Development and Ground-Test Validation of Fiber Optic Sensor Attachment Techniques for Hot Structures Applications

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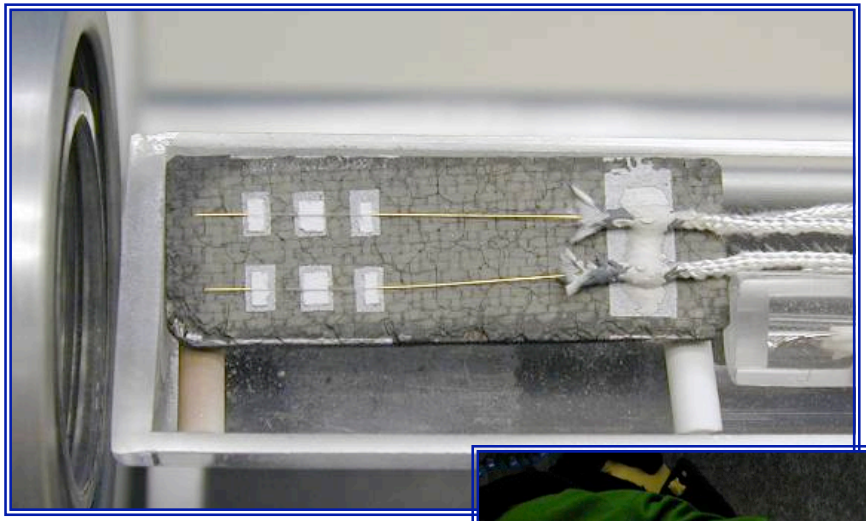
Outline

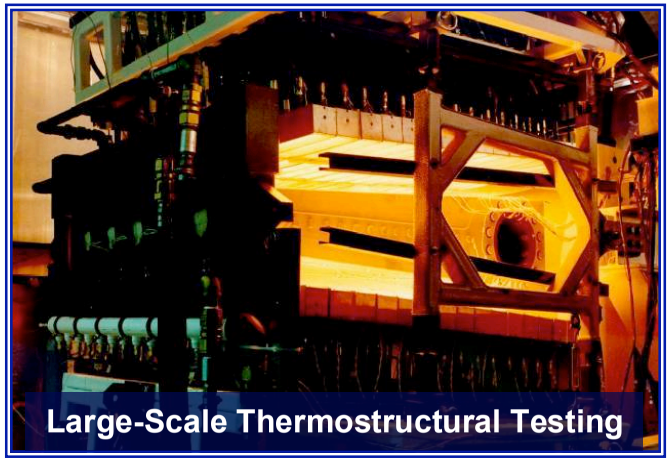


- Background
- Research Motivation
- Objectives
- Sensor Overview
  - Fiber Bragg Grating
  - Extrinsic Fabry-Perot Interferometer
- Sensor Attachment Techniques
- Laboratory Validation Testing
- Large-Scale Ground Applications
- Concluding Remarks

Background

Flight Loads Laboratory (FLL)


Large-Scale Aircraft Testing


Large-Scale Thermostructural Testing

A unique laboratory for performing large-scale structural and thermal testing of aerospace vehicles and components

- Large 20,000 ft^2 high-bay test area
- Structural loading equipment including load frames, load cells, and hydraulic actuators
- Thermal structural testing in air and nitrogen purged atmospheres
- Quartz lamp and graphite heating systems
- Large channel capacity data acquisition system
- Strain, temperature, and heat flux measurements on metallics, metal matrix composites, superalloy honeycomb, C/C, C/SiC, etc.
- Sensor attachment techniques include epoxy, ceramic cements and thermal-spraying
- Fiber optic strain and temperature validation testing for ground and flight operations

Background

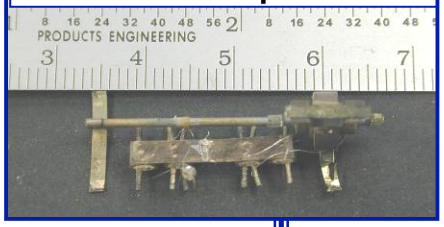
Hot-Structures Strain Measurement Research

1960-1970

Flame-sprayed Resistive

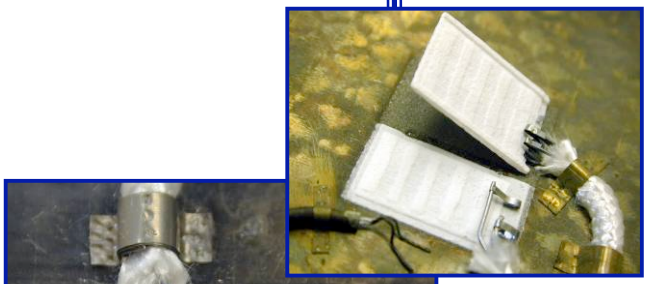
Weldable Resistive

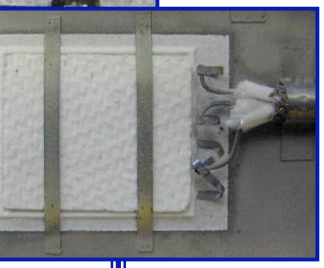
Weldable Capacitive



Large temperature-related measurement uncertainties

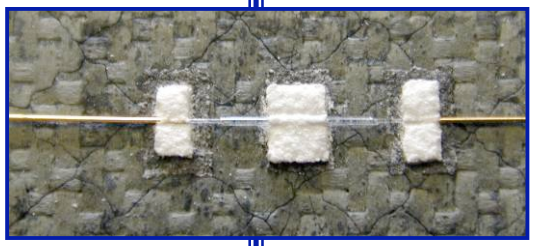
1980-1990





Improved temperature-compensation using flame-sprayed resistive gages

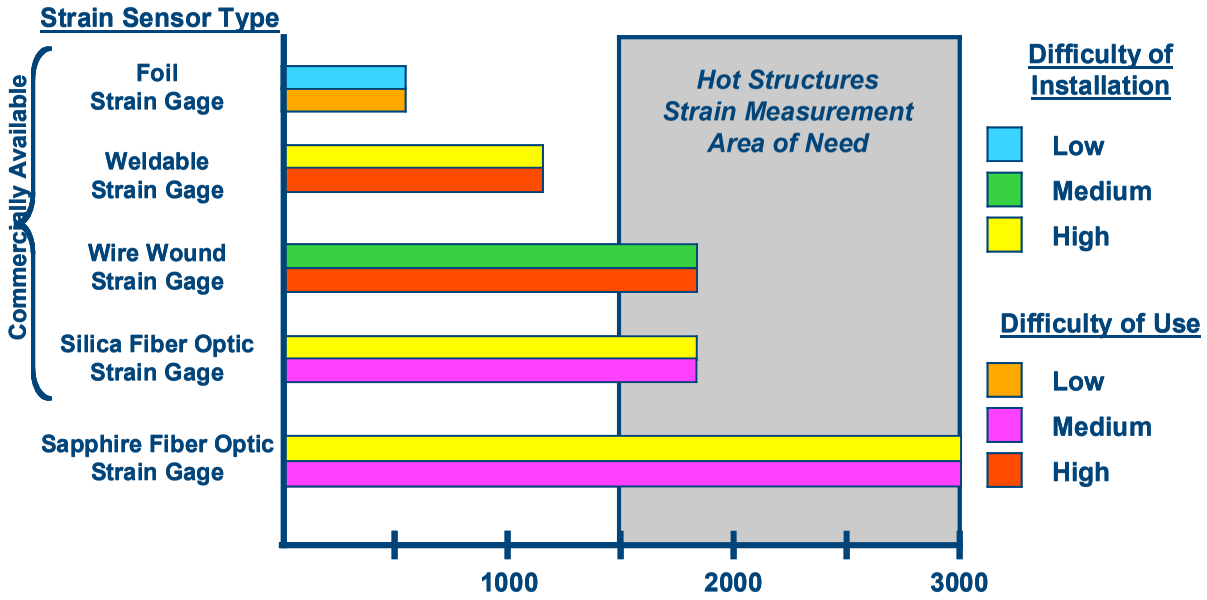
2000-present



Improved measurement accuracy applying Silica and Sapphire EFPI Technology

Research Motivation

Need for Sensor Development



Lack of Capability

- Hot structures are utilizing advanced materials that operate at temperatures that exceed our ability to measure structural performance
- Robust strain sensors that operate accurately and reliably beyond 1800°F do not exist

Implication

- Hinders ability to validate analysis and modeling techniques
- Hinders ability to optimization structural designs

Objectives

Develop Attachment Techniques

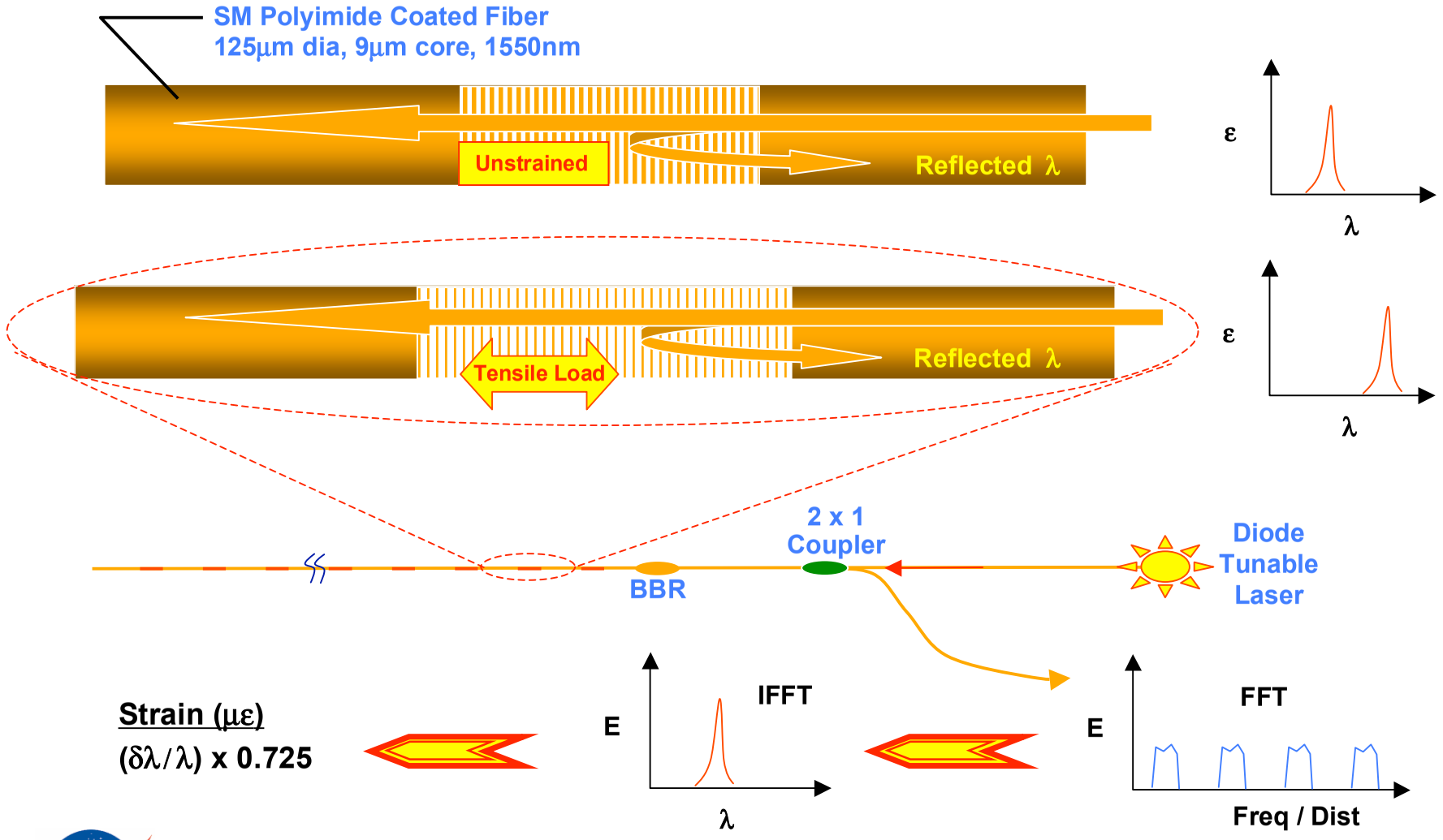
- **Develop methods of handling fragile silica sensors during installation and coarse thermal spray processes**
- **Evaluate organic cement/epoxy attachments to 550°F**
- **Develop and evaluate thermal spray and cement attachments of EFPI's for controlled laboratory testing**

Obtain Optical Strain Measurements on Relevant Substrate Materials and Structures

- **Graphite composite coupons for apparent strain (ε_{app}) characterization**
- **Monolithic Inconel load bars for baseline sensitivity characterization**
- **C-C and C-SiC substrates for sensitivity and ε_{app} characterization**
- **Large scale hot-structures for NGLT, OSP, and X-37 Control Surfaces**

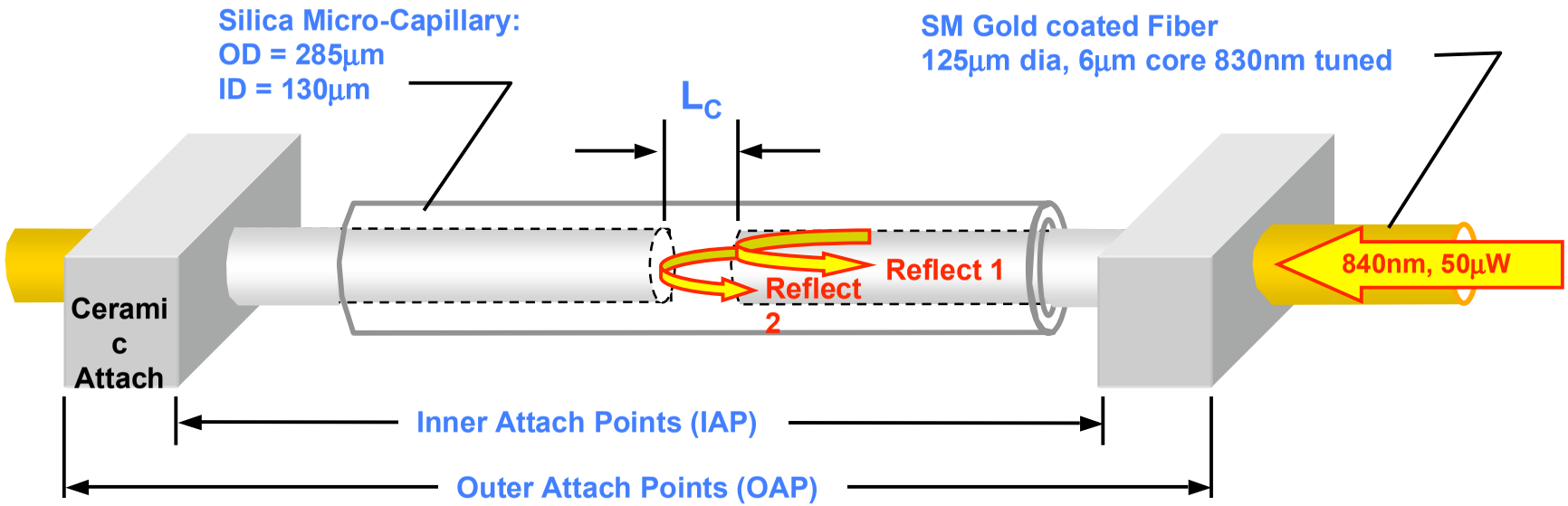
Fiber Bragg Grating (FBG)

Sensor and Multiplexing



Extrinsic Fabry-Perot Interferometer (EFPI)

Sensor Construction



- **Cavity Length (L_C),** distance (microns) separating the two reflecting fiber surfaces
- **Gage Length (L_G),** or sensitivity, distance (millimeters) separating the two points that attach the optical fiber to the substrate

Strain = $\Delta L_C / L_G$

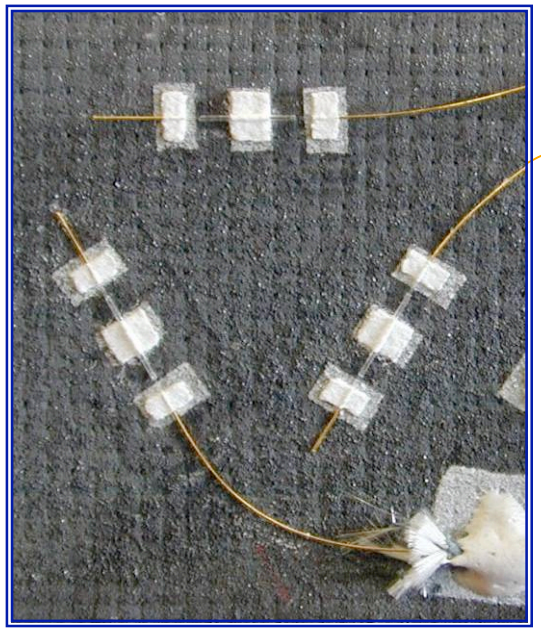
where L_G (or GF) = [2(IAP) + OAP] / 3

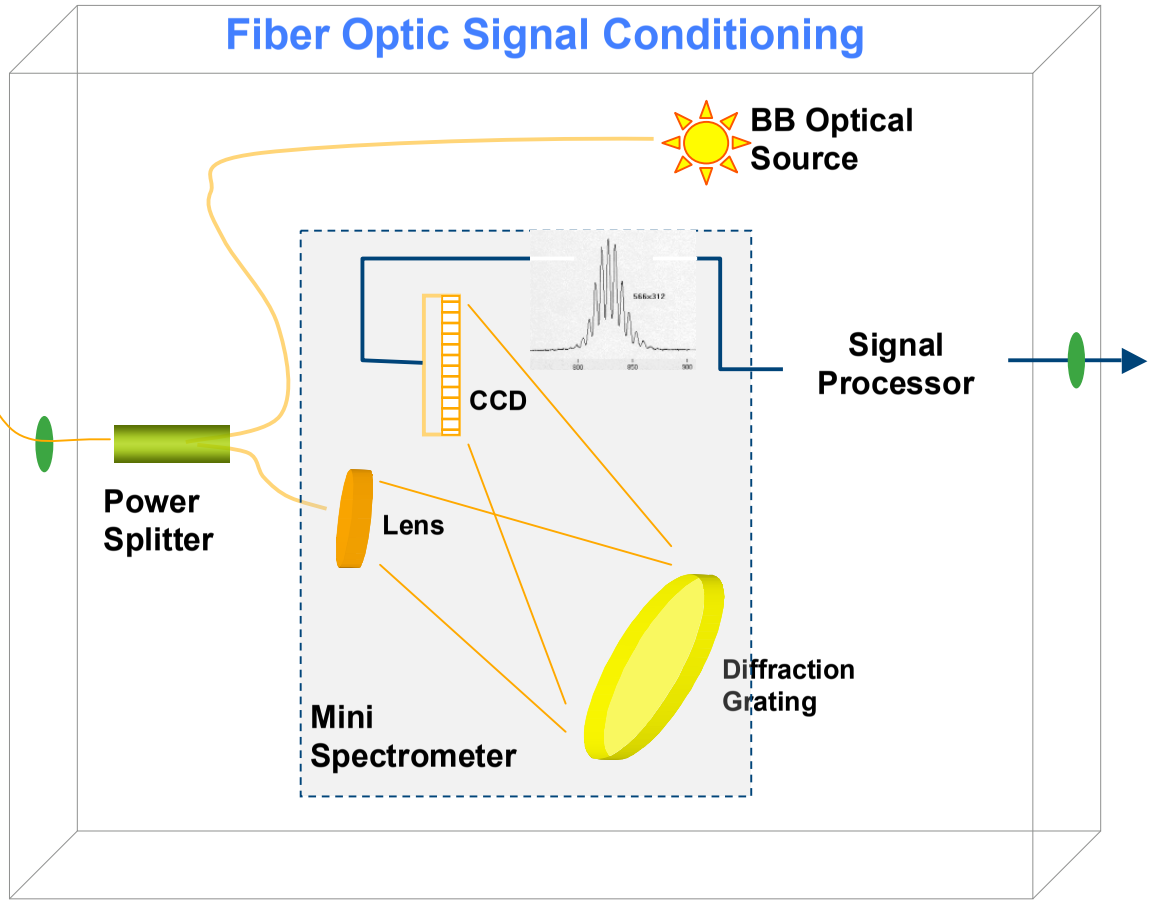
$\varepsilon_{app} = (\alpha_{sub} - \alpha_{fiber})^* \Delta T$

Extrinsic Fabry Perot Interferometer (EFPI)

Sensor Conditioning

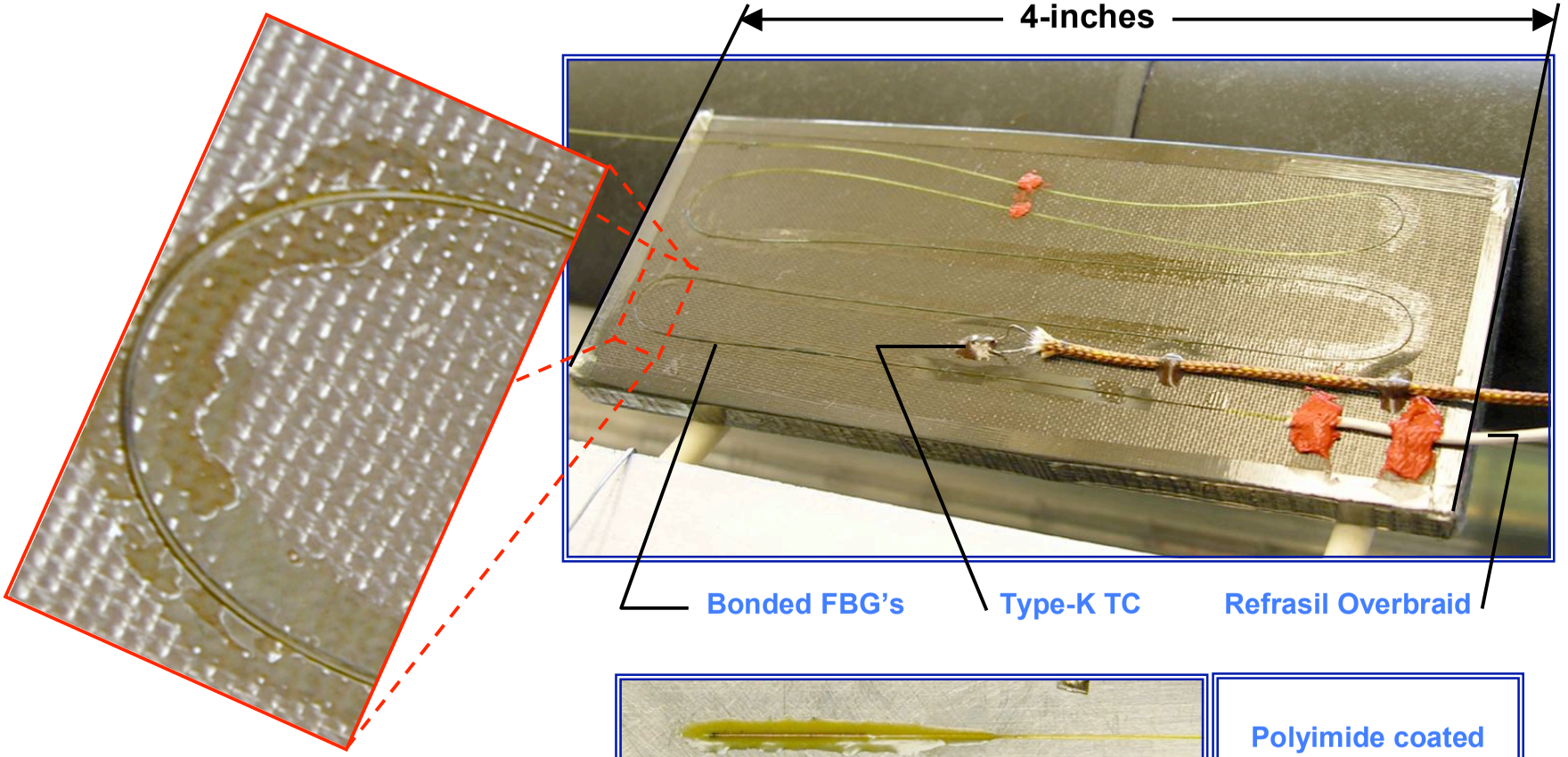
EFPI Delta Rosette on C-SiC



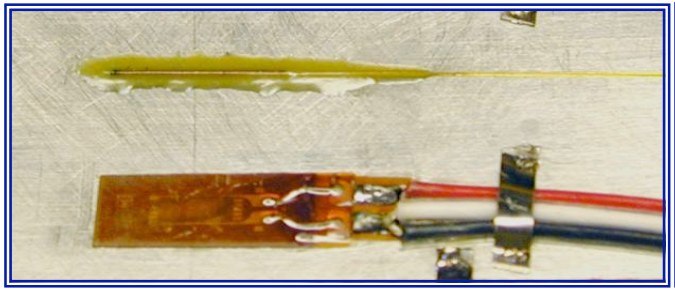


Installation and Attachment Techniques

Organic Cements (<550°F)



Two applications of MB610 sufficiently coat fiber



Polyimide coated EFPI bonded with mixture of GA-61 and MB610

Installation and Attachment Techniques

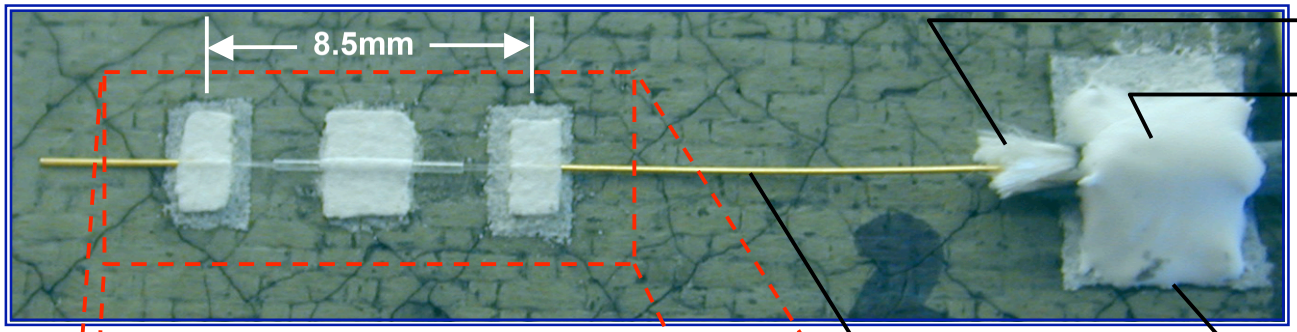
Thermal Spray Process

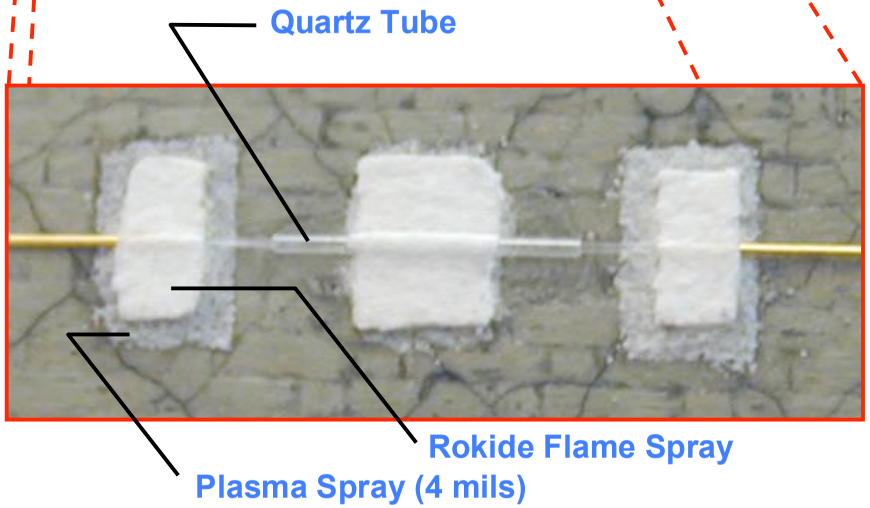
Thermal Spray Equipment Room

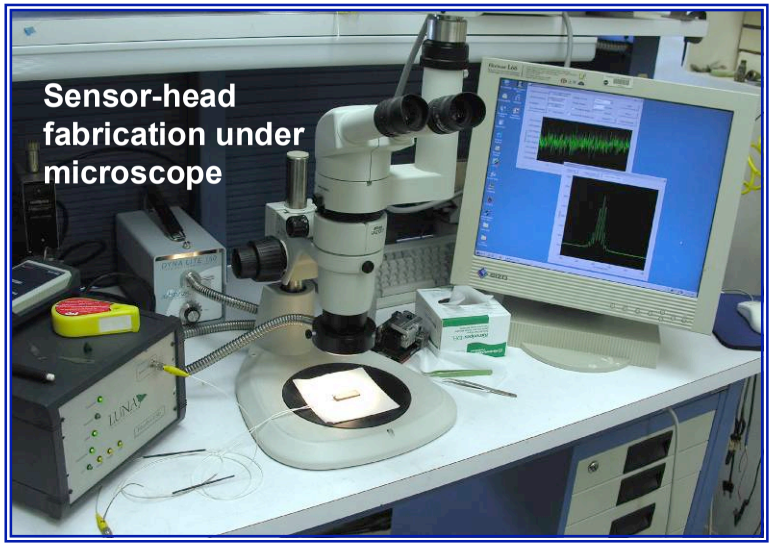
- 80KW Plasma System
- Rokide Flame-Spray System
- Powder Spray System
- Sand-Blast Cabinet
- Micro-Blast System
- Water Curtain Spray Booth

Installation and Attachment Techniques

Thermal Spray Process (>600°F)

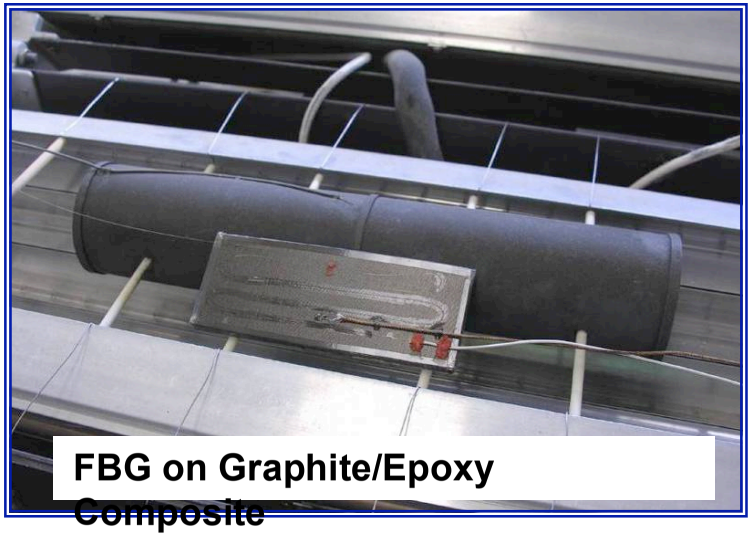






Laboratory Coupon Test Results

Fiber Bragg Gratings



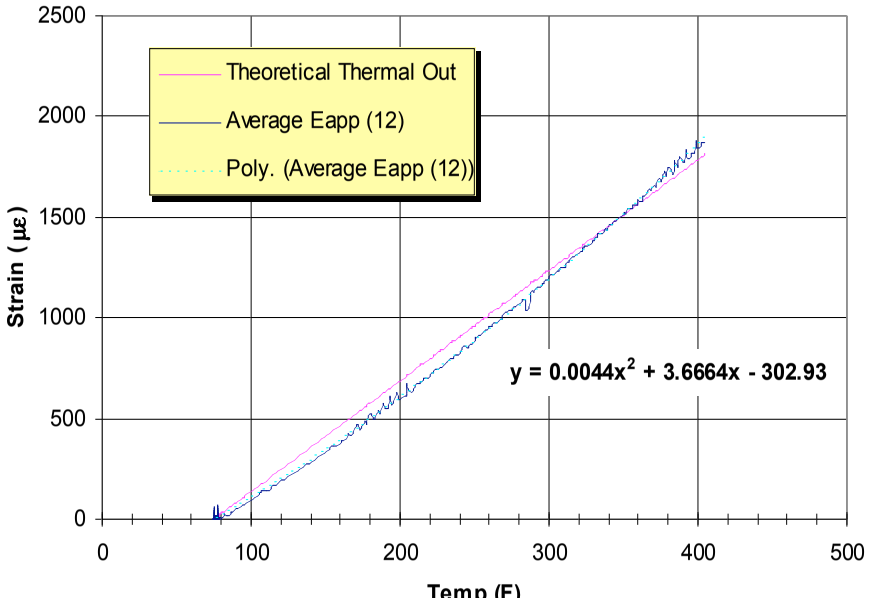
FBG on Graphite/Epoxy Composite

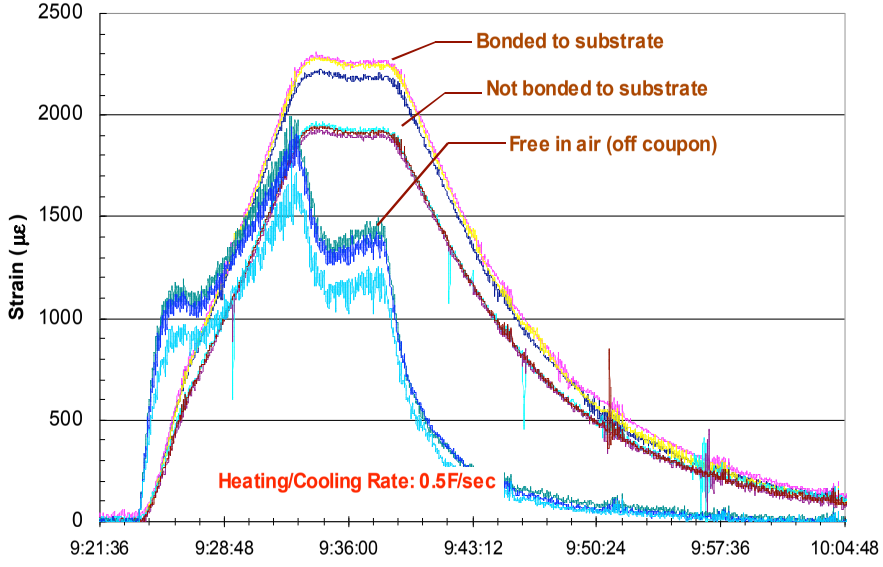
Thermal Out (unbonded) = $(\alpha_{fiber} + \xi / Pe) * \Delta T$

where:

Thermal Optic Effect (ξ) = 3.78 $\mu\varepsilon$/F

Strain Optic Constant (Pe) = 0.725

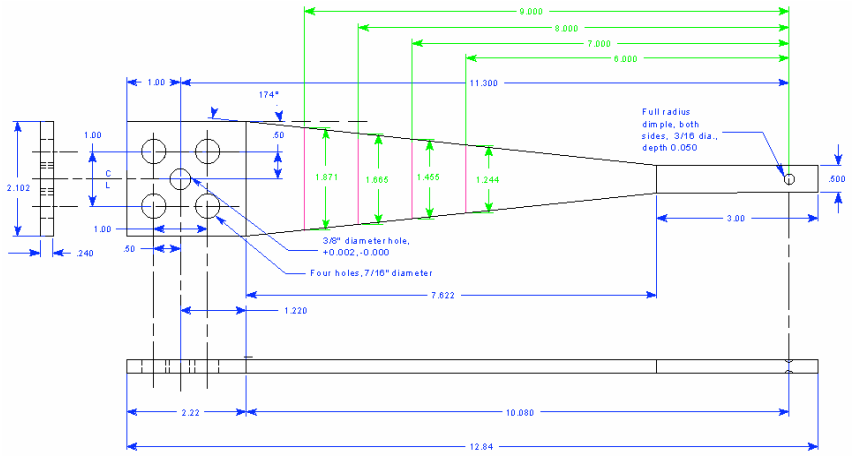


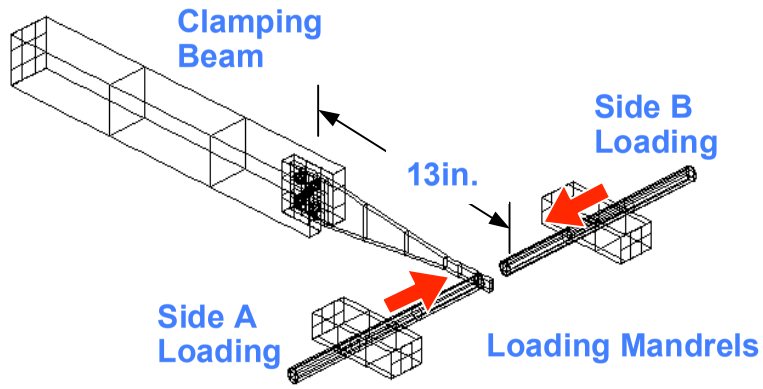


Laboratory Coupon Test Results

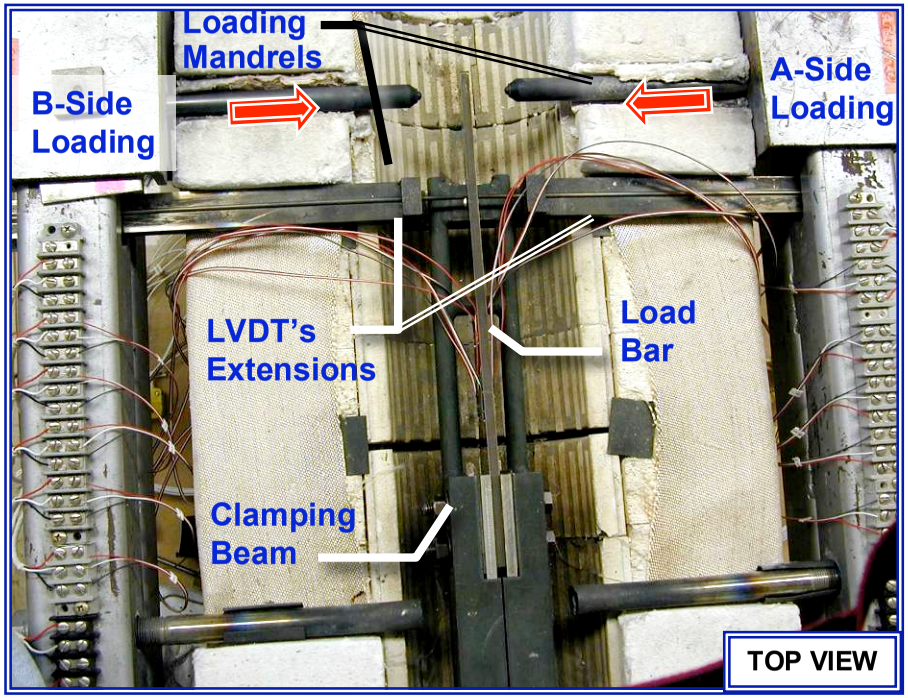
Thermal / Mechanical Test Fixture

Constant Strain Load Bar





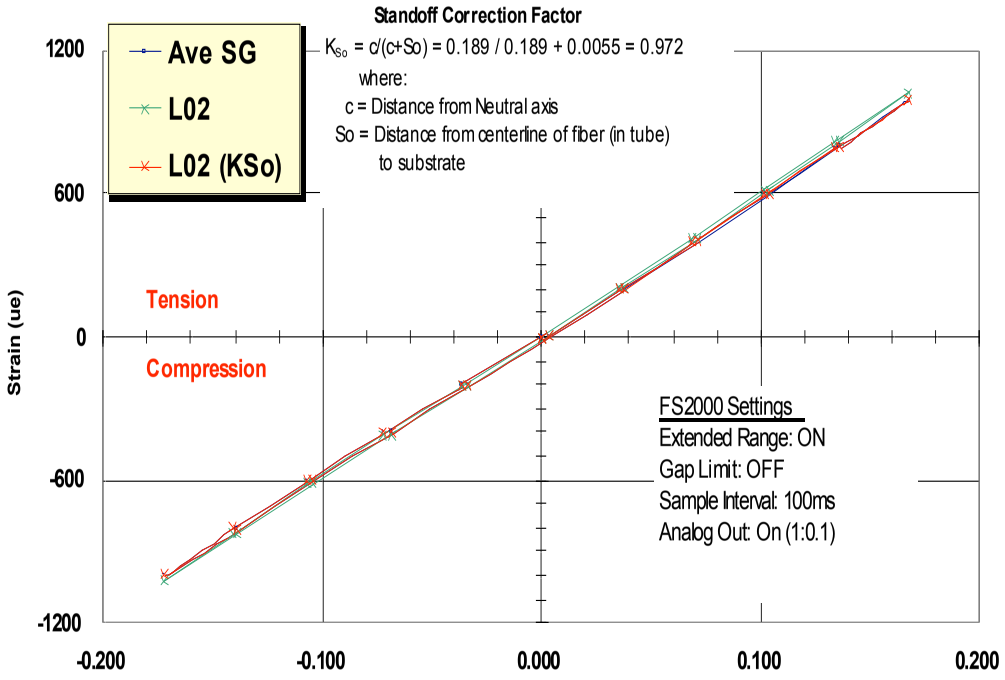
Strain Gage Evaluation System

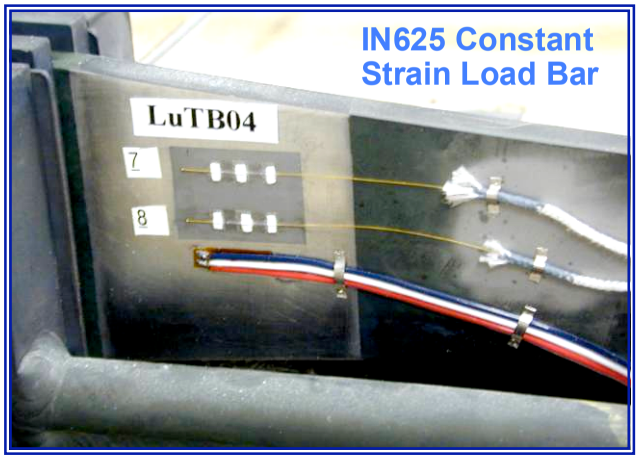


Laboratory Coupon Test Results

Gold-Coated EFPI Thermal Mechanical Test Results

EFPI Cantilever Beam Data at Room-Temp
±1000με Mechanical Load



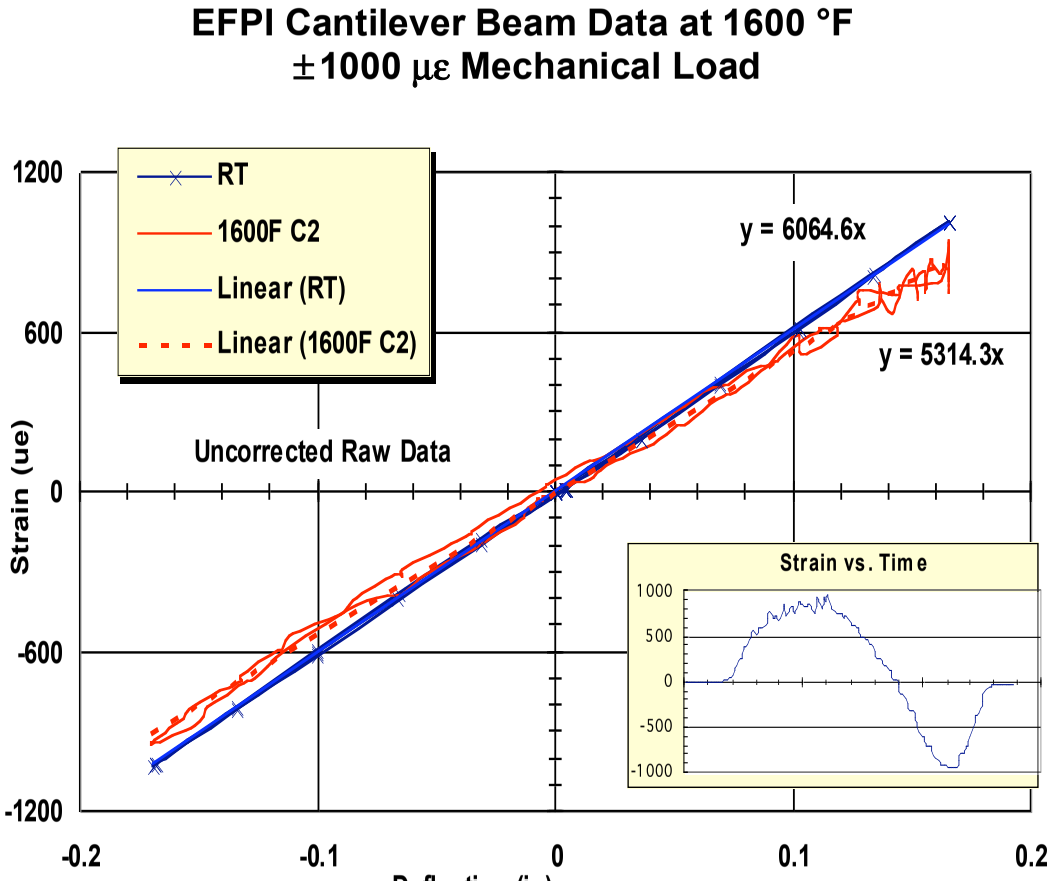


Observations

- **EFPI within 3% of SG's at RT**
- **After standoff correction sensors within 1%**
- **Subsequent testing at 500, 800, & 1200°F within 3% of RT slope**
- **Little hysteresis**

Laboratory Coupon Test Results

Thermal Mechanical Test Results

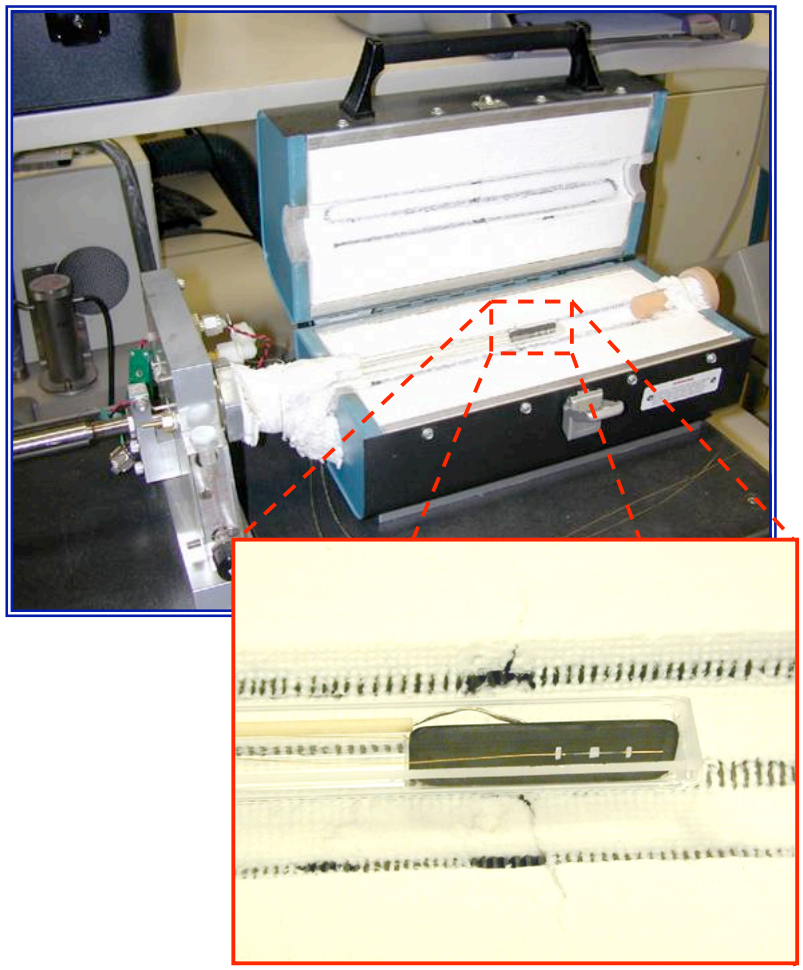


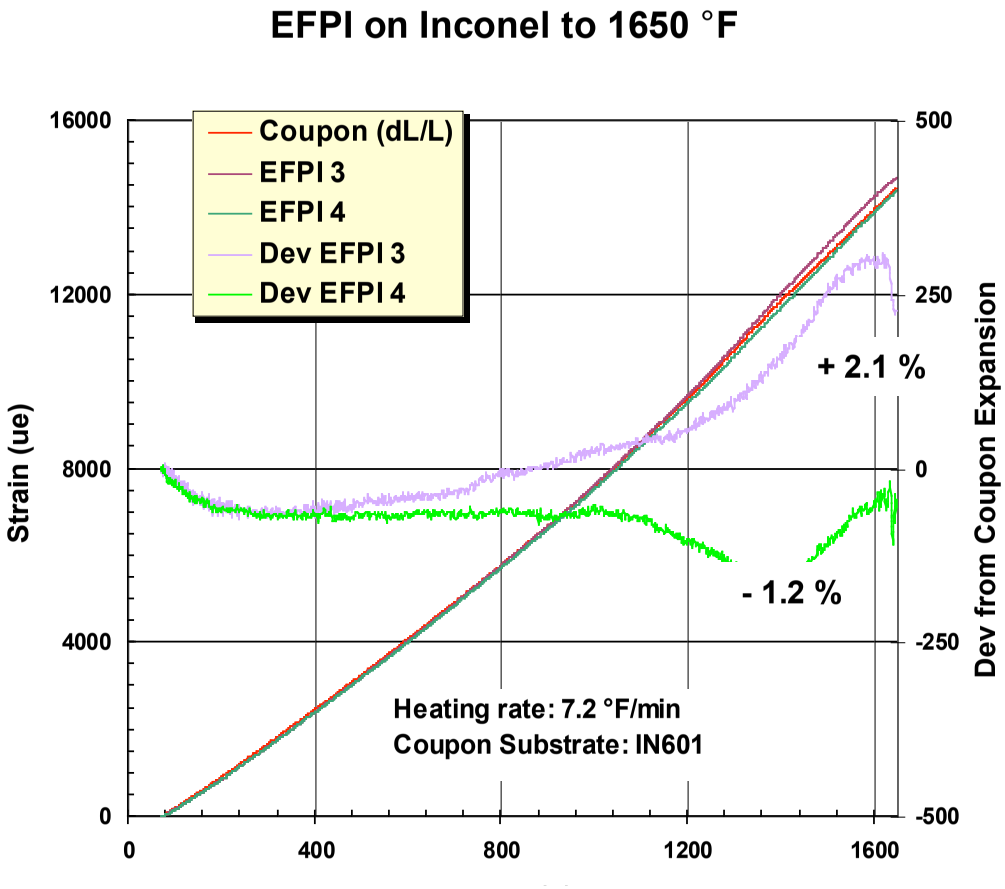
Observations

- In tension, output was noisy, sensor gap out of range (gap ≈ 203μm @14,450με)
- Overall slope down 5% from RT slope @ 1600°F
- Repeat RT tests showed good correlation with prior data
- Subsequent sensors and tests indicate an inconsistency of maximum gap readability

Laboratory Coupon Test Results

Metallic Dilatometer Results

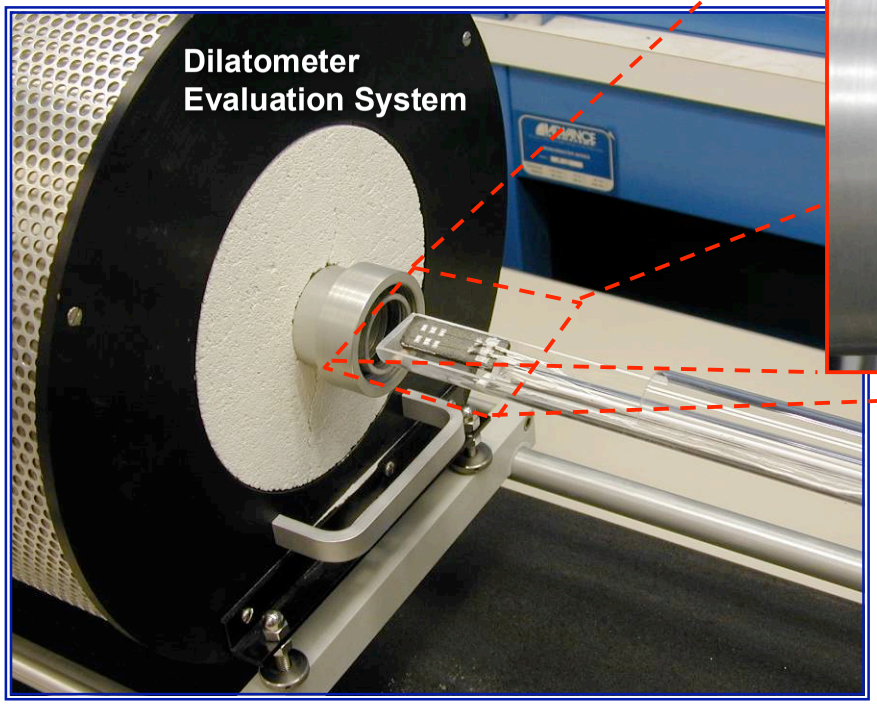


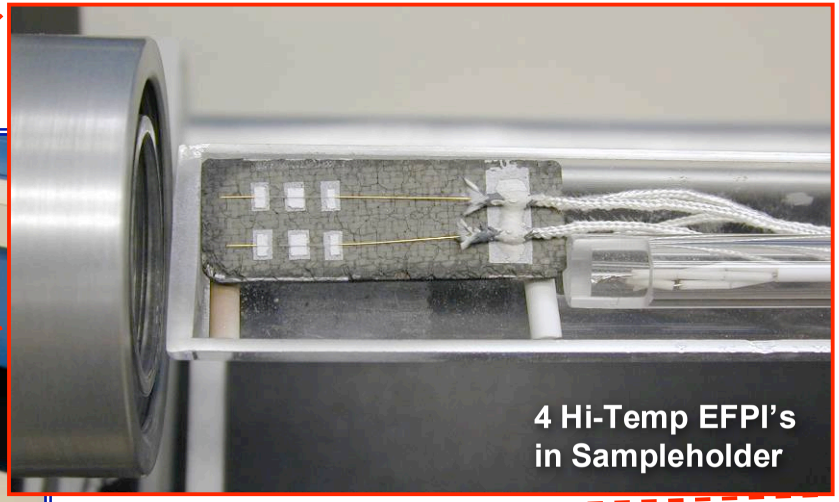


Laboratory Coupon Test Results

Dilatometer Results

EFPI Thermal Sprayed to C-C and C-SiC



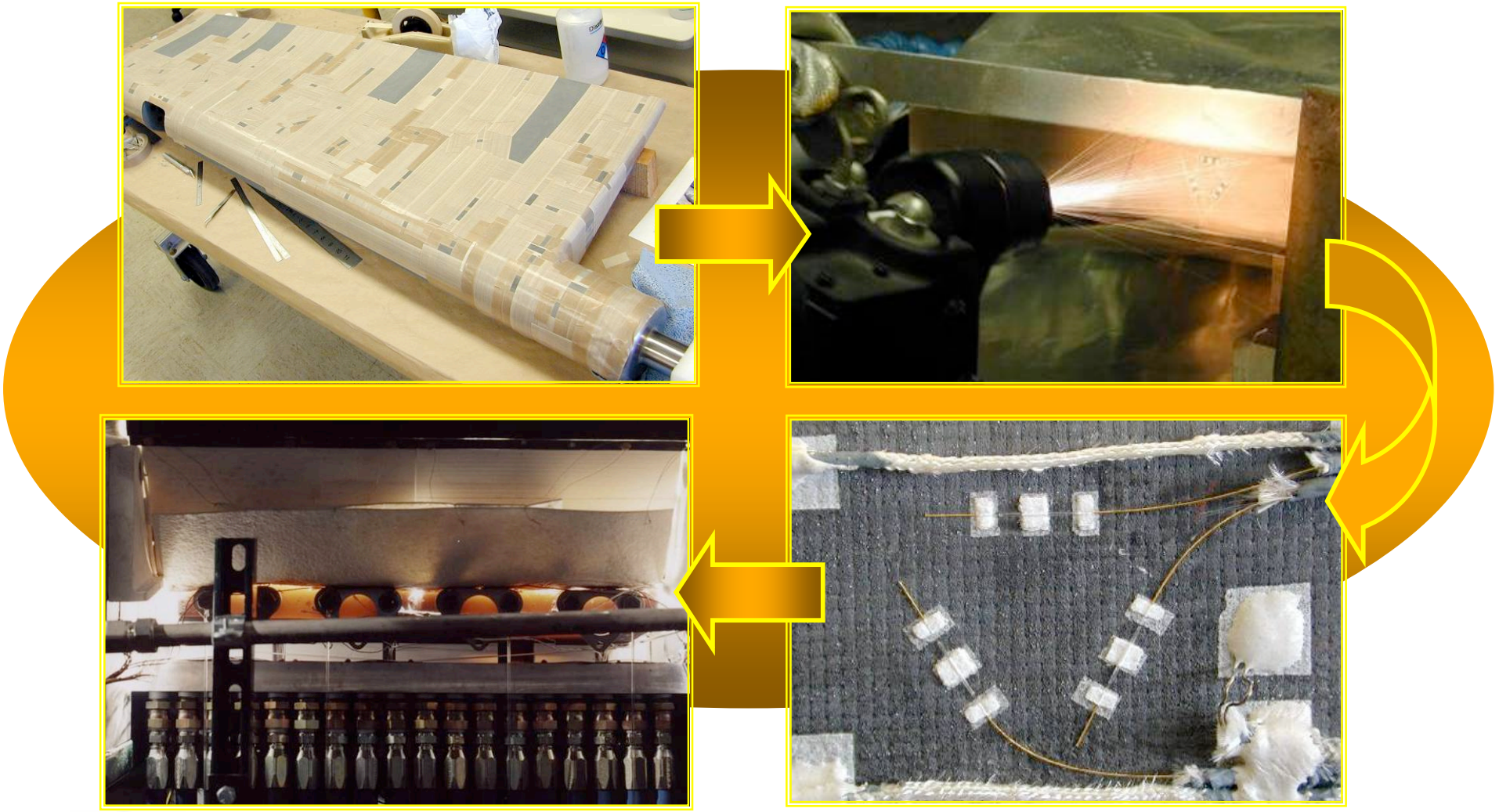


Sensor Characterization

- Evaluate bond integrity
- Evaluate sensitivity and accuracy
- Evaluate sensor-to-sensor scatter and repeatability
- Generate ε_{app} correction curves

Large Scale Ground Test Structures

C-SiC Flaperon



Large Scale Ground Test Structures

Ceramic Composite Control Surfaces

Concluding Remarks

Fiber Optic Strain Measurements

- Successfully attached silica fiber optic sensors to both metallics and composites
- Accomplished valid EFPI strain measurements to 1850°F
- Successfully attached EFPI sensors to large scale hot-structures
- Attached and thermally validated FBG bond and ε_{app}

Future Development

- Improve characterization of sensors on C-C and C-SiC substrates
- Apply application to other composites such as SiC-SiC
- Assist development of interferometer based Sapphire sensor currently being conducted under a Phase II SBIR
- Complete combined thermal/mechanical testing of FBG on composite substrates in controlled laboratory environment