Thin Film Physical Sensors for High Temperature Applications

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Advantages for temperature, strain, heat flux, & flow measurements:

- Negligible mass & minimally intrusive (microns thick)
- Applicable to a variety of materials including ceramics
- Minimal structural disturbance (minimal machining)
- Intimate sensor to substrate contact & accurate placement
- High durability compared to exposed wire sensors
- Capable for operation to very high temperatures (>1000°C)

Multifunctional smart sensors being developed

- PdCr strain sensor to T=1000°C
- Pt- Pt/Rh temperature sensor to T=1200°C
- Heat Flux Sensor Array to T=1000°C
- Multifunctional Sensor Array
High Temperature Strain Sensor Technology

- High temperature strain sensors developed based on PdCr
- Thin film gauge operated to 1100°C, compared to 700°C maximum of the commercially available technologies
- Survived fatigue tests at ±2000με up to 700Hz and 1000°C for a million cycles
- Dynamic measurements repeatable to ±10% over entire range with temperature compensation
- The gauges also demonstrated on SiC/SiC CMC components in a jet-fueled burner rig at 1100°C
- Gauges implemented to study fatigue characteristics for disk material
- Bio-MEMS applications being considered
Multi-Functional Sensor System

• Multifunctional thin film sensor designed and built in-house
• Temperature, strain, and heat flux with flow all on the same microsensor
• Enables measurements on component surfaces, and reduces boundary layer trip on metals compared to wires or foils
• Weldable shim designed to simplify sensor mounting
• Dynamic measurements demonstrated in lab
Static Strain Gauges

• Required accuracy: ±200 με (±10% full scale)
  • Currently accomplished with a temperature compensating bridge circuit with PdCr

• Multifunctional Sensor design does not lend itself to compensating bridges
  • Multiple strain gauges in a rosette pattern does not allow compensation to be included in design
  • Design eliminates temperature effects if apparent strain is low enough

• High Temperature Static Strain measurements with Multifunctional Sensor requires a more passive method of reducing or eliminating apparent strain
  • Accomplished by using a TaN/PdCr multilayer for <20 με/C apparent strain
Heat Flux Sensors

**Thermopile-type Heat Flux Sensor**
- Temperature difference across a thickness of insulation is measured by thin film thermocouples
- Insulation is a thin film TBC
- Sensitivity is increased by adding many thermocouple pairs in series to form a thermopile

**RTD-based Heat Flux Sensor**
- Temperature difference across a thicknesses of insulation is measured by thin film RTD’s
- Insulation may be a thin film TBC or the substrate itself
- Utilizing a Wheatstone bridge, this sensor is easier to fabricate and has a larger signal than thermopile-type
Heat Flux Sensor Applications

- High Temperature Heat Flux Sensors packaged and delivered to GRC Seals Group for CEV/TPS Heat Shield Interface Seal Studies at ARC

- High Temperature Au-Pt Heat Flux Sensors fabricated and delivered to GRC Advanced Stirling Development Group for direct measurement of thermal to electrical conversion efficiency in ASC Units
VIPR Thin Film Thermocouple

OBJECTIVE
• Enable improved dynamic temperature measurements at higher temperatures using thin film sensor technology

APPROACH
• Thin film sensors have negligible mass, are minimally intrusive, and can be applied to a variety of materials including ceramics
• Two high temperature prototype thermocouple probe designs fabricated and demonstrated
• Each sensor probe design demonstrated different thin film thermocouple types and packaging approaches

SIGNIFICANCE
• Operation of thin film thermocouple sensor prototypes validated as installed in bleed-air borescope ports
• Sensors tracked dynamic engine temperature changes through multiple power cycles with faster response than embedded thermocouples
• Data included monitoring VAE performance trends
• Tracked performance changes were observed elsewhere in engine
• Application not limited to bleed-air borescope ports
• Part of information fusion to better understand the overall health state of the engine
Ceramic Thermocouples

- Silicides and Carbides have highest thermoelectric output of non-metallic thermocouple (TC) elements as bulk materials.
- Carbides have a very high use temperature in inert and reducing atmospheres (>>3000°C).
- Most Robust Carbides: TaC, HfC, and ZrC.
- Silicides form a natural passivation layer in oxygen.
- High Performance Silicides: CrSi$_2$ and TaSi$_2$. 

Thermoelectric Output (mV) vs. Temperature (°C) (referenced to 0°C)

- Thin Film Ceramic TC Sample and measured performance.
ITO-Based Heat Flux Sensor

- Fine-lined 50-µm thermopile using Al:ZnO vs. ITO on 1” disk of α-SiC
  - ITO deposited at GRC
  - Al:ZnO deposited at URI
  - Mullite used as insulation

- Sensor survived fabrication
- Response tested on two heat sources with similar heat flux but different temperatures
  - 0.2 W/cm², 250°C and 500°C
  - Response 0.6 mV/W/m²
LLISSE Venus Sensors

- Miniaturized sensor systems produced by microfabrication techniques and high temperature compatible materials
  
- Wind Sensor
  - Goal to measure wind speed, direction and variability in harsh Venus atmosphere
  - Approach uses strain gauges on a cantilever (miniature drag force anemometer)

- Radiometer
  - Goal to measure the amount of sunlight reaching the Venus surface over time
  - Approach uses a thin film thermopile-type heat flux sensor (bolometer)
Summary

• For the advanced engines in the future, knowledge of the physical parameters of the engine and components is necessary on the test stand and in flight

• NASA GRC is leveraging expertise in thin films and high temperature materials to measure hot section gas and surface temperature, heat flux and static and dynamic strain
  • Investigating the applications of thin film ceramic sensors
  • Demonstrating these technologies in aeronautics and space applications