Online, In-Situ Monitoring Combustion Turbines Using Wireless Passive Ceramic Sensors

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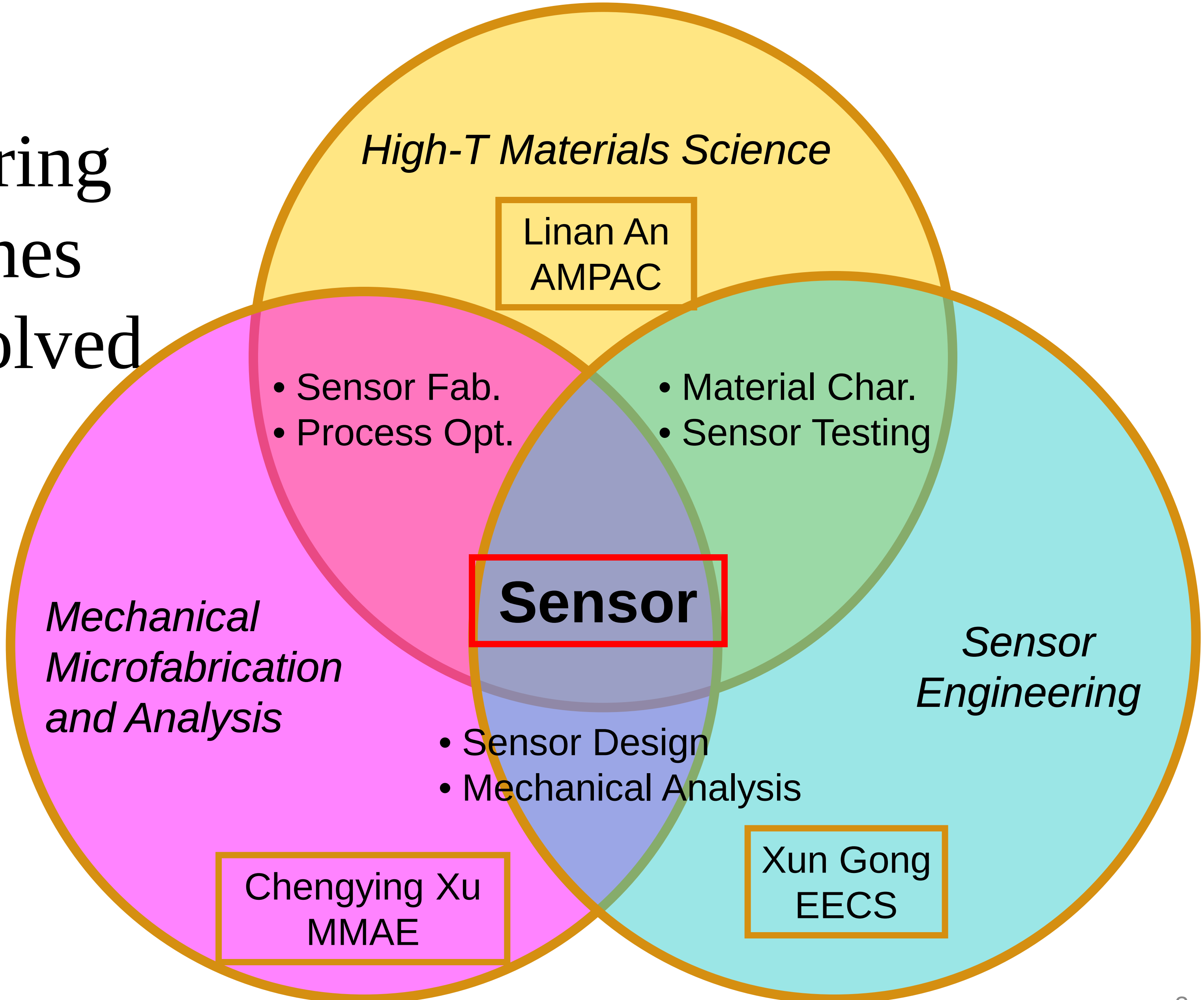
Motivation

- Harsh Environments
  - Combustion turbines
- Physical Parameters Need to be Sensed
  - Higher efficiency and less pollution
  - Performance and reliability improvement
- Sensor Requirement
  - Survive in harsh environments (**1300^{o}C**)
  - High accuracy
  - No electronic components
  - Wireless and passive
  - Small size
  - Robust and inexpensive
  - **New materials needed**

Courtesy
http://www.powerlabs.org/turbine.htm

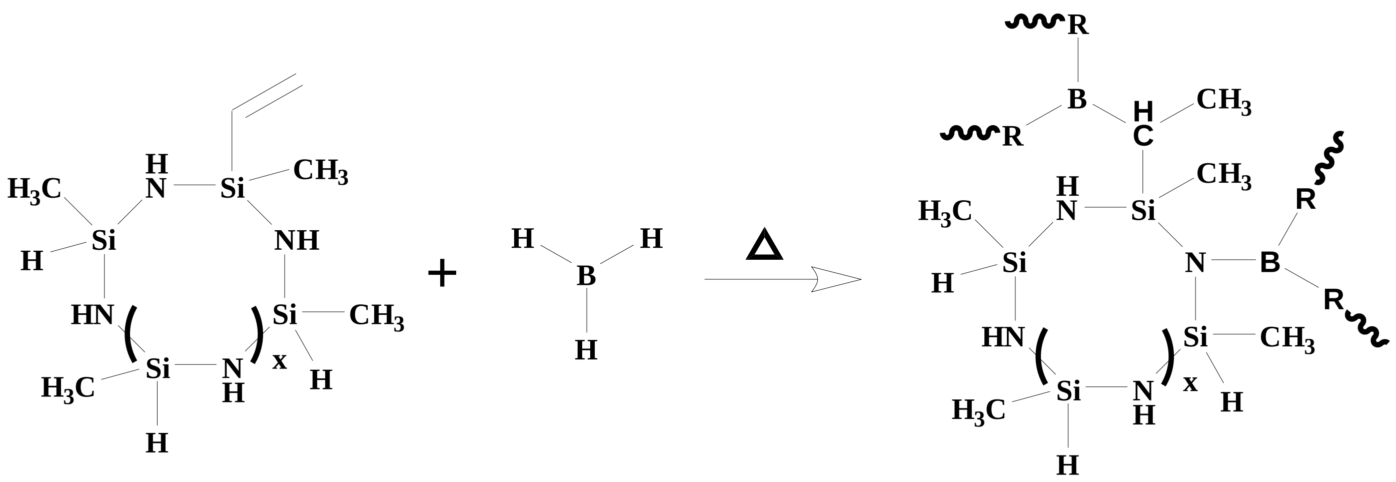
Three Engineering Disciplines Are Involved



High-Temperature Ceramic Materials

- Requirements
  - ✓ Reasonable temperature-dependent dielectric constant
  - ✓ Low dielectric loss
- Problems
  - ✓ Decrease dielectric loss
- Possible mechanisms of dielectric loss of PDCs
  - ✓ Electron loss
  - ✓ Atomic loss
- Approach
  - ✓ Strengthening the network structure
  - ✓ Decreasing the defects

Boron Doped SiBCN

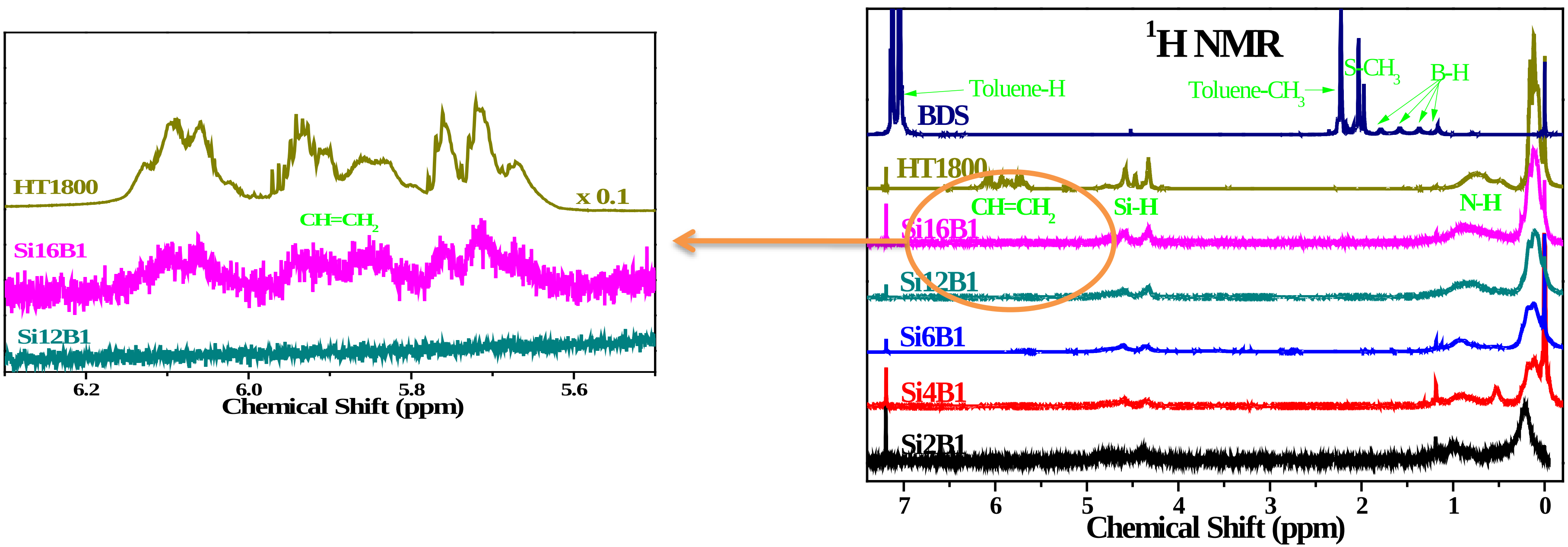


R= $[CH_3NBSi]_4[C_3H_8NBSi]$or H

HT1800 **Borane dimethyl sulfide** **Polyborosilazane**

Tailor the HT1800-to-BDS ratio to Control the Si-to-B ratio

Reaction Mechanisms



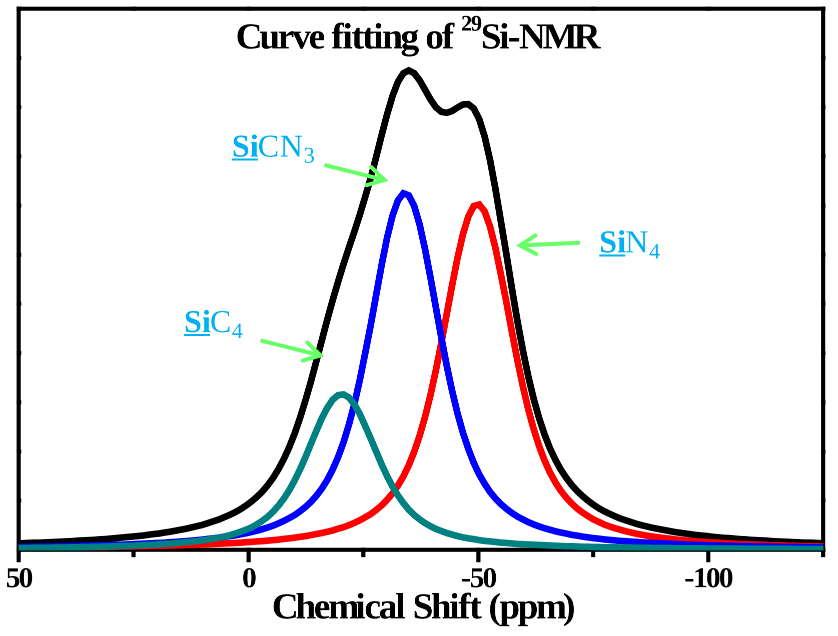
Polyborosilazanes with various boron content were synthesized by:

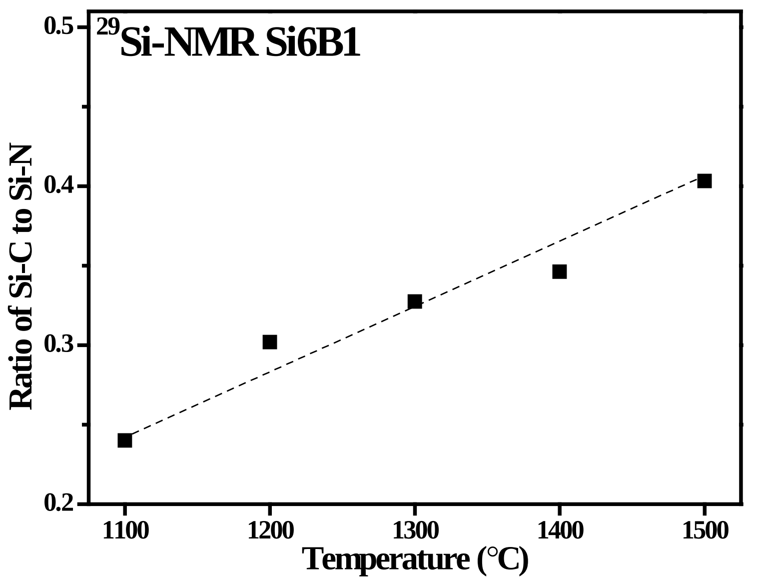
1. Hydroboration reaction $CH = CH_2 + B - H \xrightarrow{\Delta} B - CH - CH_3$

2. Dehydrocoupling reaction $N - B + B - H \xrightarrow{\Delta} B - N + H_2$

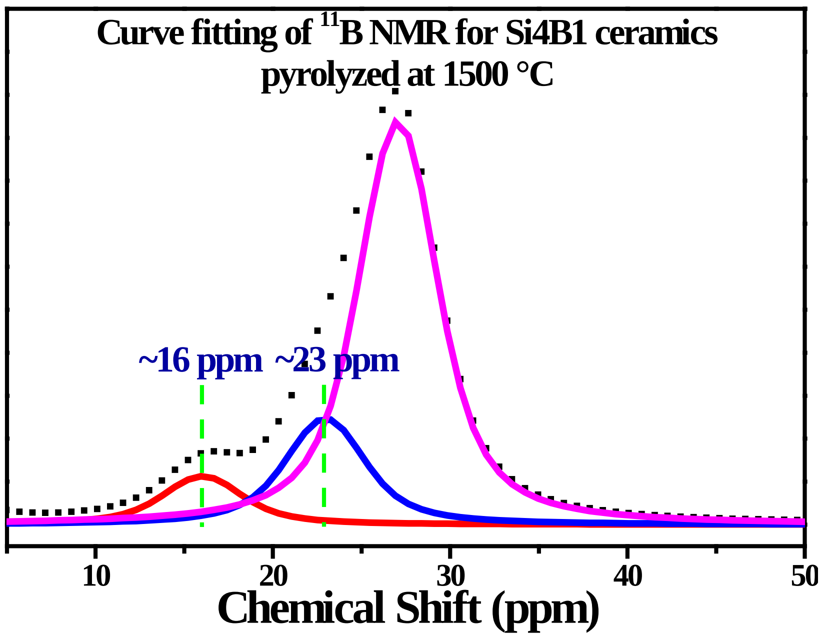
3. Hydroboration is prior to dehydrocoupling reaction (B prefers to bond C)

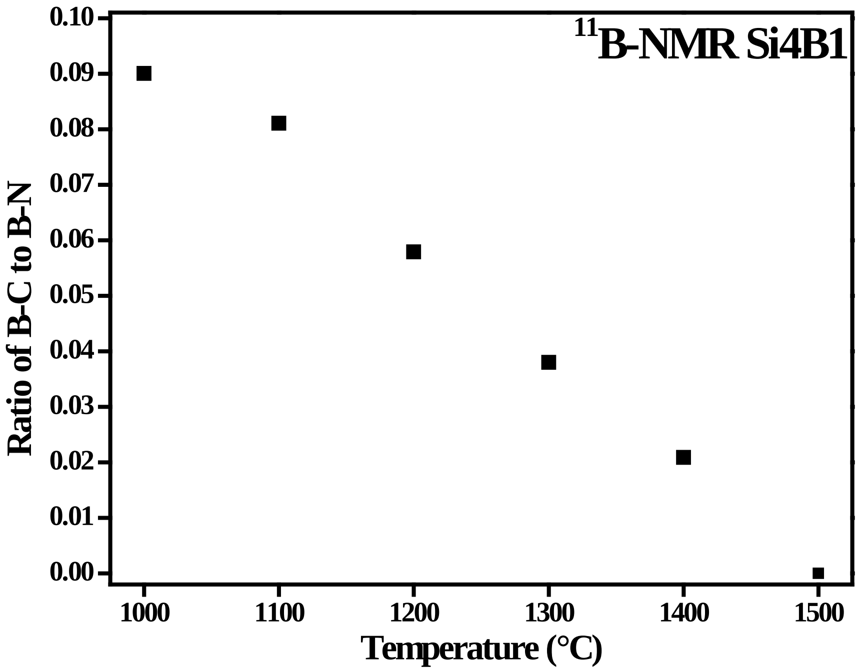
Structure of SiBCN





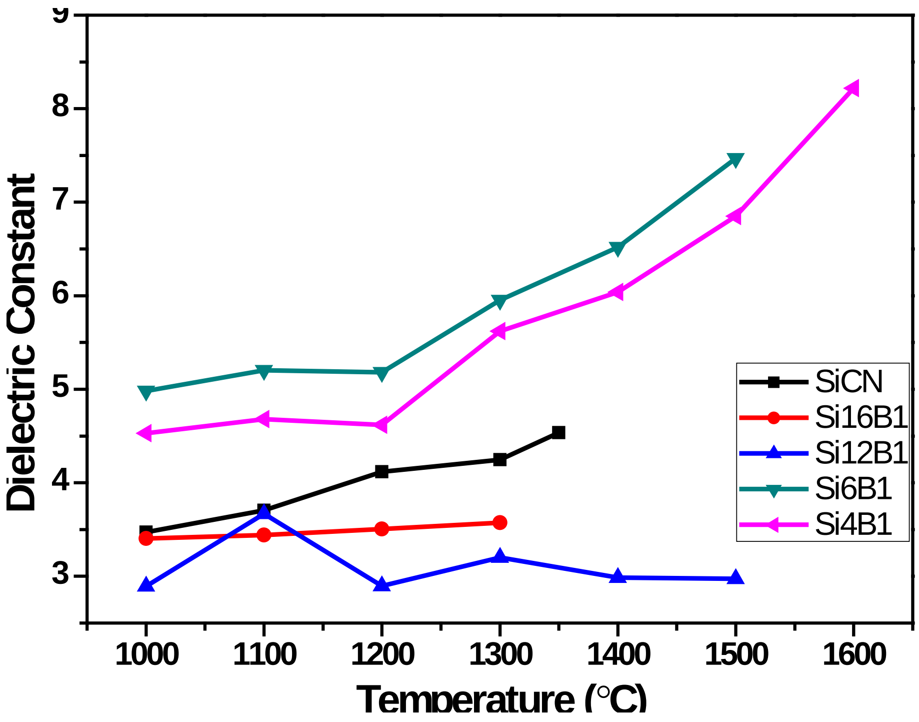
1. ^{29}Si-NMR was curve-fitted by three peaks.
2. SiC-to-SiN ratio increase with increasing temperature.

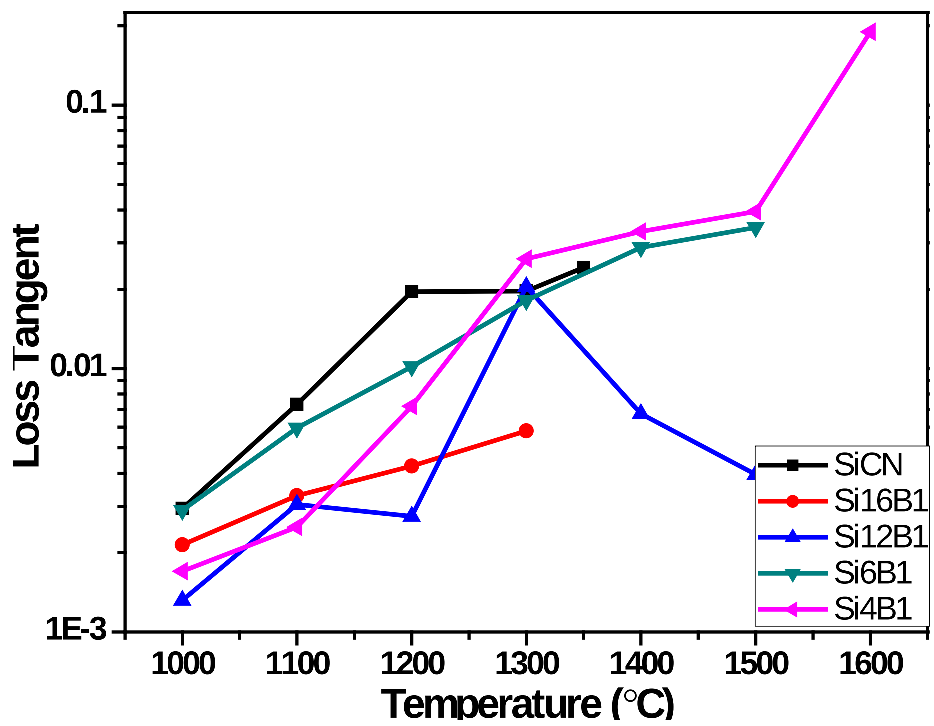




1. **Curve fitting of ^{11}B-NMR identify the <u>B</u>N_2C group at 35 ppm and <u>B</u>N_3 groups at 26 ppm.**
2. **B-C to B-N ratio suggests that the C atoms are excluding from <u>B</u>N_2C unit.**
3. **Hexagonal BN phase (h-BN) evolved from amorphous BN phase for at 1500 °C.**

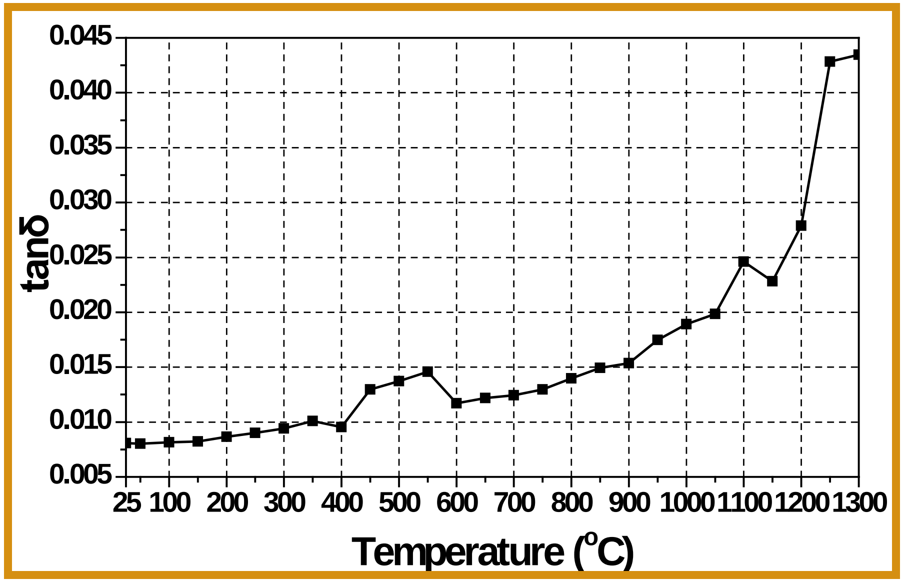
Room-Temperature Characterization of Different Material Compositions

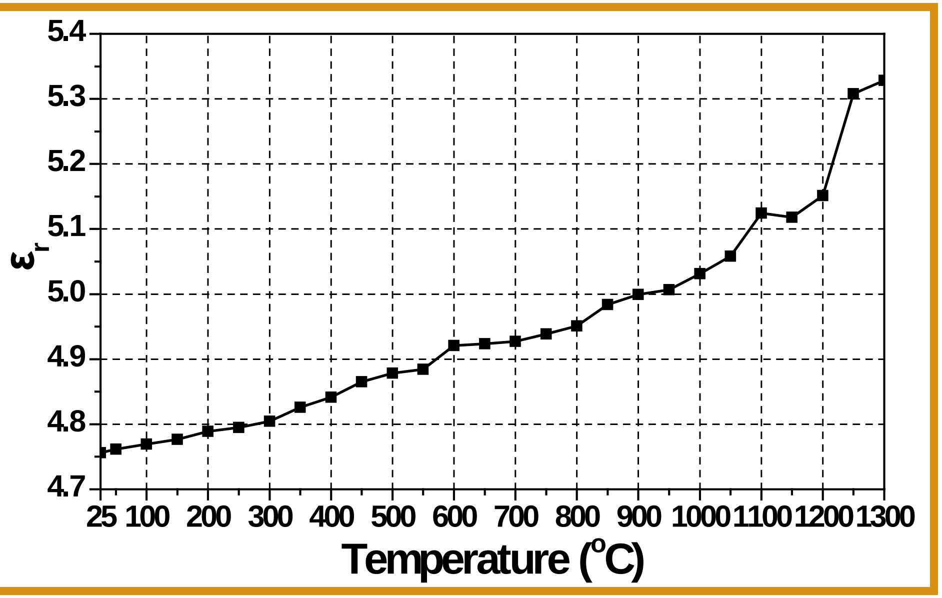




Measurement Results (1300^{o}C)

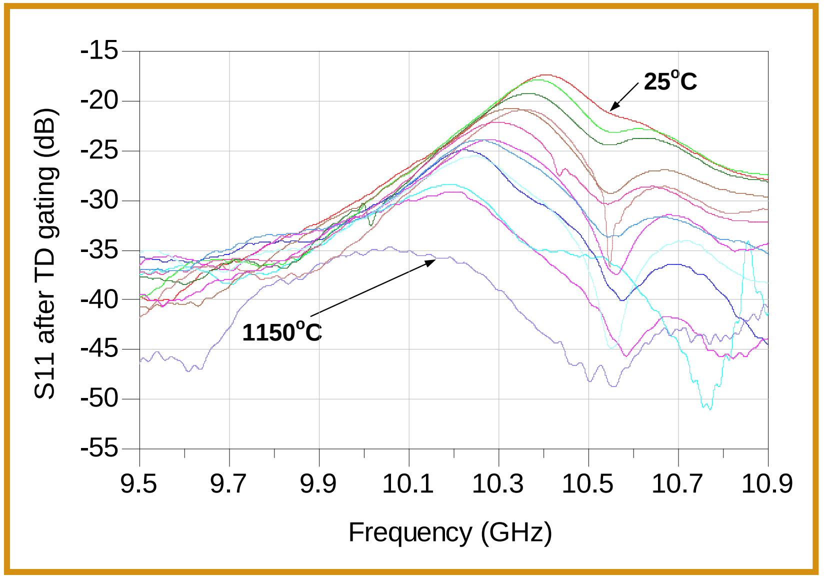
- Si_4B_1CN Sample
- Sintered at 1200^{o}C
- Measured up to 1300^{o}C

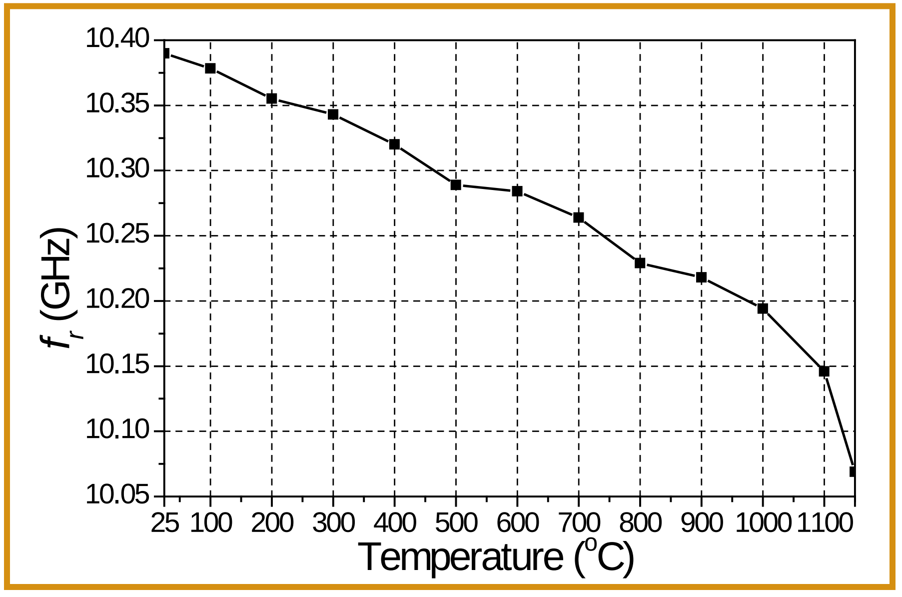


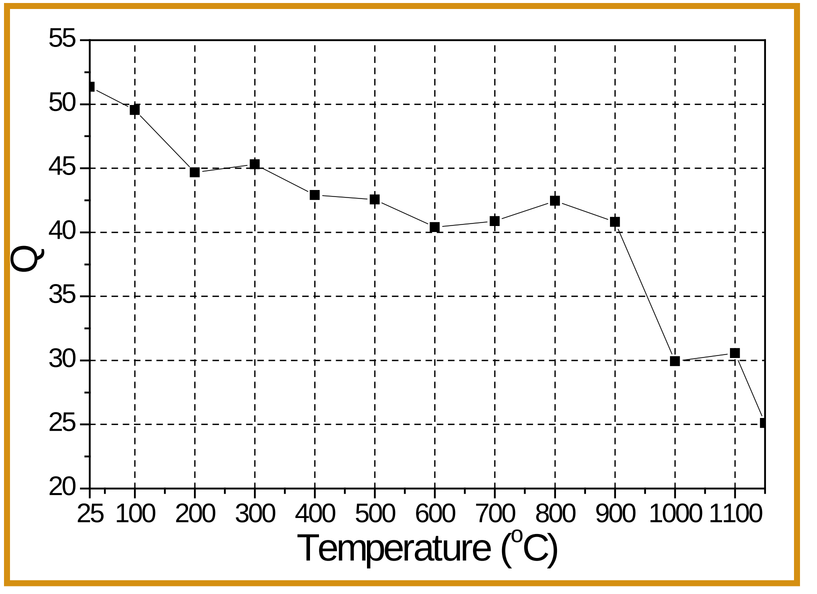


Temperature Sensor

- Measurement Results
  - Si_4B_1CN Sample
  - Sintered at 1100ºC
  - Measured up to 1150ºC
  - Sensing distance: 10 mm



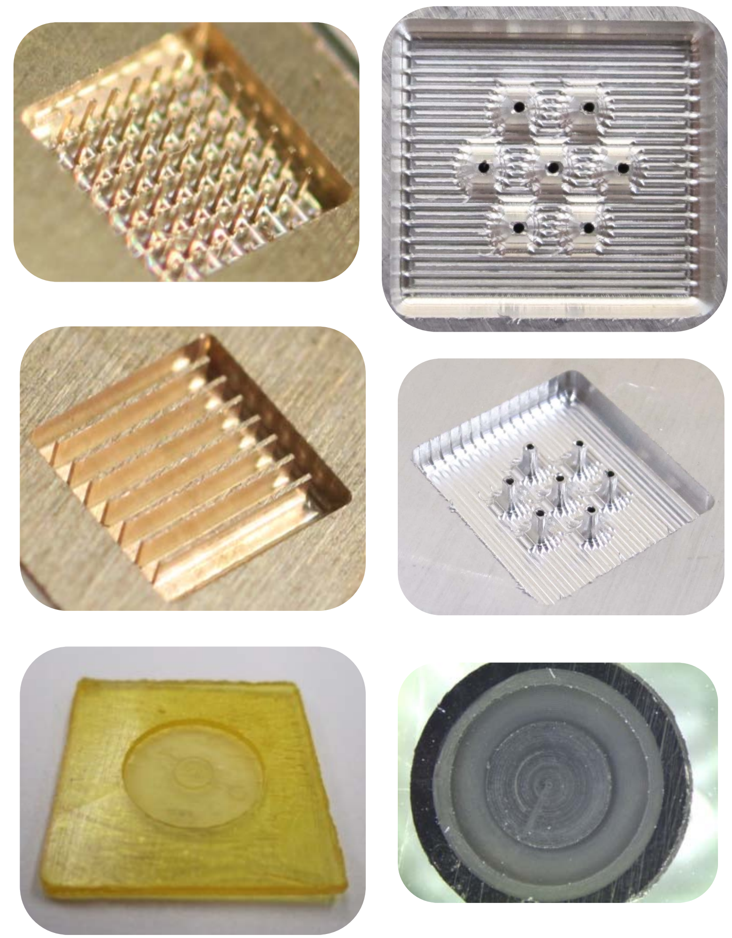




Pressure Sensor Fabrication Details: Micro-machining

- Micro-level Fabrication Methods for Advanced Materials
  - Traditional MEMS methods
  - EDM, ECM methods
  - Laser based method

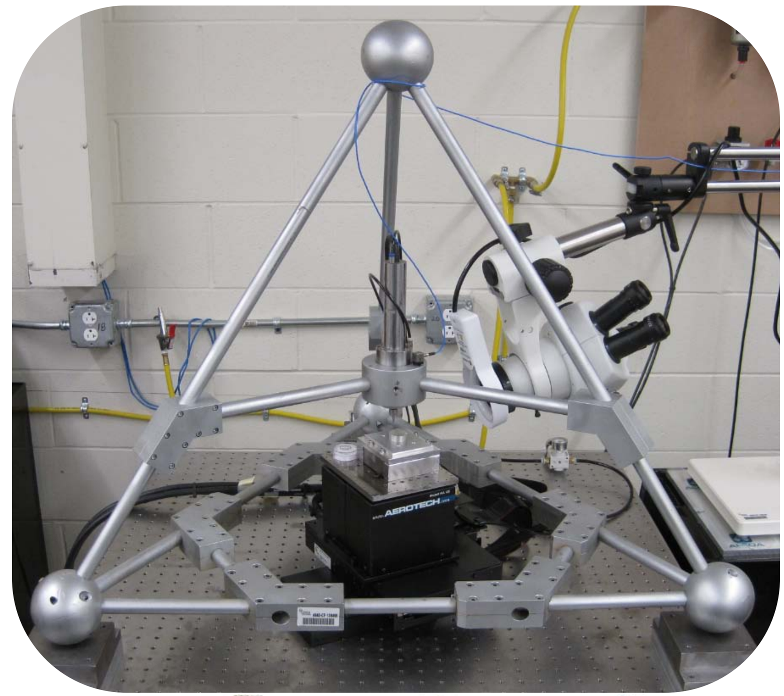
- **Mechanical Micro-machining**
  - 3-D patterning ability
  - Cost-effective
  - High Aspect ratio
  - Highly productive
  - Super precise and good quality
  - Flexible and controllable



Fabricated in RISE lab (2011)

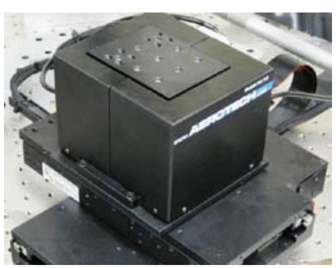
Micro-machinability Study on PDCs

- Experiment set-up of 5-axis micro machine tool
  - Tetrahedral Frame
  - Spindle system
  - Feed system
  - Measurement system
  - Real time controller

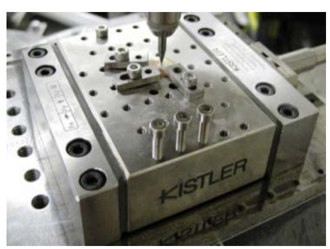


High speed electrical spindle

NI real-time controller



High resolution motion table



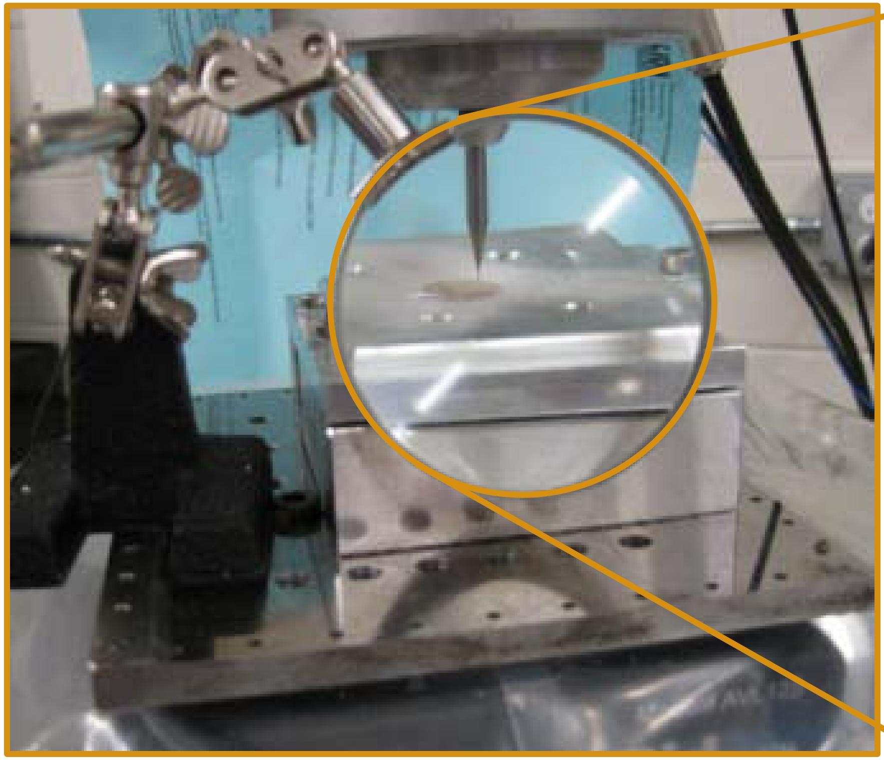
Kistler dynamometer

PCB accelerometer

PXI data acquisition cards

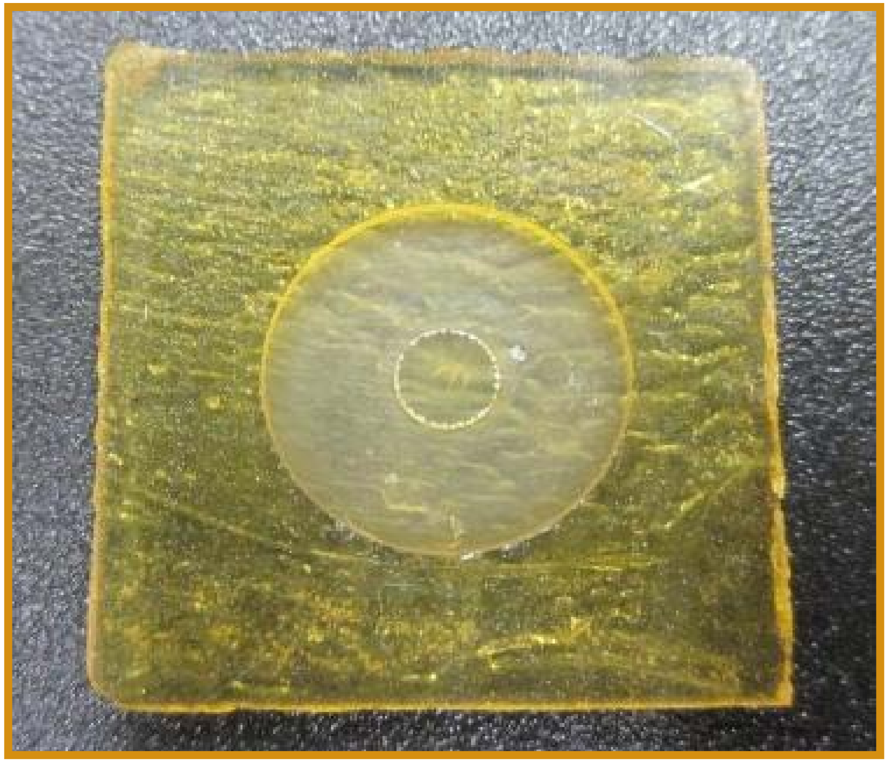
Sensor Fabrication Study on PDCs

- Micro Milling Sensor Base
  - Optimal cutting condition: spindle speed 20,000 RPM; feed speed 0.5 mm/s and depth of cut 20 μm

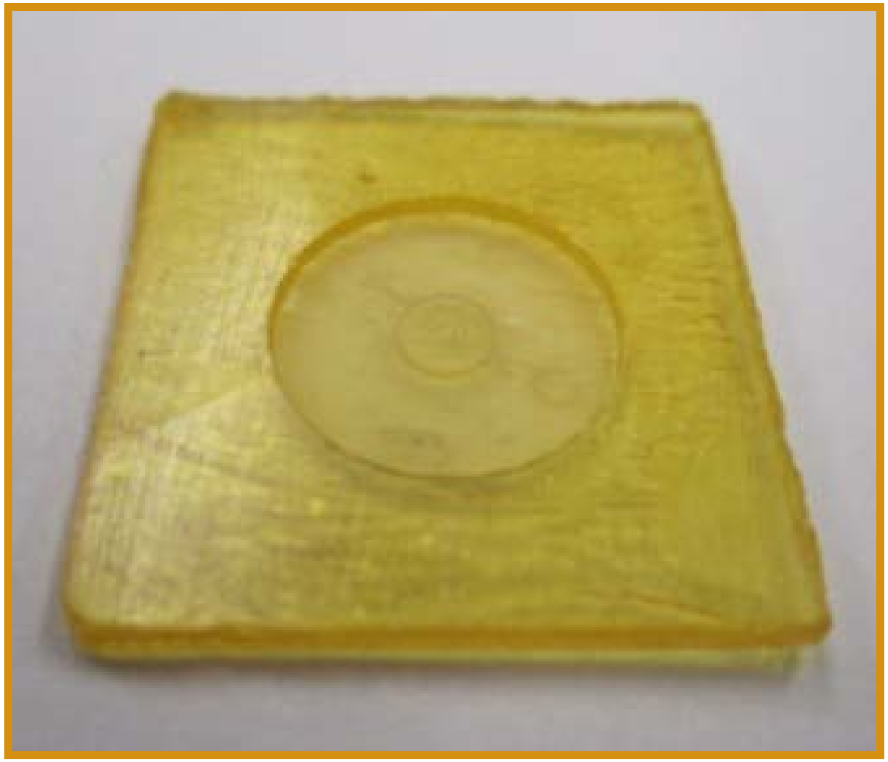


Sensor Fabrication Study on PDCs

- Micro Milling Sensor Base
  - Feed rate: 0.5 mm/s
  - Spindle speed: 20,000 RPM
  - Depth of cut: axial 20 μm; radial 200 ~ 260 μm
  - Tool diameter: 635 μm (solid carbide 4 flutes end mill)



Top view of the machined sensor base

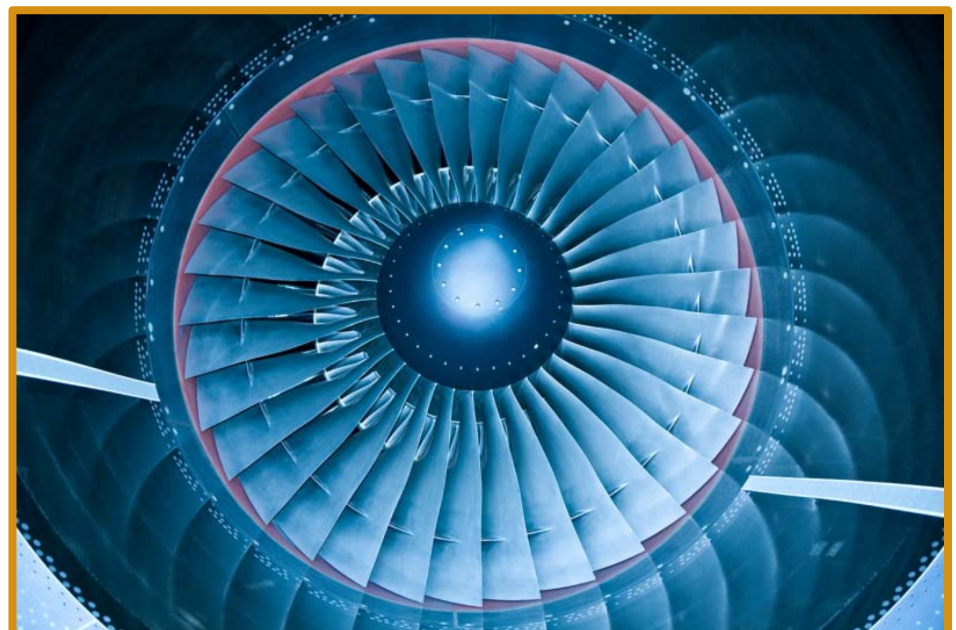


Oblique view of the machined sensor base

Conclusion

- Novel characterization setup is presented
  - SiCN materials have been characterized up to 1300^{o}C
- Various wireless passive sensing mechanisms are investigated
- Wide applications in new generation of efficient turbines

Acknowledgements:



[Courtesy
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