Thin Film Physical Sensor Instrumentation Research and Development at NASA Glenn Research Center

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Presenters

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• Research Engineers / Physicists at NASA Glenn Research Center (GRC/RIS)

• Primarily Physical Sensors Instrumentation Research:
  – Thin Film Sensors
  – Temperature
  – Strain
  – Flow

• Also dabble in Radiation Detectors, and Research in Sonoluminescence & other Revolutionary Concepts
Outline

Introduction
Development of Specialized Sensors
• High Temperature Strain Sensors
• Thermocouples
• Heat Flux Sensors
• Flow Sensors
• Multifunctional Sensors

Development of Instrumentation Techniques
• Capabilities and Facilities
• 3D Fabrication Techniques
• Multi-Layered Thin Film Insulation

Future Directions & Summary
Instrumentation Challenges for Propulsion System Environments

- High gas temperatures
- High material temperatures (>1000°C)
- Rapid thermal transients
- High gas flows
- High combustion chamber pressures

Wire-based sensors are bulky and disruptive to the true operating environment

Air breathing propulsion systems

Chemical propulsion systems
Thin Film Physical Sensors for High Temperature Applications

Advantages for temperature, strain, heat flux, flow & pressure measurement:

- 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
- Capable for operation to very high temperatures (>1000°C)

Multifunctional smart sensors being developed
Next generation ceramic-based sensor under development

- 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
Recent Collaborations

- University of Rhode Island
  - ITO-based Thin Film Sensors
- Rolls-Royce (UK)
  - Multilayered Thin Film Insulator
- NASA GRC Ceramics Branch & CWRU
  - Thermoelectric & Piezoelectric Power Generators
- Goodyear Tire & Rubber Company
  - Heat Flux Sensors
- The Cleveland Clinic Foundation
  - Bio-MEMS Applications
- GE Transportation / Aircraft Engines
  - High Temperature Thermocouples
- Air Force Research Lab (ML)
  - High Temperature Strain Gauges
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 currently being implemented to study fatigue characteristics for disks
- Bio-MEMS applications being considered
Cervical Plate Instrumentation Concept for Spinal Implants

Conceptual Strain Gauge Fabricated on a Ti-alloy Cervical Plate to Assist in Bone Fusion

Prototype Strain Gauge in Test on Ti-alloy Sample

Instrumented Plate Surgically Implanted To Monitor Healing
**Thin Film Thermocouples**

- Development concentrated on the application of high temperature Pt-13%Rh vs. Pt thermocouples (ANSI Type R)
- Fabricated and tested on several substrate systems:
  - Ni-based superalloys
  - Silicon carbide, Silicon nitride
  - Oxide ceramics
  - CMC’s, Intermetallics
- Entire sensor thickness 10-20 µm
- Thin film thermocouples demonstrated on SSME turbo pump blades under 1000°C test conditions
- Several SiC fiber/SiC matrix CMC panels, cylinders, and combustor liners instrumented with thin film thermocouples and successfully tested to 1100°C for over 25 hours of testing
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
Flow Sensors

Thermocouple Boundary Layer Rake
- Conventional boundary-layer flow sensors cannot measure very close to the surface (>250µm)
- Thermocouple boundary layer rake can measure the boundary layer velocity profile to about 65 µm from the surface
- Device detects the flow using a thin-film thermocouple array on a quartz strut with low heat conductivity (US Patent 6,382,024)

RTD-based Air Mass Flow Sensor
- Current air mass flow sensors designs lack robustness, unobtrusiveness, accuracy and simplicity in determining bulk air mass flow
- The sensor consists of thin film RTD’s in a resistor bridge arrangement fabricated on a thin, constant-thickness airfoil (US Patent 6,684,695)
Multi-Functional Sensor System

- Multifunctional thin film sensor designed and built in-house (US Patent 5,979,243)
- Temperature, strain, and heat flux with flow all one the same microsensor
- Enables measurements on relatively rough 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 version under development
Thin Film Sensor Fabrication & Testing

Film layers are fabricated with physical vapor deposition methods (sputter deposition, e-beam vapor deposition)

Sensors are patterned by photolithography methods and/or stenciled masks

Evaluation of thin films with in-house Materials Characterization Facilities

Testing of films with in-house high-temperature furnaces
3D Fabrication Techniques

Shadow Masking
- Metal masks from castings of components pattern sensor during sputtering

Photolithography
- Flexible plastic masks (Kodalith® Film or applied patterns) allow sensor to be patterned using lift-off processes and sputtering

Laser Trimming
- Film is first sputtered on component and then patterned with a laser
- Focal field of laser limits curvature of components

Masks from Castings of SSME Blades
Film Masks
Laser Trimmer
3D Fabrication Techniques - Examples

RTD on Fan Blade

Strain Gauge on an Engine Valve

TC’s on SSME Turbo Pump Blade
Multilayered Thin Film Insulator

- Non-conductive thin films to electrically insulate thin film sensors on engine components
- Minimizes the intrusiveness of the sensors and allows a more accurate measurement of the environment
- Pinholes and other defects in thin film dielectrics are a major cause of insulation failure
- By alternating the insulating material, eliminates direct pathways for conduction to the substrate
- The insulating properties of multilayered insulators of Al2O3 and YSZ or CrC were tested to 1000°C

YSZ-alumina multilayer insulating a RTD on a nickel-alloy fan blade

YSZ-alumina multilayer on a metal substrate for testing
Future Directions: Thin Film Ceramic Sensors

• The limits of noble metal thin film sensors of 1100°C (2000°F) may not be adequate for the increasingly harsh conditions of advanced aircraft and launch technology (>1650°C/3000°F)
• NASA GRC investigating ceramics as thin film sensors for extremely high temperature applications
• Advantages of the stability and robustness of ceramics and the non-intrusiveness of thin films
• Advances have been made in ceramic thin film sensors through collaborations with CWRU & URI
• Developed a microfabricated ceramic multifunctional sensor rosette of TaN in-house
• Preliminary tests indicate that TaN thin film ceramic multifunctional sensor is comparable to noble-metal alloys used for high temperature applications
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 has a history of pioneering the development and application of thin film, embedded sensor technology for aeronautic engine applications and extreme environments.
• Technology also has applications to future launch vehicles, space vehicles, and ground systems.
• Range of sensor technology has been demonstrated enabling measurement of multiple parameters individually or in sensor arrays including strain, temperature, heat flux, and flow.
• Multiple techniques exist for refractory thin film fabrication, fabrication and integration on complex surfaces, and multilayered thin film insulation.
• Leveraging expertise in thin films and high temperature materials, investigations for the applications of thin film ceramic sensors has begun.
• Current challenges of instrumentation technology are to further develop systems and component testing of specialized sensors, further develop instrumentation techniques on complex surfaces, and to address needs for extreme temperature applications.
Researchers

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http://www.grc.nasa.gov/WWW/sensors/PhySen/
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