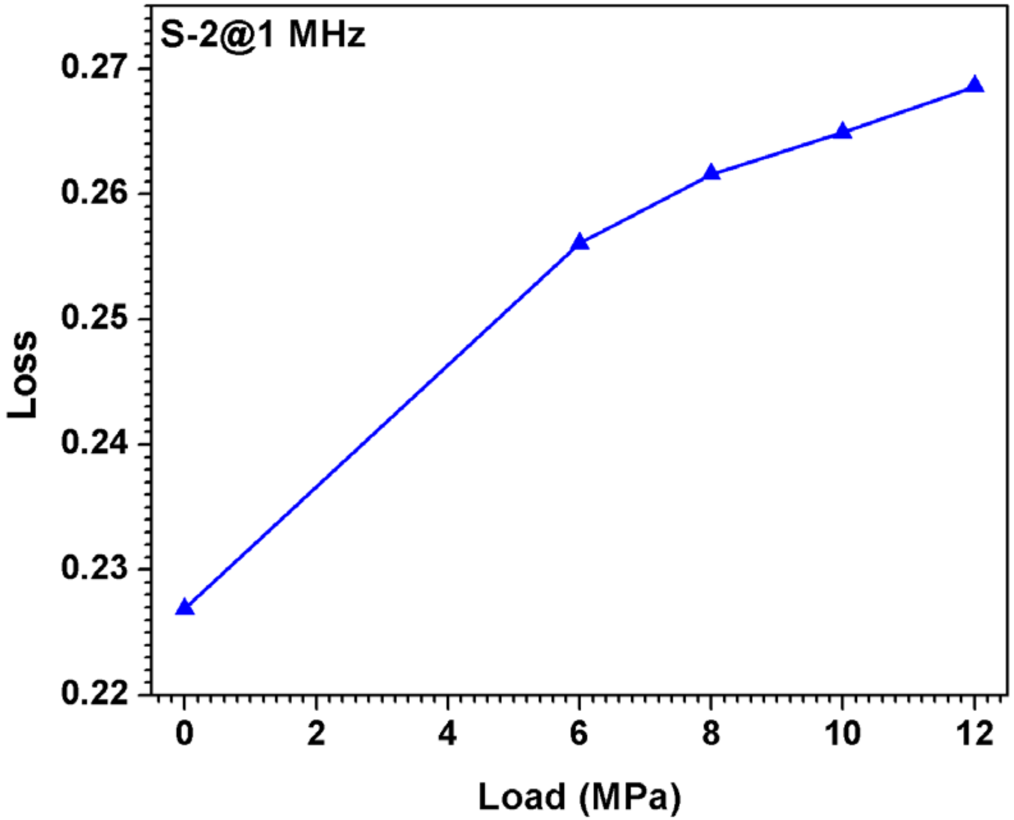
Accomplishments

- Property characterization
  - Comparison of dielectric constant



Accomplishments

- Property characterization
  - Comparison of dielectric loss



Future work

- Material development
  - Finalize room-temperature material characterization
  - Design, synthesize and characterize optimal materials
- Design and fabricate sensors
  - Design the resonator based strain sensors
  - Fabricate the designed sensors
- Sensor characterization
  - Pack the sensor for testing
  - Test the sensors in different temperatures

Summary

- Polymer-derived ceramics possess necessary properties for making wireless, passive strain/stress sensors for high-temperature applications.
- We have finished materials synthesis and have started material property characterization.
- Our preliminary results showed that the dielectric properties of PDCs can be tailored in a large range.
- The dielectric constant varied significantly with applied stress, indicating the sensor could have very high sensitivity.
- The R&D progress follows the proposed schedule.