UNIVERSITY OF CENTRAL FLORIDA

FROM PROMISE TO PROMINENCE
CELEBRATING 40 YEARS

Developing Piezo-Dielectric Polymer-Derived Ceramics For Wireless Strain Sensor Applications

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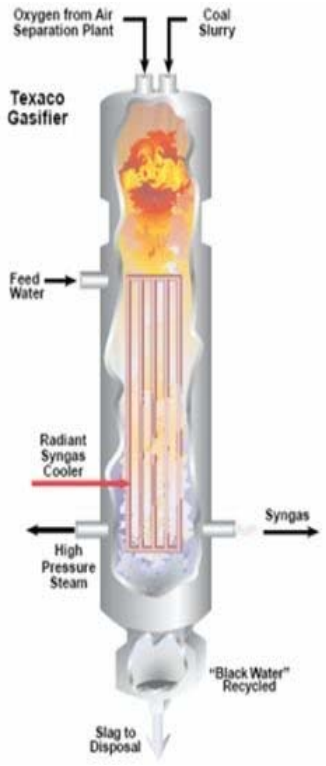
Outline

- Introduction
  - Needs
  - Current state
- Developing polymer-derived ceramics
  - Introduction to PDCs
  - Dielectric properties of SiAlCN
- Sensor design and fabrication
  - Effect of sensor dimension on sensor performance
  - Sensor fabrication
- Summary and Future work

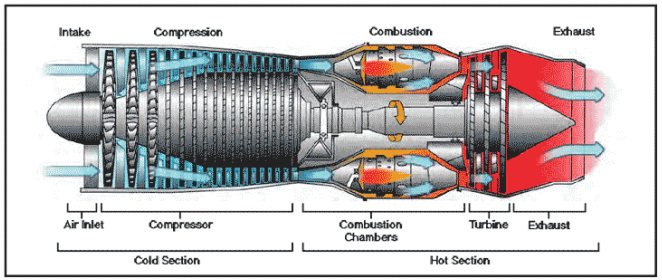
Introduction: Needs

- **Physical sensors**
  - Temperature
  - Heat flux
  - Pressure
  - Strain/stress
  - Shear
  - Flow rate
  - Vibration
  - .....
- **Chemical sensors**
  - Gas
  - .....

- **Feedback control**
  - Improve efficiency
  - Reduce pollution
- **Health monitoring**
  - Improve safety
  - Reduce maintenance cost
- **Design optimization**
  - Improve efficiency
  - Reduce cost



Gasification



Turbine for power generation/propulsion

Material manufacturing

Introduction: Current State

Environments:

- High-temperature
- High-pressure
- Corrosive
- Radiation
- ……..

Desires:

- Long-term
- High accuracy
- Passive/wireless
- ……..

- Silicon, polymer-composite based sensors
- Silicon carbide based sensors
- Optical based sensors

Future:

- Materials
  - High-temperature survivability
  - Piezo-dielectricity
  - Microfabrication
- Sensor design
- Fab. and packaging
- Signal access/process
- ……..

Materials

Sensor design

Signal processing

Packaging

Introduction: Passive Wireless Sensors

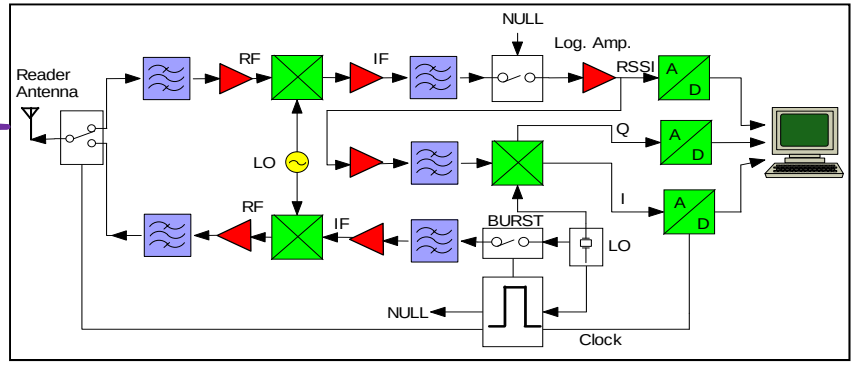
- New sensor concept developed at UCF, leading by Dr. Gong
- Principle: RF cavity based resonator
- Polymer-deriv

Can we develop a PDC with piezo-dielectricity (permittivity varied with pressure) and very low loss?

$$f_R \propto \frac{1}{\sqrt{\varepsilon(T)}}$$

requency

Wide band
RF wave



We have demonstrated a temperature sensor that can work at temperatures up to 1300°C

PDCs: Processing

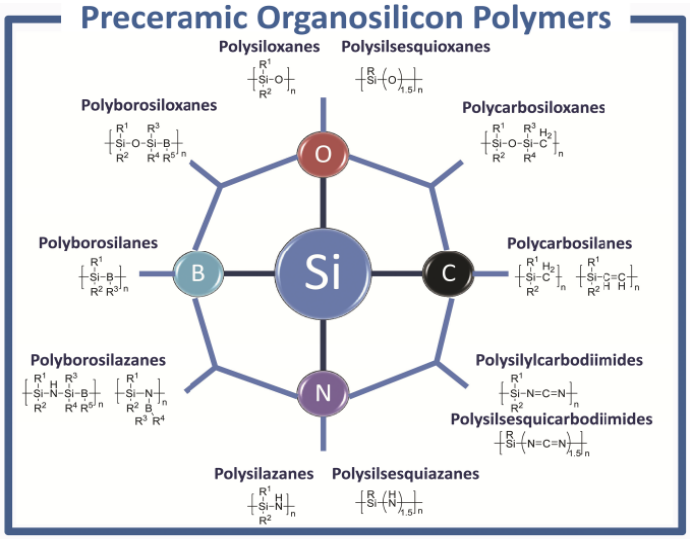
Starting materials → **Chemical synthesis** → **Polymer precursor**

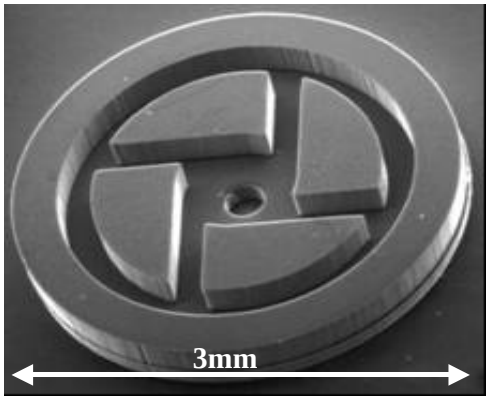
Cross linking → **Infusible preceramic network** → **Pyrolysis** (**800-1000°C**) → **Amorphous Ceramics**

Heat at high temp. → **Polycrystalline Ceramics**

Advantages

- ✓ Unique properties
- ✓ Flexible manufacturing
- ✓ Multi-scale material manipulation





PDCs: Properties

❖ Excellent high-temperature structural properties

o Excellent thermal stability

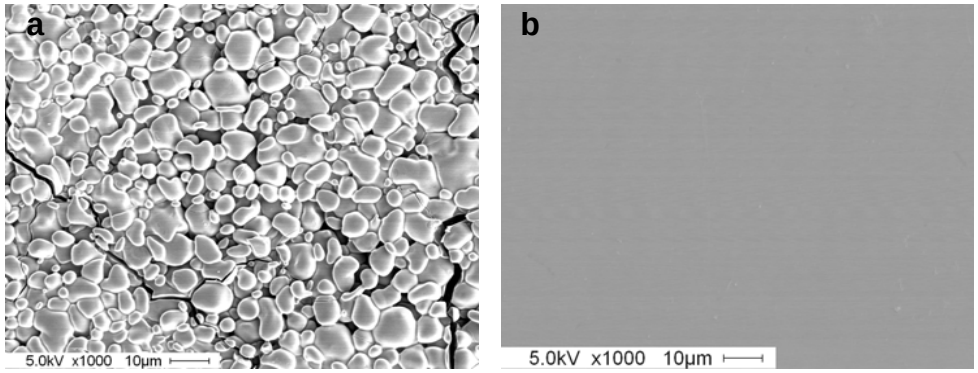
- PDCs can be stable up to 1800-2200^{o}C against decomposition and crystallization

o Excellent mechanical behavior

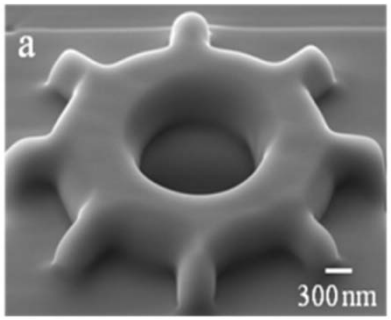
- Creep resistance of PDCs can be higher than polycrystalline SiC/Si_3N_4
- Excellent high-temperature strength and Elastic modulus

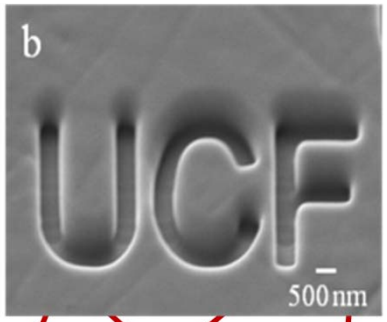
o Excellent oxidation/corrosion resistance

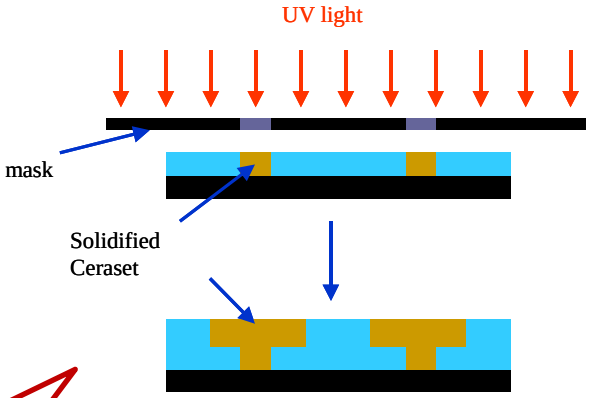
- Oxidation rate of PDCs is more than 10 times lower than conventional silicon based materials
- Corrosion rate of PDCs is about 10 times higher than silicon based materials
- Excellent strength retention

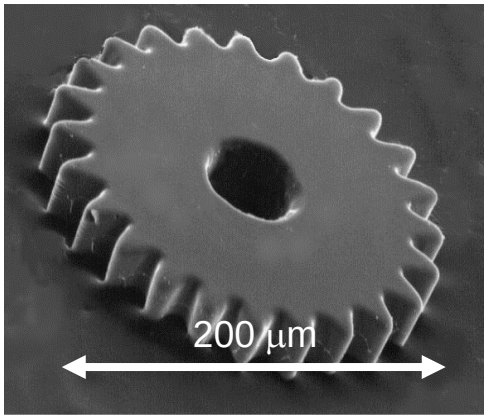


PDCs: Microfabrication Capability

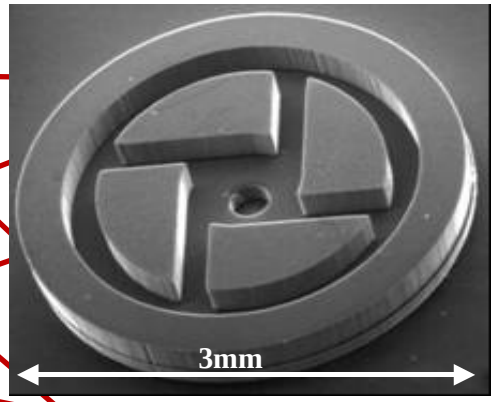


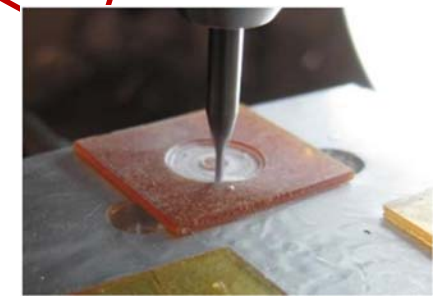


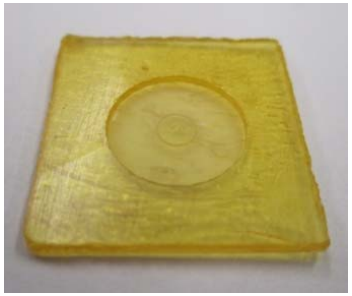




- Lithography
- Micro-casting
- Electric-pan direct writing
- Spin-on thin/thick film
- Mechanical machining
- FIB nano-machining





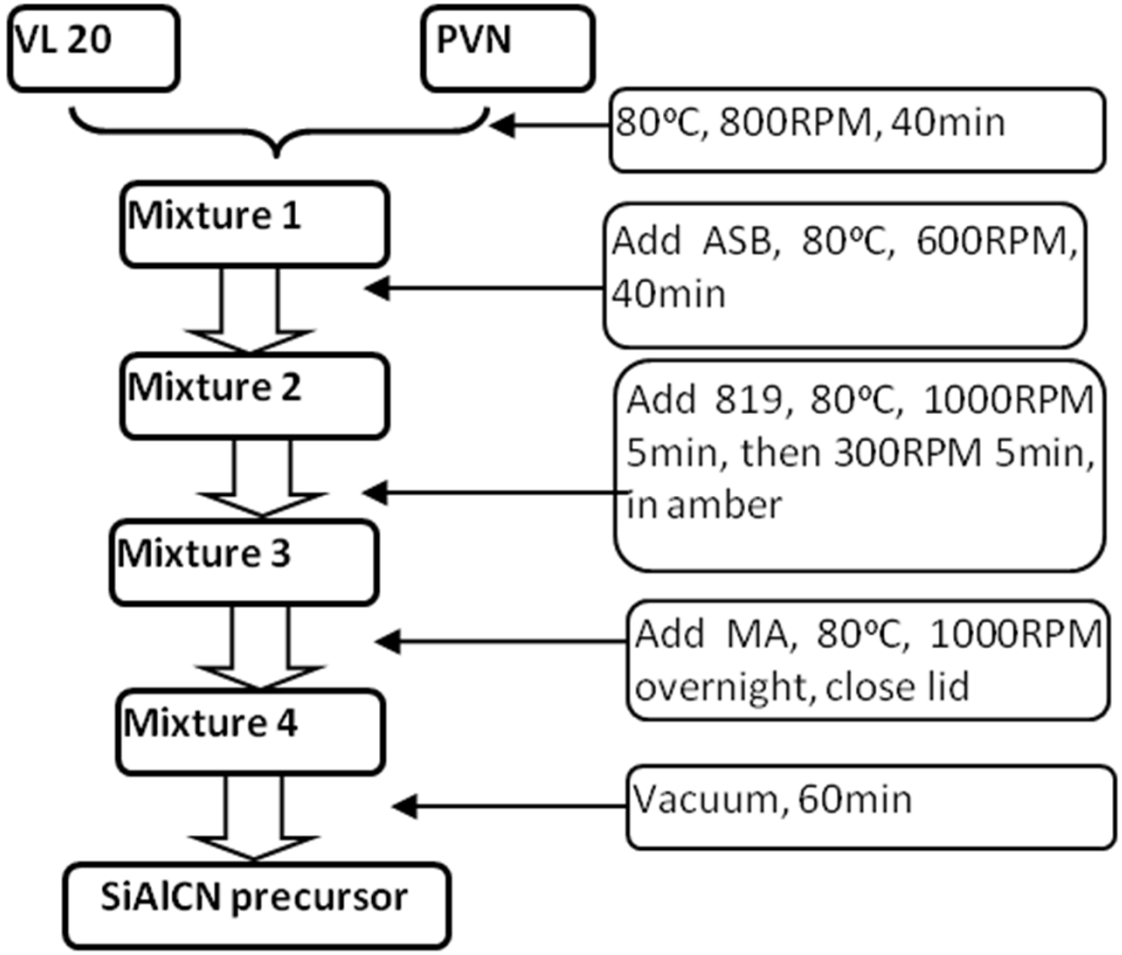


PDC SiAlCN: Materials Synthesis

SiAlCN has excellent oxidation resistance and thermal stability

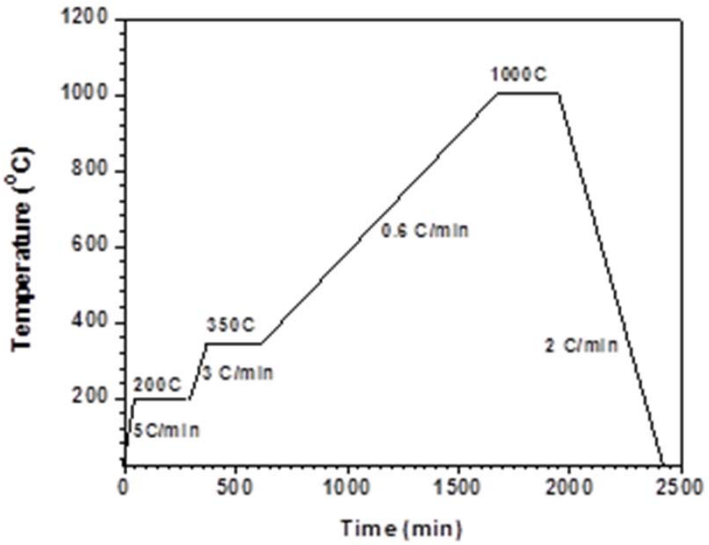
Objective: Investigate the effects of compositions on dielectric behavior of SiAlCN for obtain optimal materials with sufficient low dielectric loss.

- **Starting materials**
  - ✓ **Polysilazane (VL 20) - main precursor.**
  - ✓ **Phenylbis (2, 4, 6-trimethylbenzoyl) phosphine oxide (819) - the photo/thermal initiator for UV curing.**
  - ✓ **Methacrylic Acid (MA) - for enhancing the effectiveness of UV/thermal curing.**
  - ✓ **Aluminum-tri-sec-butoxide (ASB) - source for Al.**
  - ✓ **Poly (melamine-co-formaldehyde) acrylated solution (PVN) - source for N.**



PDC SiAlCN: Materials Synthesis

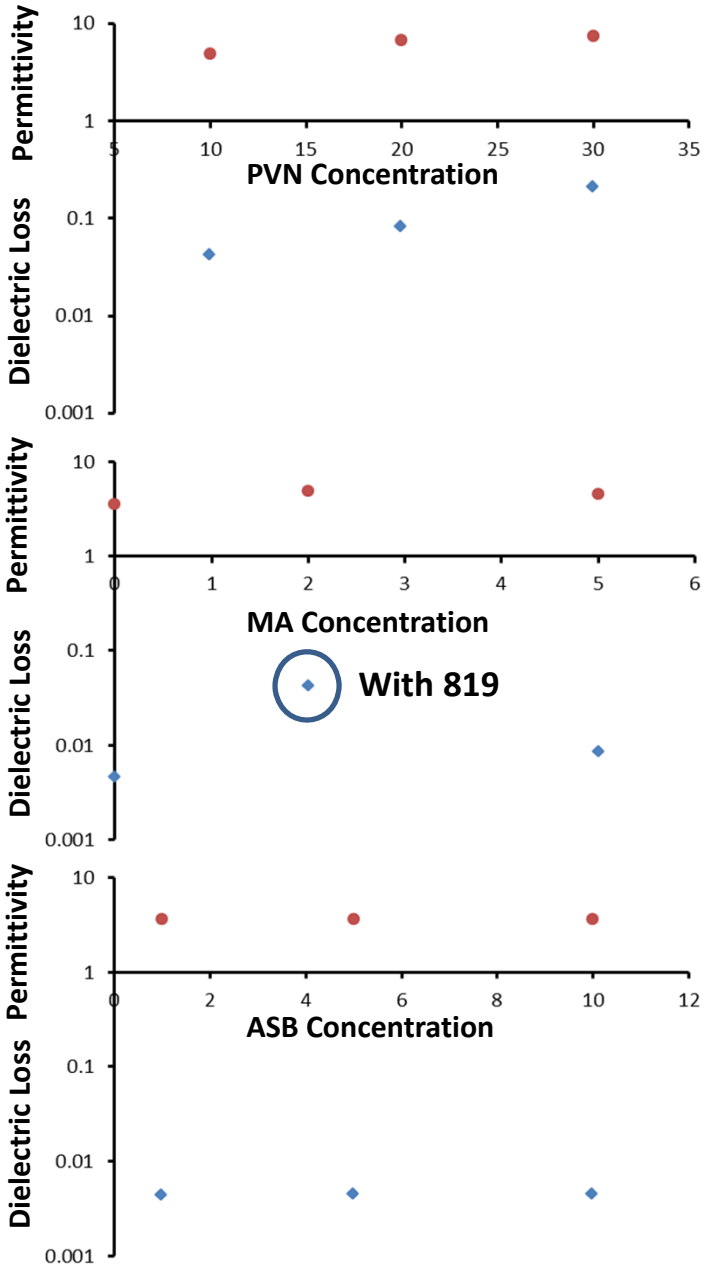
Sample	MA	ASB	819	VL20	PVN
SA-1	2 wt%	5 wt%	5 wt%	78 wt%	10 wt%
SA-2	2 wt%	5 wt%	5 wt%	68 wt%	20 wt%
SA-3	2 wt%	5 wt%	5 wt%	58 wt%	30 wt%
SA-4	5 wt%	5 wt%	/	90 wt%	/
SA-5	/	1 wt%	/	99 wt%	/
SA-6	/	5 wt%	/	95 wt%	/
SA-7	/	10 wt%	/	90 wt%	/
SA-8	2 wt%	1 wt%	/	97 wt%	/



PDC SiAlCN: Dielectric Properties

Sample	Dielectric loss	Dielectric permittivity
SA-1	0.042	4.87
SA-2	0.083	6.66
SA-3	0.21	7.40
SA-4	0.0085	4.45
SA-5	0.0045	3.6
SA-6	0.0046	3.55
SA-7	0.0046	3.85
SA-8	0.0045	4.8

PDC SiAlCN: Dielectric Properties



- **Effect of PVN**
  - Permittivity increase with PVN
  - Loss increase with PVN
  - Loss is too high for the samples with PVN
- **Effect of MA/819**
  - Permittivity increase slightly with MA
  - Loss increase slightly with MA
  - Loss increase significantly with 819
- **Effect of ASB**
  - Permittivity/loss remain unchanged with ASB
  - Loss is good for high temperature sensing

PDC SiAlCN: Materials Selection

Sample	MA	ASB	819	VL20	PVN
SA-1	2 wt%	5 wt%	5 wt%	78 wt%	10 wt%
SA-2	2 wt%	5 wt%	5 wt%	68 wt%	20 wt%
SA-3	2 wt%	5 wt%	5 wt%	58 wt%	30 wt%
SA-4	5 wt%	5 wt%	/	90 wt%	/
SA-5	/	1 wt%	/	99 wt%	/
SA-6	/	5 wt%	/	95 wt%	/
SA-7	/	10 wt%	/	90 wt%	/
SA-8	2 wt%	1 wt%	/	97 wt%	/

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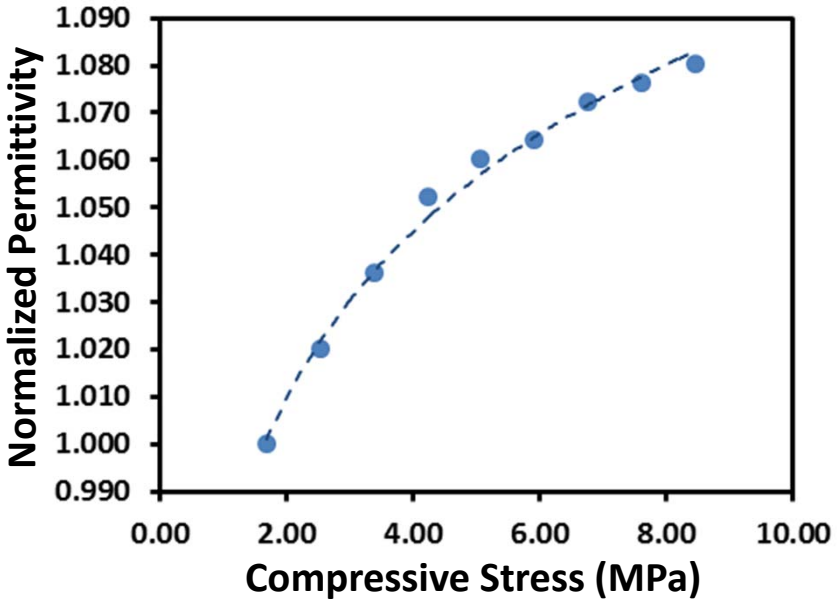
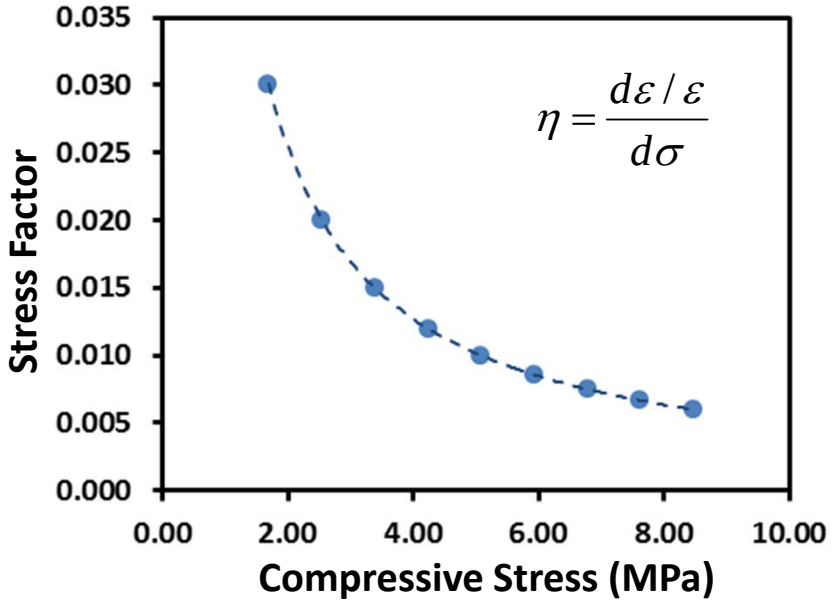
SA-8	0.0045	4.8

PDC SiAlCN: Piezo-Dielectricity



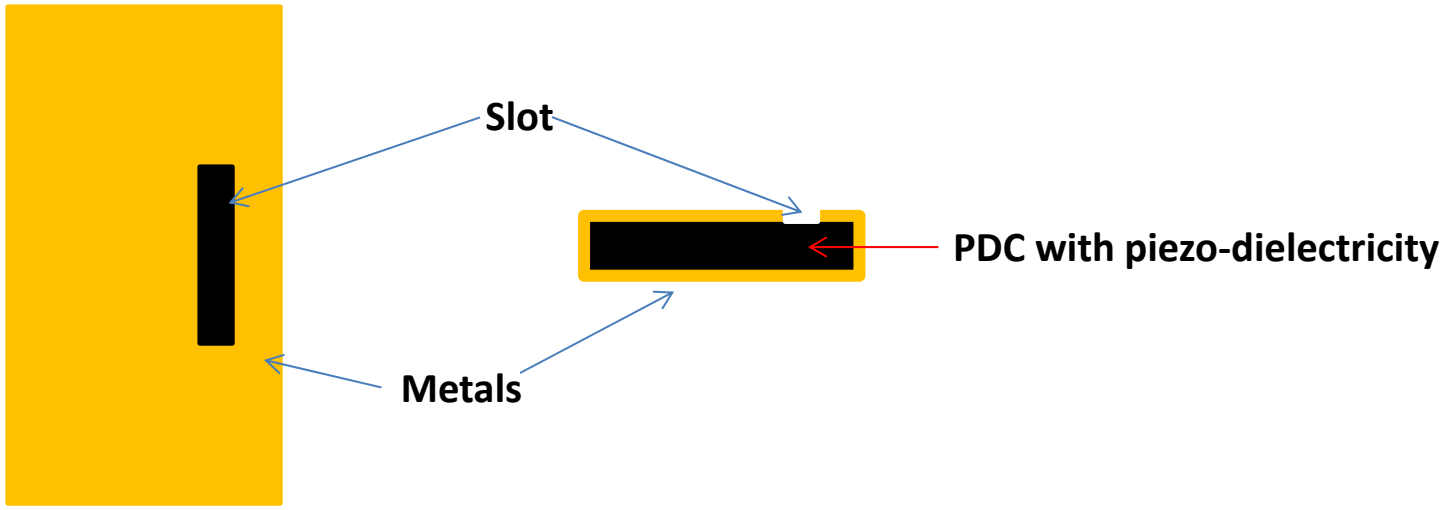
- Permittivity monotonically increases with pressure.
- Suitable for strain/stress sensor

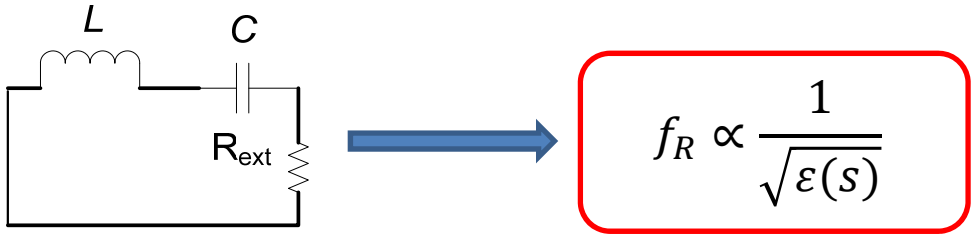
- Very high piezo-dielectric coefficient
- Lead to high sensitivity and wide sensing range



PDC Sensors: Principle

Principle: RF Resonator

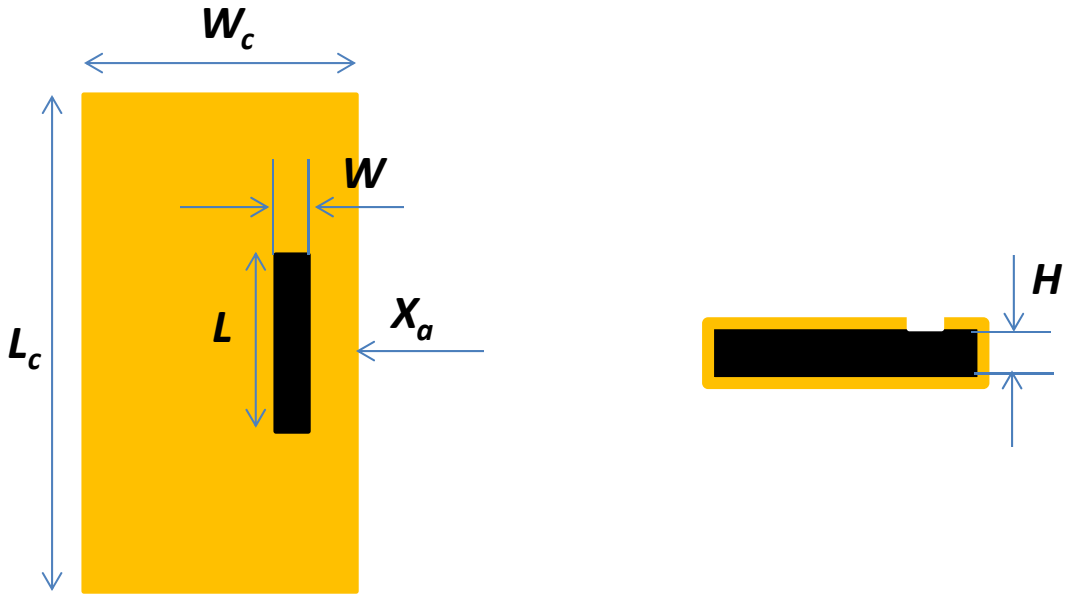




$$f_R \propto \frac{1}{\sqrt{\varepsilon(s)}}$$

- **Material exhibits piezo-dielectricity;**
- **Material with low dielectric loss to gain sufficient high *Q*-factor.**

PDC Sensors: Wireless Strain Sensor



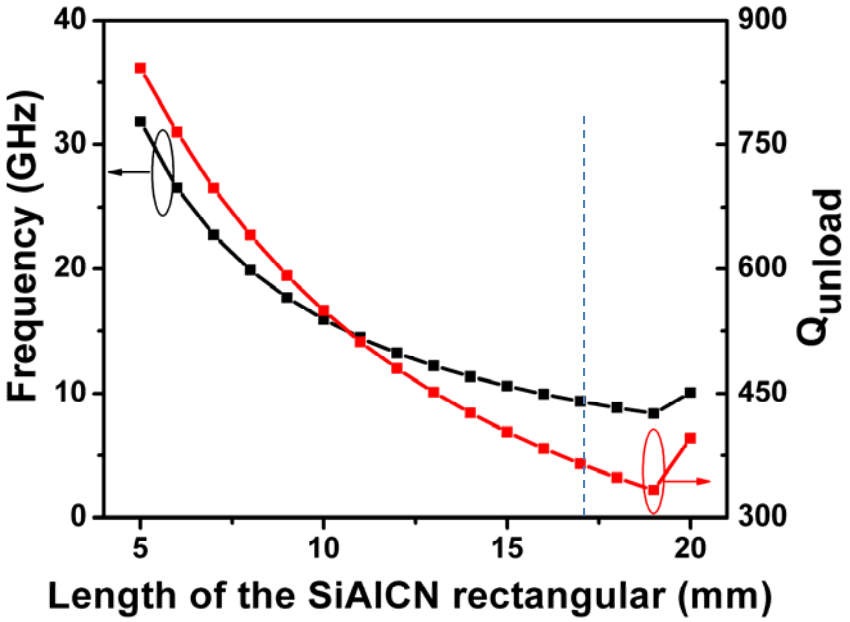
Parameters:

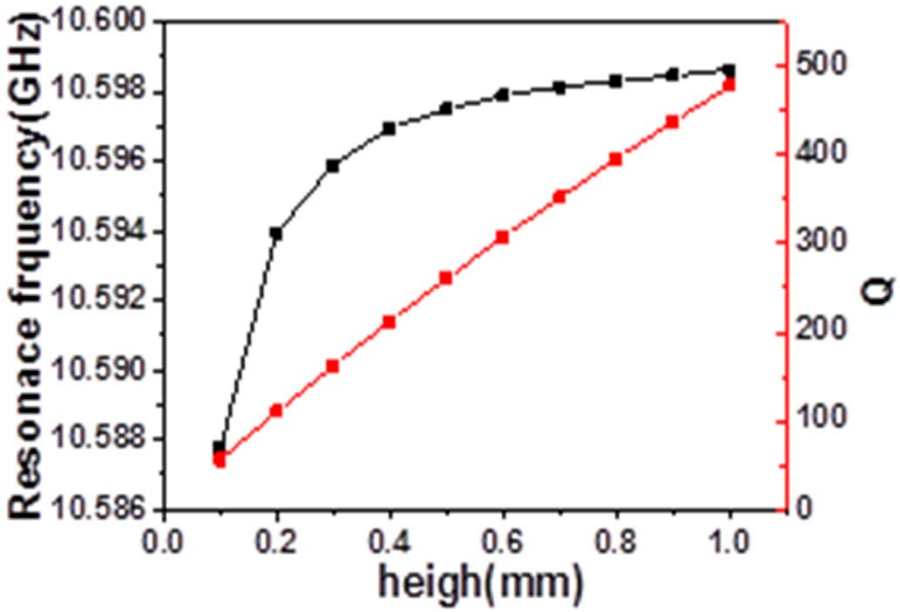
- Dimensions of SiAlCN: L_c, W_c, and H
- Slot dimensions: L, W, and X_a

PDC Sensors: Sensor Design

Effect of SiAlCN Dimension

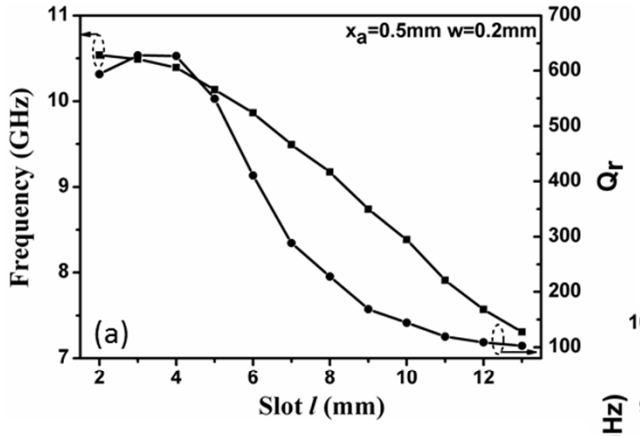
$L_c = 2W_c$

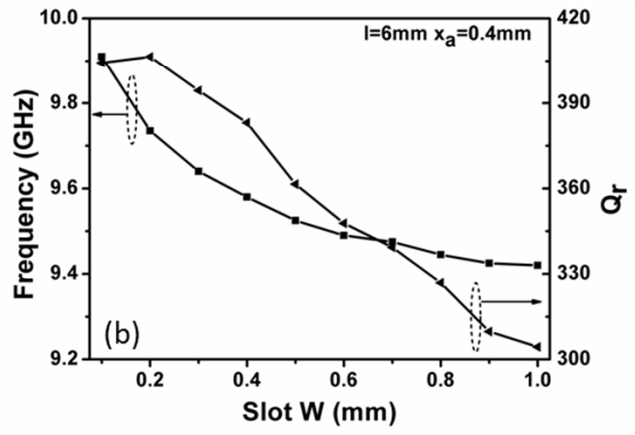


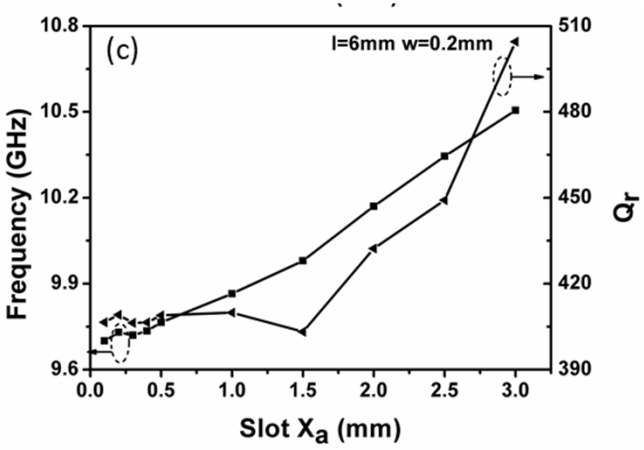


PDC Sensors: Sensor Design

Effect of Slot Dimension

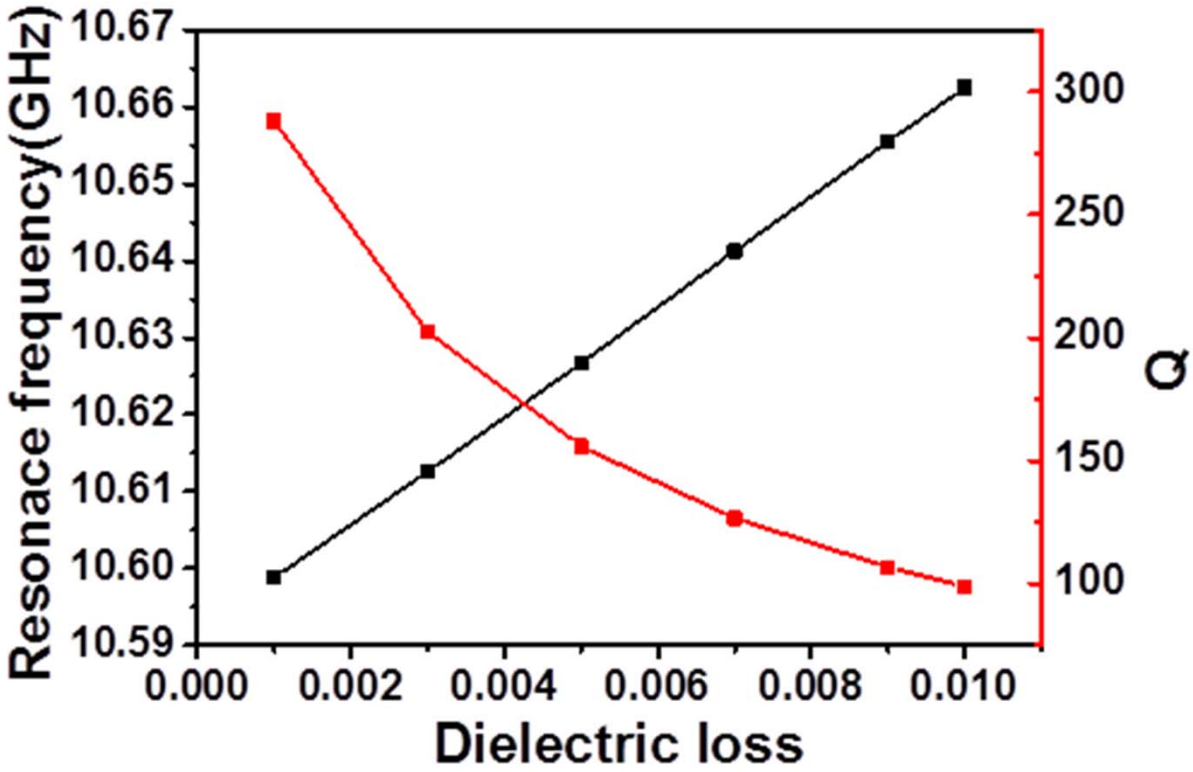






PDC Sensors: Sensor Design

Effect of SiAlCN Dielectric Loss



PDC Sensors: Fabricated Sensor

Summary and Future Work

- Dielectric properties of polymer-derived SiAlCN ceramics have been systemically investigated to understand the effect of material composition on the dielectric loss.

- A SiAlCN ceramic with significant piezo-dielectric behavior and sufficient low dielectric loss has been identified for strain sensor application.

- The effects of sensor dimension on resonant frequency and Q-factor have been studied. A strain sensor has been fabricated accordingly.

- The fabricated sensor will be tested to demonstrate the concept.