Thin Film Physical Sensors for High Temperature Applications

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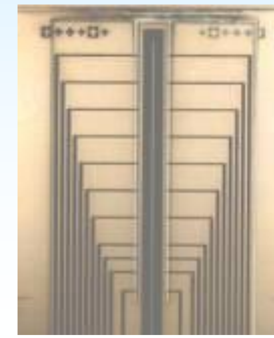
Thin Film Physical Sensors for High Temperature Applications

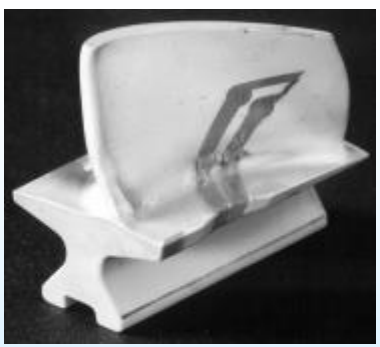
Advantages for temperature, strain, heat flux, & flow measurements:

- 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)

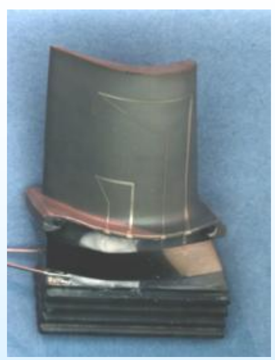


Flow sensor made of high temperature materials

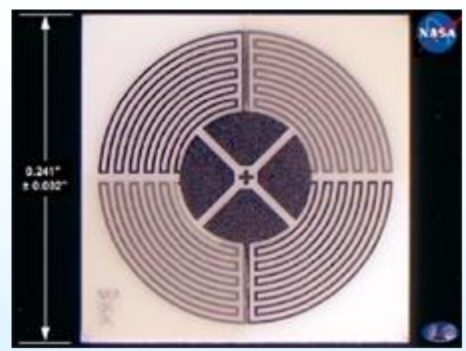
Multifunctional smart sensors being developed



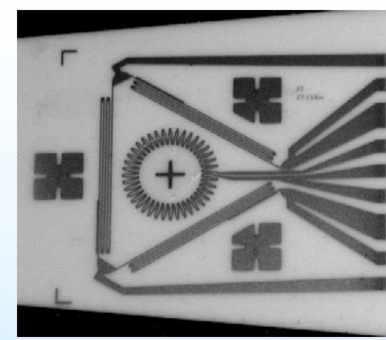
PdCr strain sensor to T=1000°C



Pt- Pt/Rh temperature sensor to T=1200°C



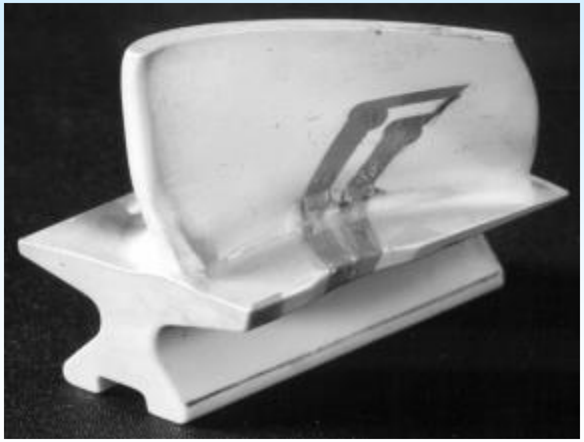
Heat Flux Sensor Array to T=1000°C



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

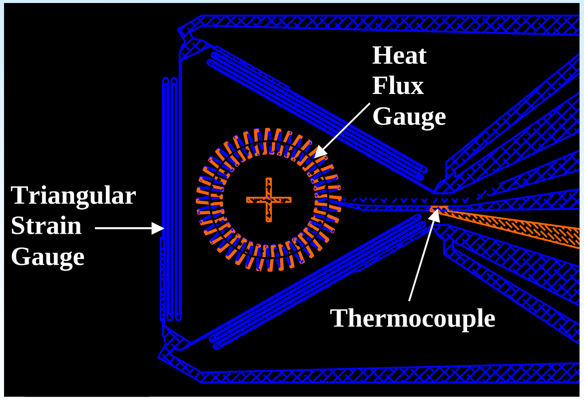


PdCr thin film gauge applied on a ceramic turbine blade

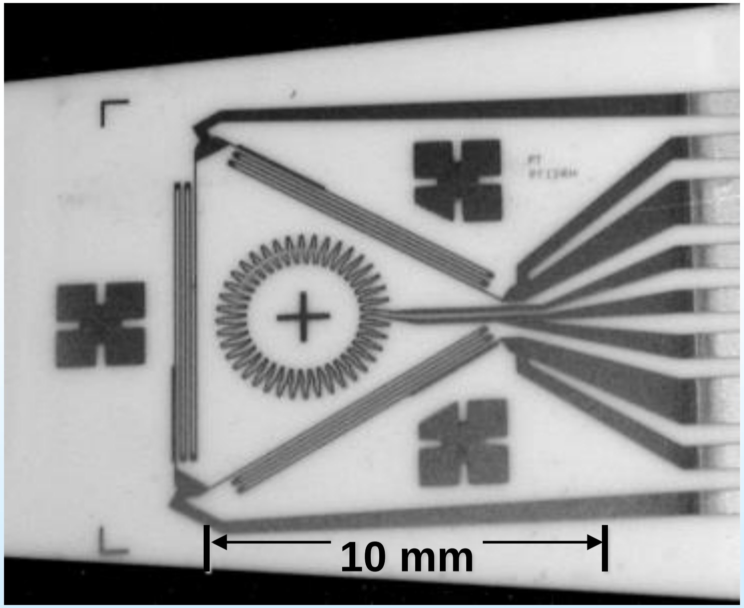
PdCr thin film strain gauge applied to a material sample for disk life fatigue testing

Multi-Functional Sensor System

- Multifunctional thin film sensor designed and built in-house
- Temperature, strain, and heat flux with flow all one 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



Schematic of Multifunctional Sensor

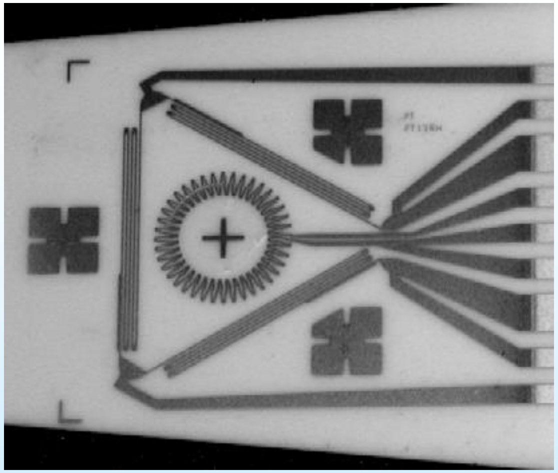


Multifunctional Sensor Prototype

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

PdCr Strain Gauge in Compensation Bridge



Multifunctional Sensor Design

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

Thermopile Heat Flux Sensor on a plug (left) and as part of a Multifunctional Sensor (right)

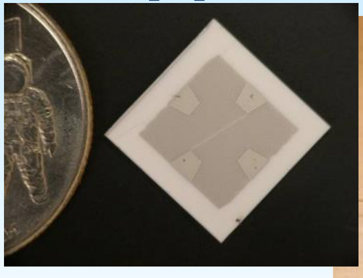
RTD-based Heat Flux Sensor

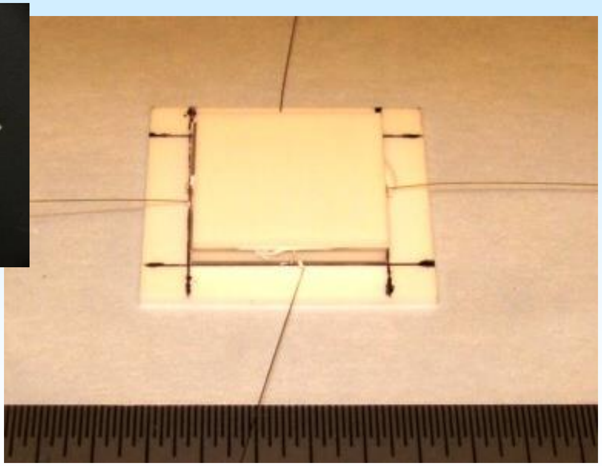
- Temperature difference across a thicknesses of insulation is measured by thin film RTD's
- Insulation may be a thin film TBC or the substrate itself
- Utilizing a Wheatstone bridge, this sensor is easier to fabricate and has a larger signal than thermopile-type

One-sided RTD Heat Flux Sensor (above); Double-Sided on Kapton (right)

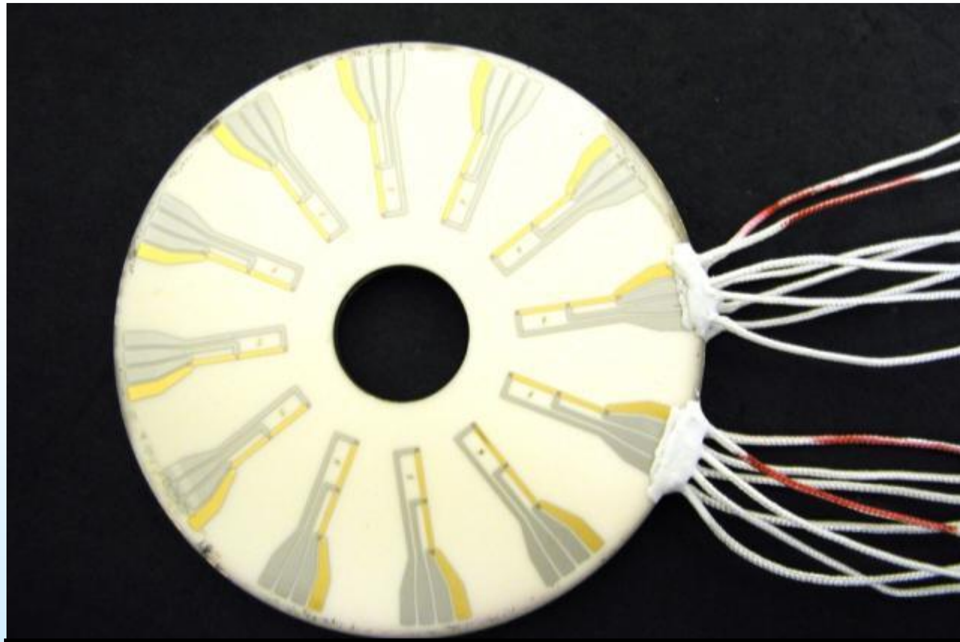
Heat Flux Sensor Applications

- 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





Delivered High Temperature Heat Flux Sensor for CEV/TPS (above); as packaged (left)



6.66 cm dia. Thin Film AuPt Heat Flux Sensor for Advanced Stirling Convertor Demonstration

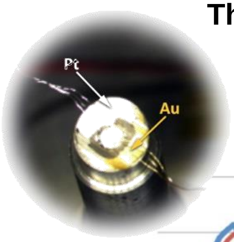
VIPR Thin Film Thermocouple

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

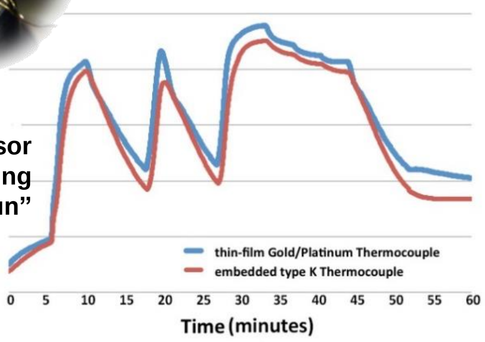
SIGNIFICANCE
- Operation of thin film thermocouple sensor prototypes validated as installed in bleed-air borescope ports
- Sensors tracked dynamic engine temperature changes through multiple power cycles with faster response than embedded thermocouples
- Data included monitoring VAE performance trends
- 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

VIPR 2 Design: Metal Probe / Au-Pt Thermocouple



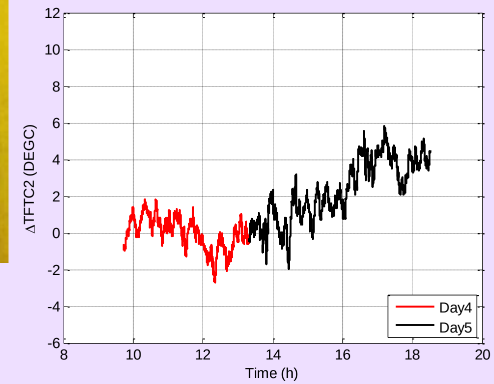
Sensor tip with 0.003" wires attached to deposited thin films

Thin Film Sensor Operation During "Green Run"



VIPR 3 Design: Spark Plug / Pt-Pd Thermocouple

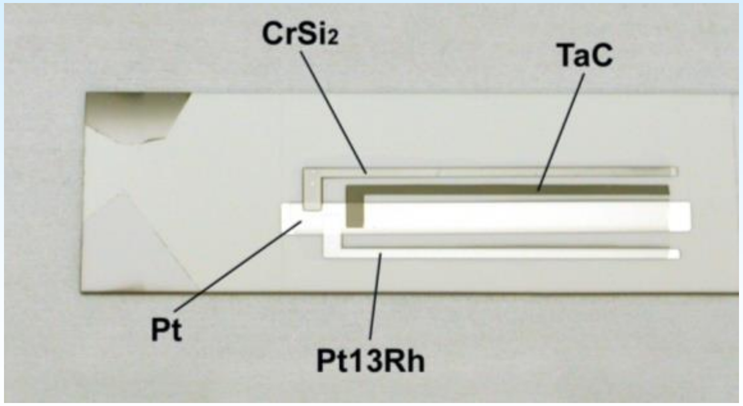
Thin film deposition processing on "Spark Plug" sensor tip



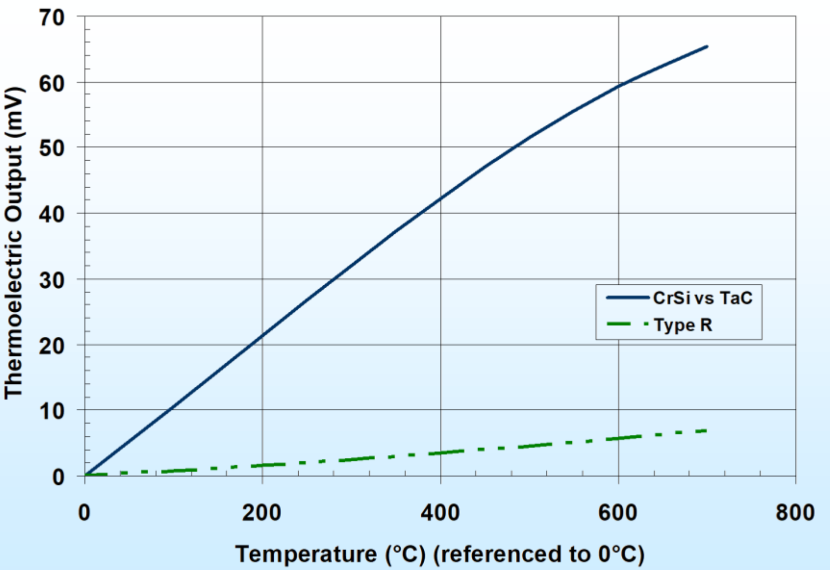
Thin Film Sensor Data: Volcanic Ash Runs Day 4-5

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 $TaSi_2$

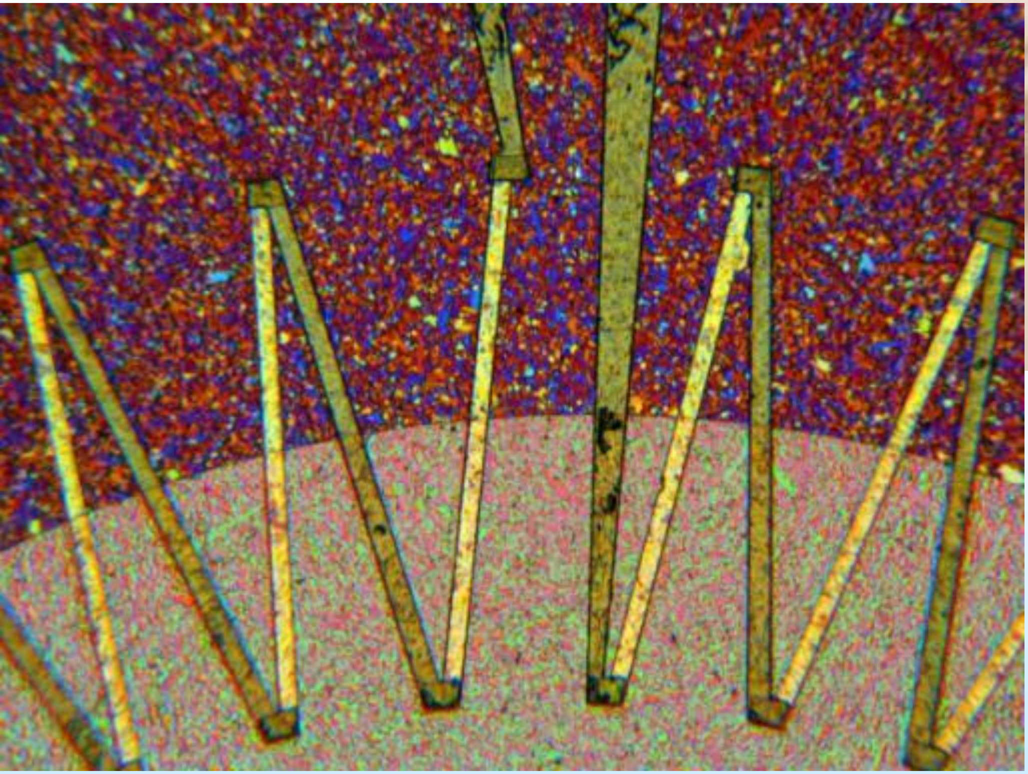


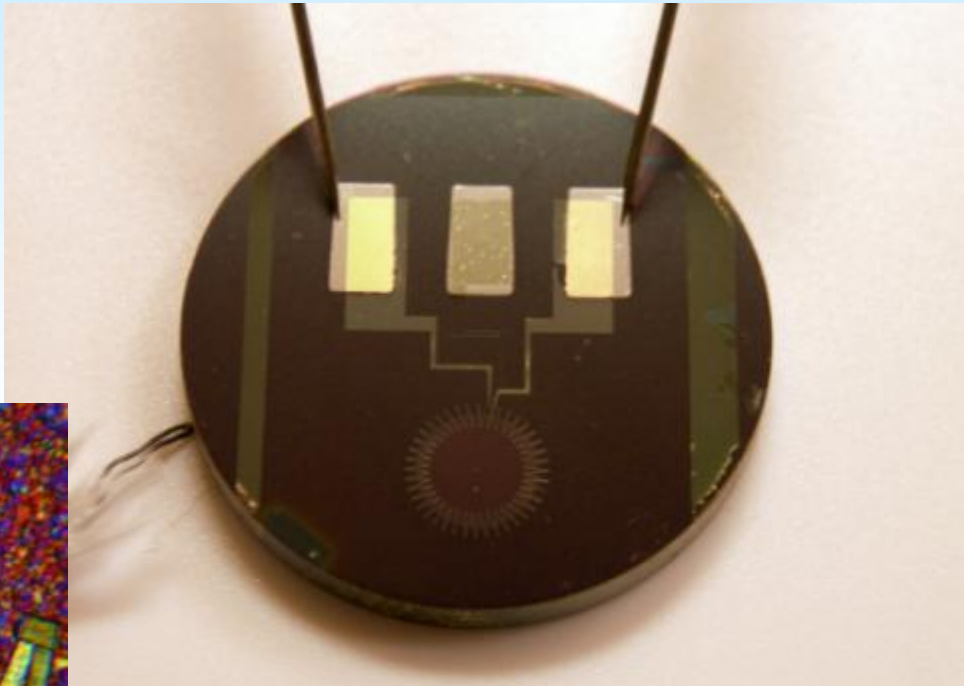
- **Thin Film Ceramic TC Sample and measured performance**



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



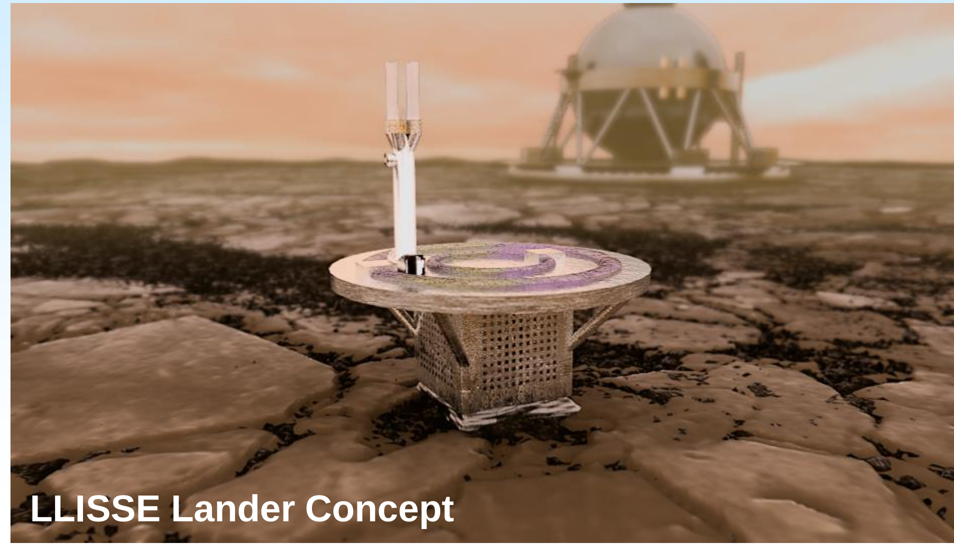


Thin Film Heat Flux Sensor on α-SiC (Films are transparent; detail left)

- Sensor survived fabrication
- Response tested on two heat sources with similar heat flux but different temperatures
  - 0.2 W/cm^2, 250°C and 500°C
  - Response 0.6 mV/W/m^2

LLISSE Venus Sensors

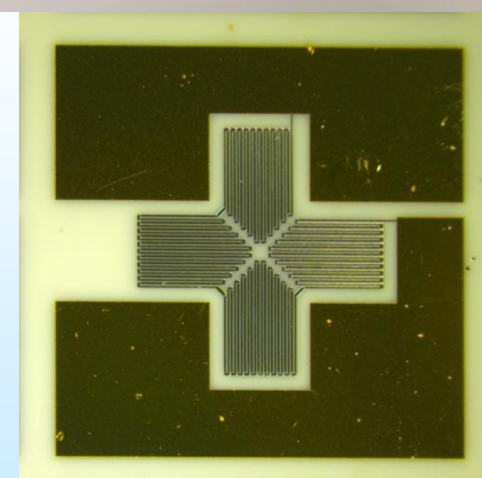
- Miniaturized sensor systems produced by microfabrication techniques and high temperature compatible materials
- Wind Sensor
  - Goal to measure wind speed, direction and variability in harsh Venus atmosphere
  - Approach uses strain gauges on a cantilever (miniature drag force anemometer)
- Radiometer
  - Goal to measure the amount of sunlight reaching the Venus surface over time
  - Approach uses a thin film thermopile-type heat flux sensor (bolometer)



LLISSE Lander Concept

LLISSE Wind Sensor Proof-of-Concept (above)

Bolometer for LLISSE Radiometer Proof-of-Concept (right)



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