Optical Fiber Instrumentation for Slagging Coal Gasifiers

Kristie L. Cooper, Anbo Wang

Center for Photonics Technology
Bradley Department of Electrical and Computer Engineering

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Program Manager: Robie Lewis

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- **Physical sensing applications**
  - **Pressure: static (20,000psi) and dynamic (150kHz)**
  - **Strain at temperatures up to 1600°C**
  - **Temperature up to 1600°C**
  - **Acoustic waves (0.001-300,000Hz)**
  - **Fluid flow**
  - **Index of refraction (0.0001)**
  - **Magnetic fields (50-40,000nT)**
- **Field test sites**
  - **Coalinga, CA; Tulsa, OK; London, UK; Blacksburg, VA; Polk County, FL**

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Gasification sensing needs

- ## Refractory wear
    - 3-30 month lifetime
    - Most critical factor limiting availability
    - Replacement downtime

- ## Temperature monitoring
    - High: efficiency, refractory wear
    - Low: plugging
    - Thermocouple failure and drift

Advantages of fiber optic instrumentation

- Immunity to EMI
- Avoidance of ground loops
- Functional flexibility
- High resolution
- Resistance to harsh environments
- Ease of multiplexing and system integration
- Waveguide selection

Objective: To develop a fiber optic sensing system to monitor refractory wall thickness and temperature inside a slagging coal gasifier.

Basis:

- Optical time domain reflectometry (OTDR) distance measurement
- Extrinsic Fabry-Perot interferometric (EFPI) temperature measurement
- White light interferometry data processing algorithm
- Silica to sapphire fiber connectorization

Thickness Measurement Scheme

- Embedded silica-based fiber sensor head, suitable for operation up to 800-900°

- Time of flight

- Resolution determined by the light pulse duration and the timing accuracy of the OTDR electronics

OTDR → Reference Reflection → Refractory Wall / Corrosive Environment
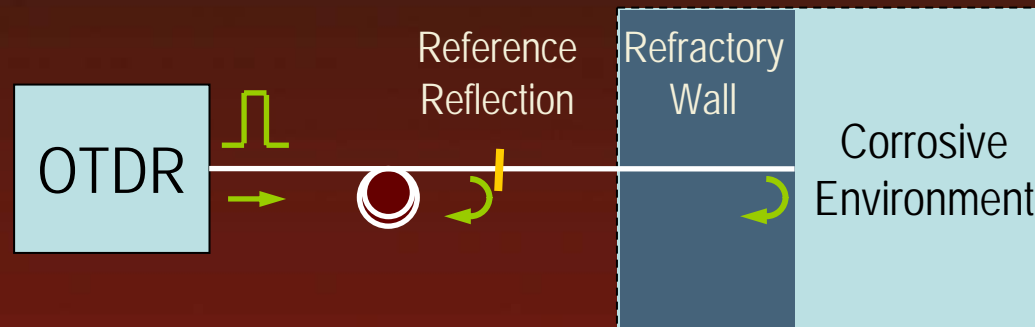
Creating the Reference Reflection

- Quality and intensity critical to measurement accuracy
- Fabrication methods
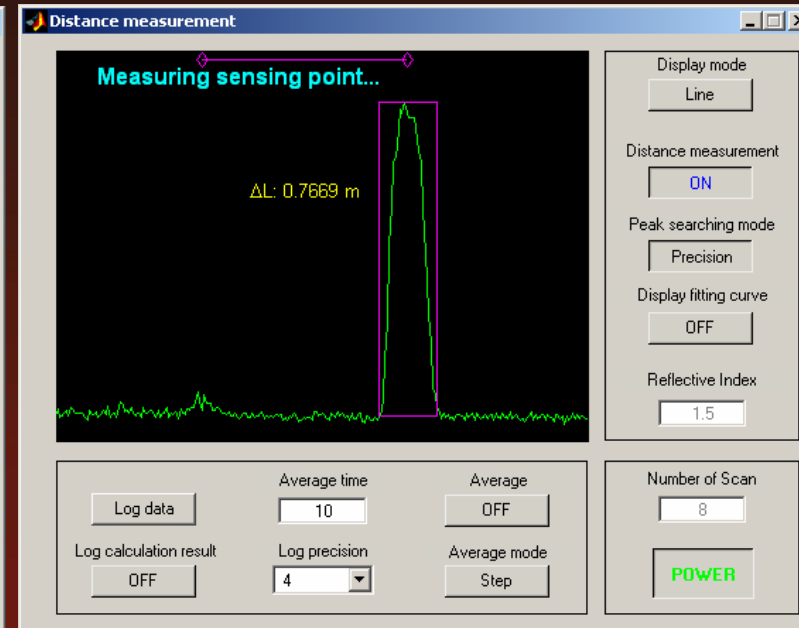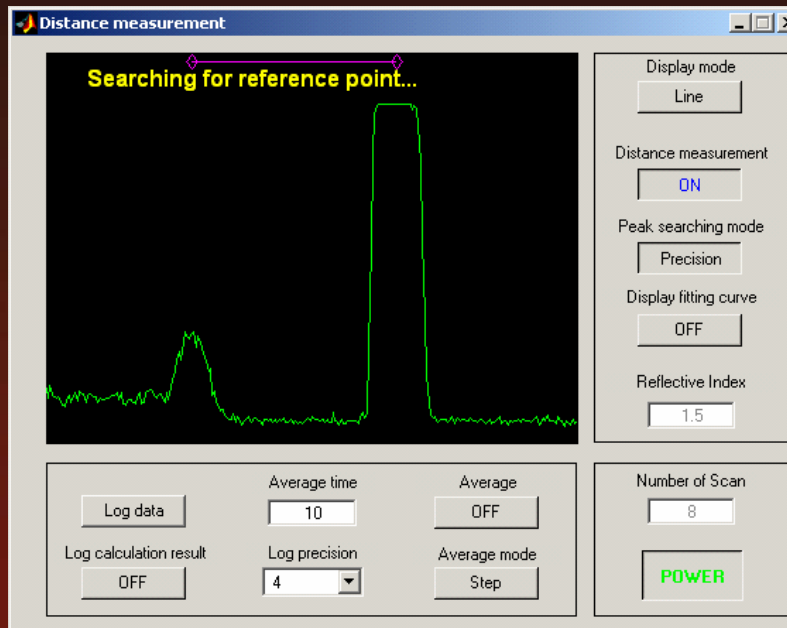 - Microgap
  - Misalignment
  - Hollow core fiber
  - Capillary tube alignment

Data Processing Algorithm

- **User interface**
- **Data acquisition**
- **Data processing and storage**

Data Processing Algorithm

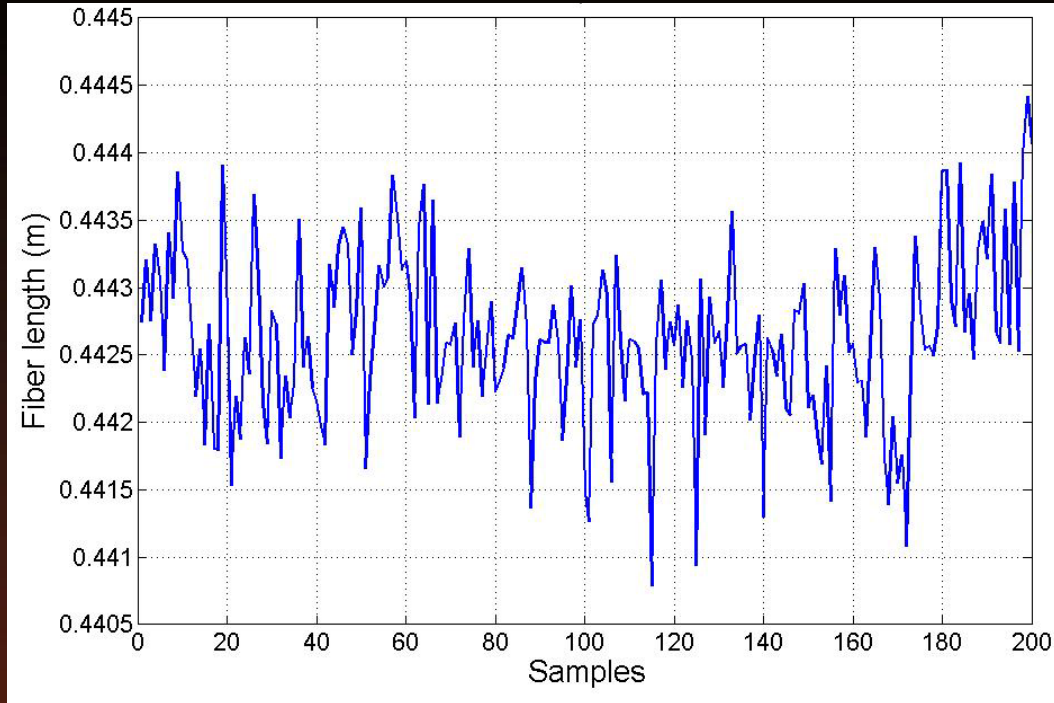- Peak intensity range

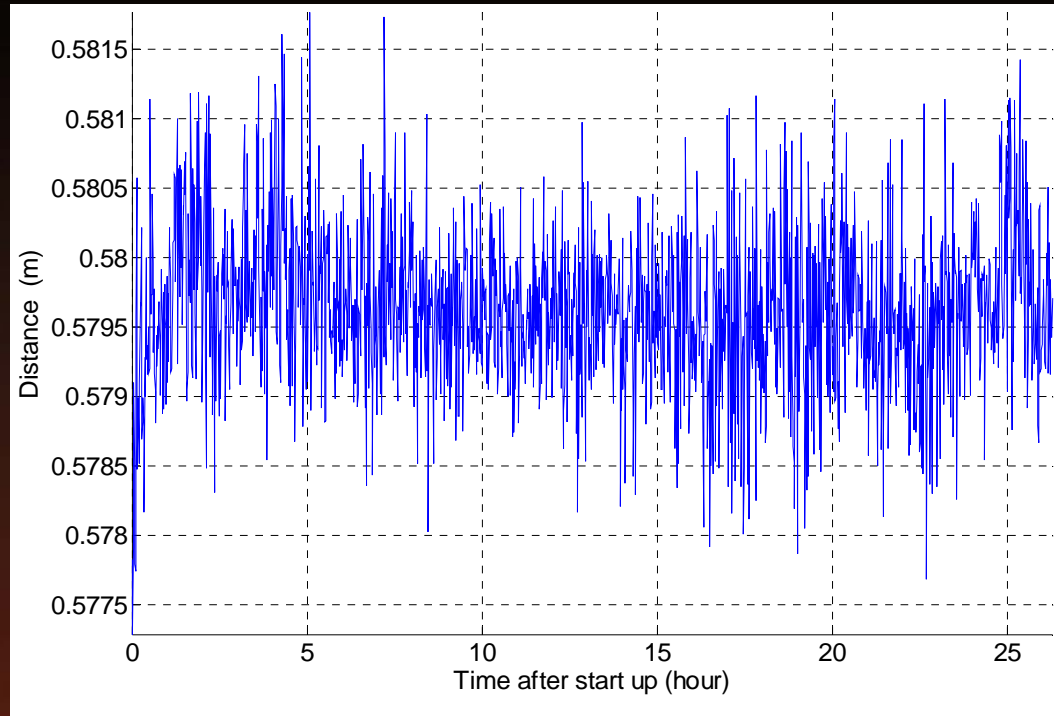- Peak search vs. peak measurement scan
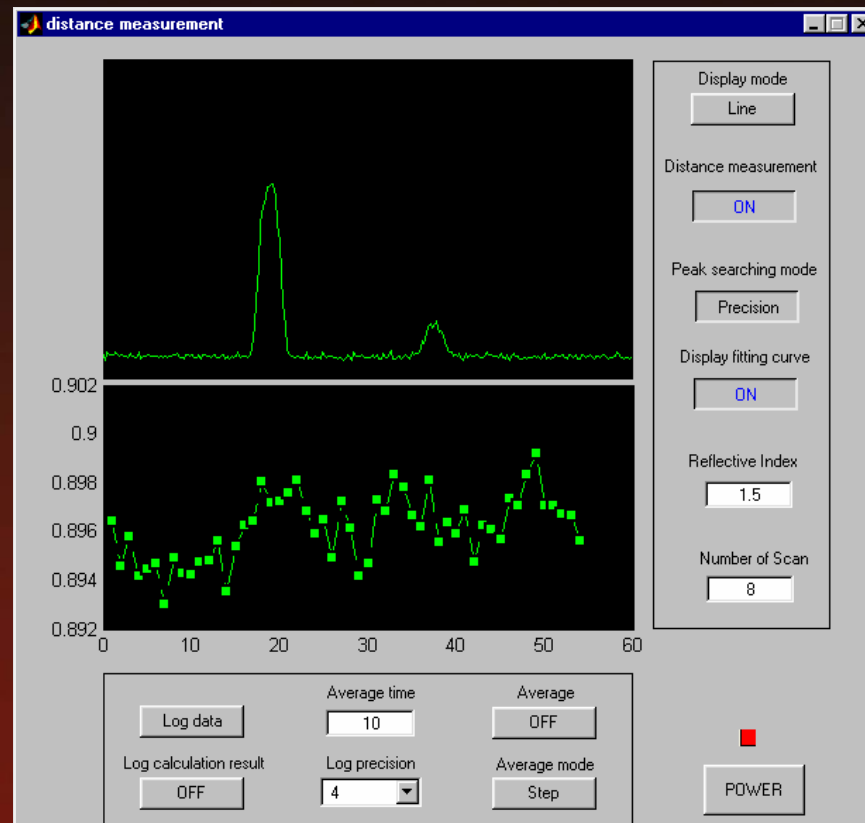
Room Temperature Evaluation

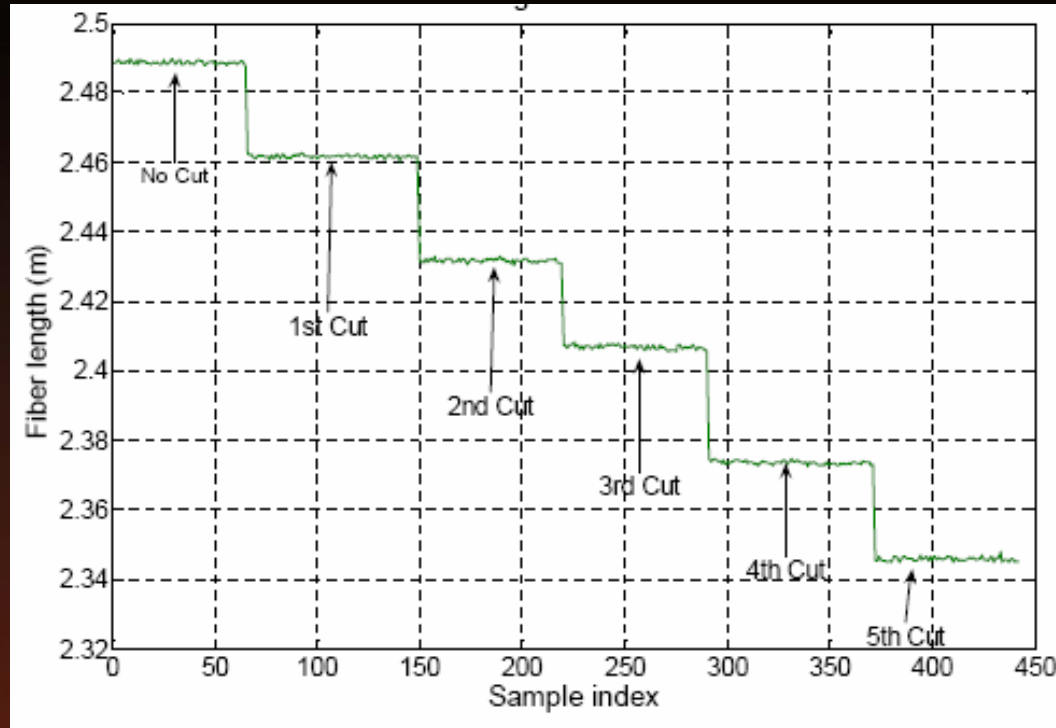- Approx. 200 minutes
- Standard deviation 0.63 mm/0.34 mm

600°C Testing

- **24-hour test**
- **Cleaved end**
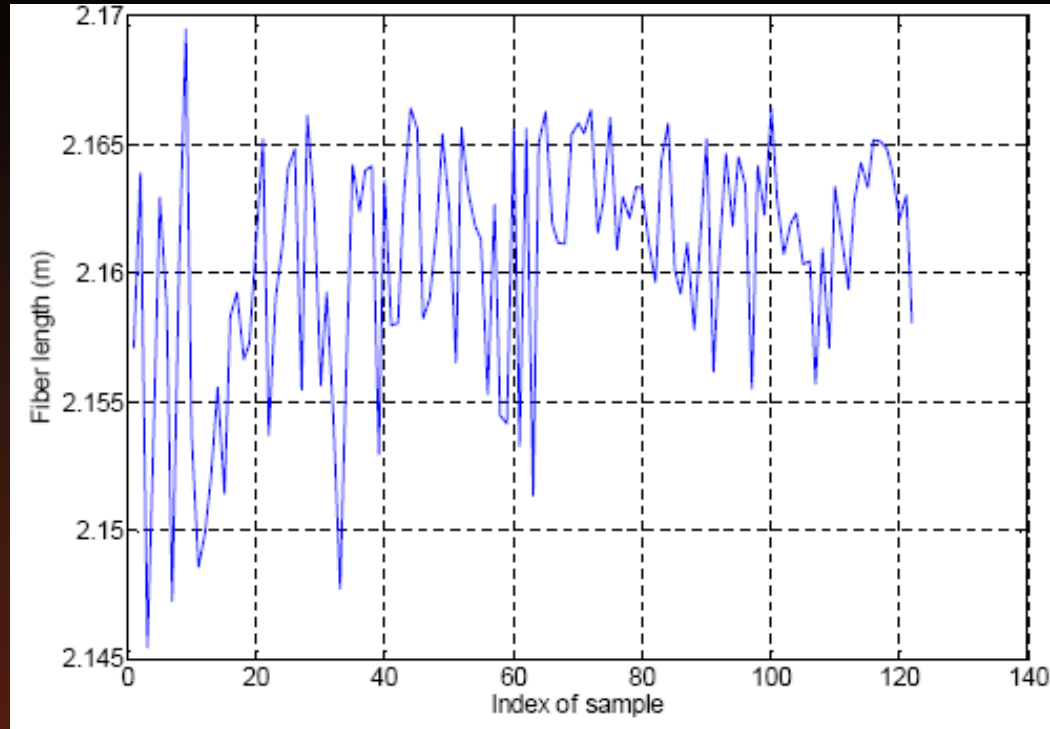- **Standard deviation 0.58/0.27 mm**

600°C Testing

- Approx. 3 cm cuts
- Rough cut fiber end
- Standard deviation 0.88/0.76 mm

Initial 1000°C Testing

- Static length, 3 hours
- Rough cut fiber end
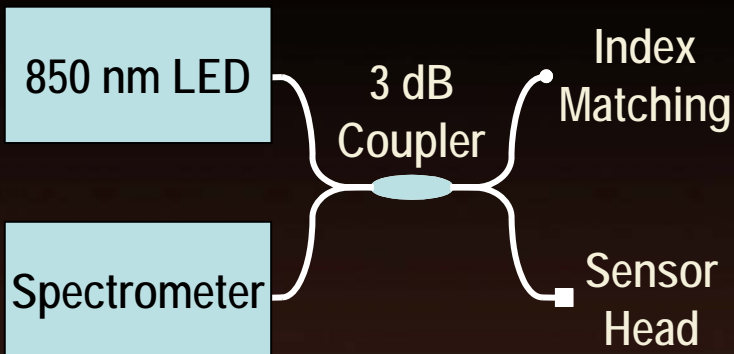- Standard deviation 2.5mm
- Filter mismatch
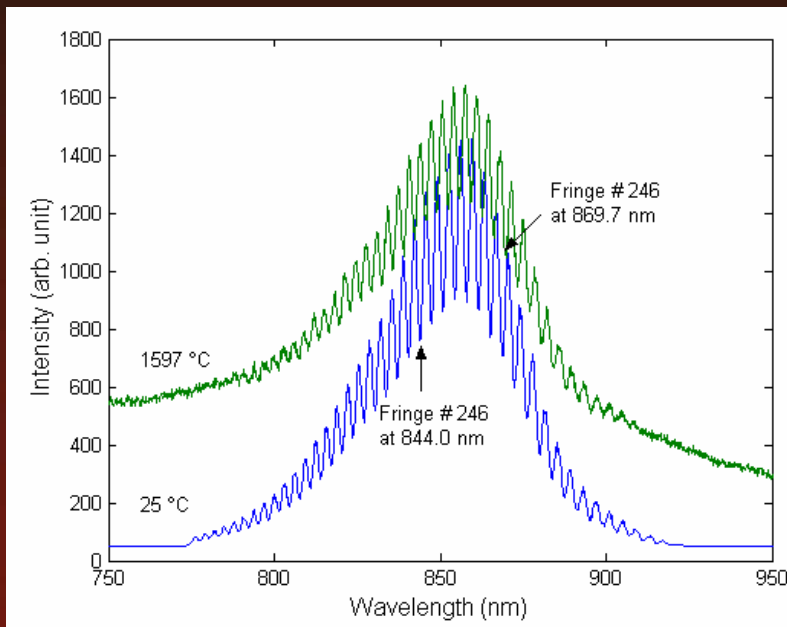
High Temperature Measurement

- Based on previous work utilizing the optical birefringence of a sapphire disk interrogated by free space propagation

- Extrinsic Fabry-Perot interferometer (EFPI) formed by the reflections from both surfaces of a single-crystal sapphire wafer
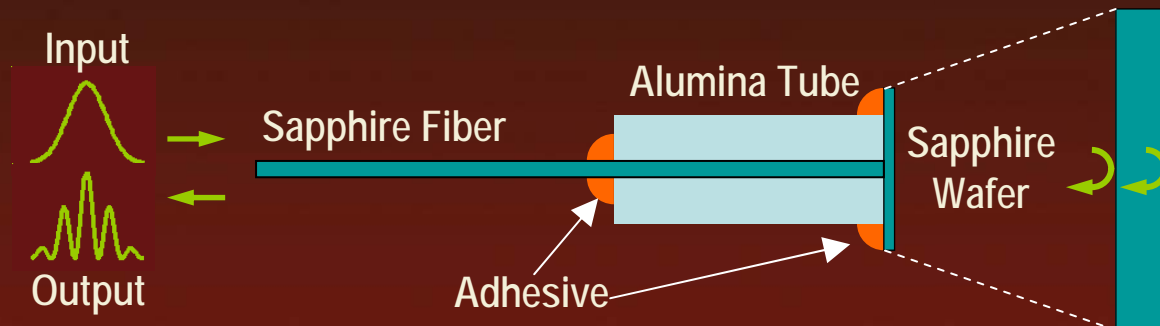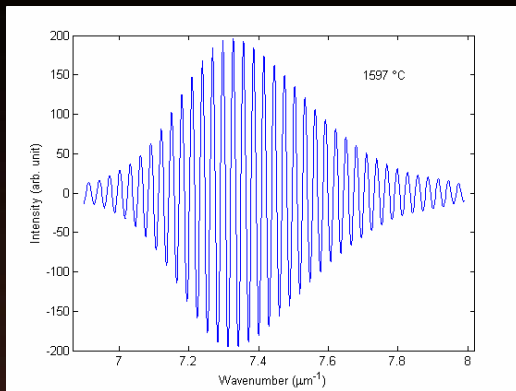
Temperature Signal Processing

$$I_t = I_B(\lambda) + I_D(\lambda) + I_{LED}(\lambda)\left(r_{couple} + r_{end} + r_{s1} + r_{s2}\right) - 2I_{LED}(\lambda)\sqrt{r_{s1}r_{s2}}\cos\frac{4n(T)d(T)\pi}{\lambda}$$
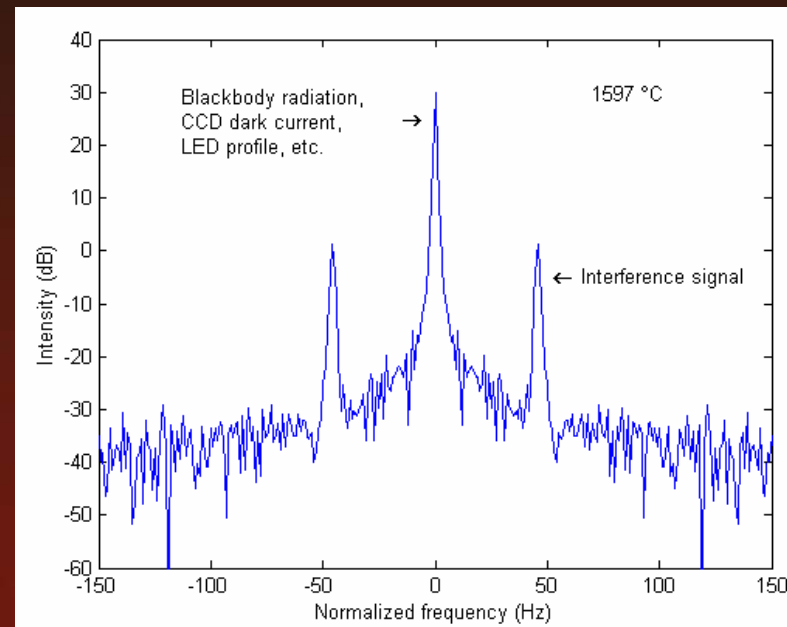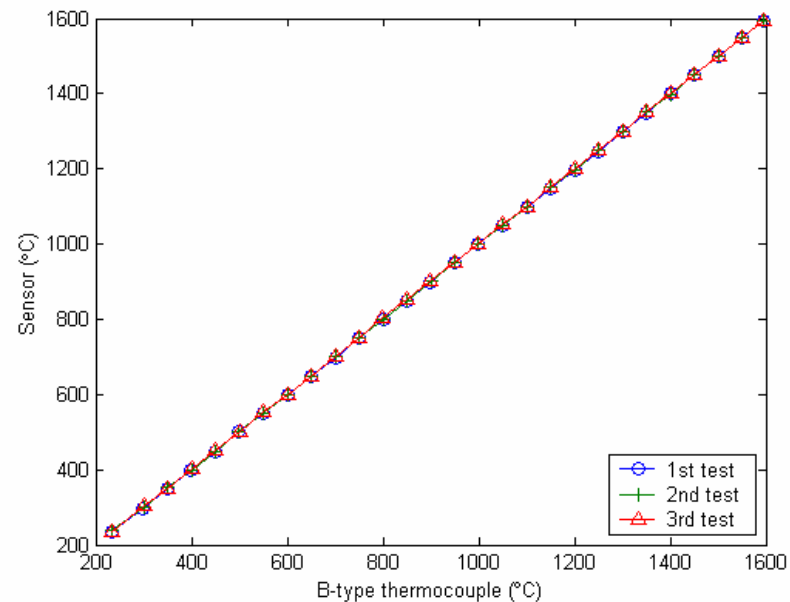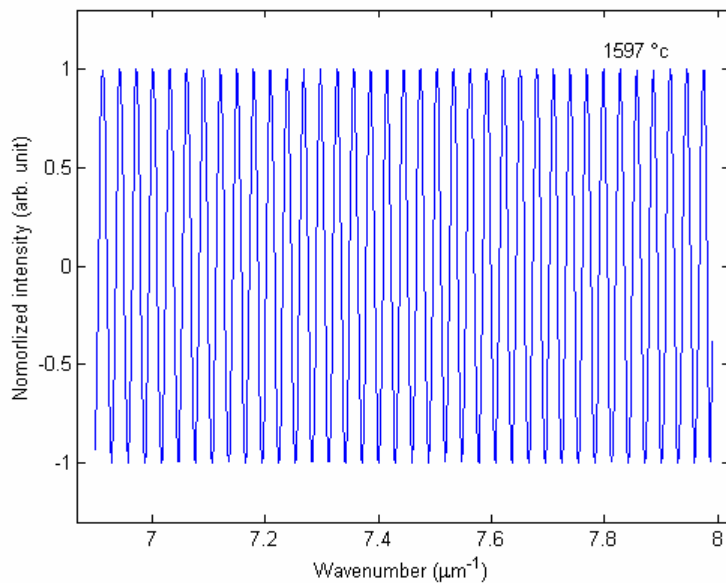
Temperature Signal Processing

$$I_t = -\cos\frac{2n(T)d(T)}{\lambda} = -\cos\frac{OPD}{\lambda}$$

Related Sapphire Fiber-Based Temperature Sensor Field Test

This technology survived 7 months in the gasifier at TECO's Polk Power Station and is currently undergoing additional laboratory testing
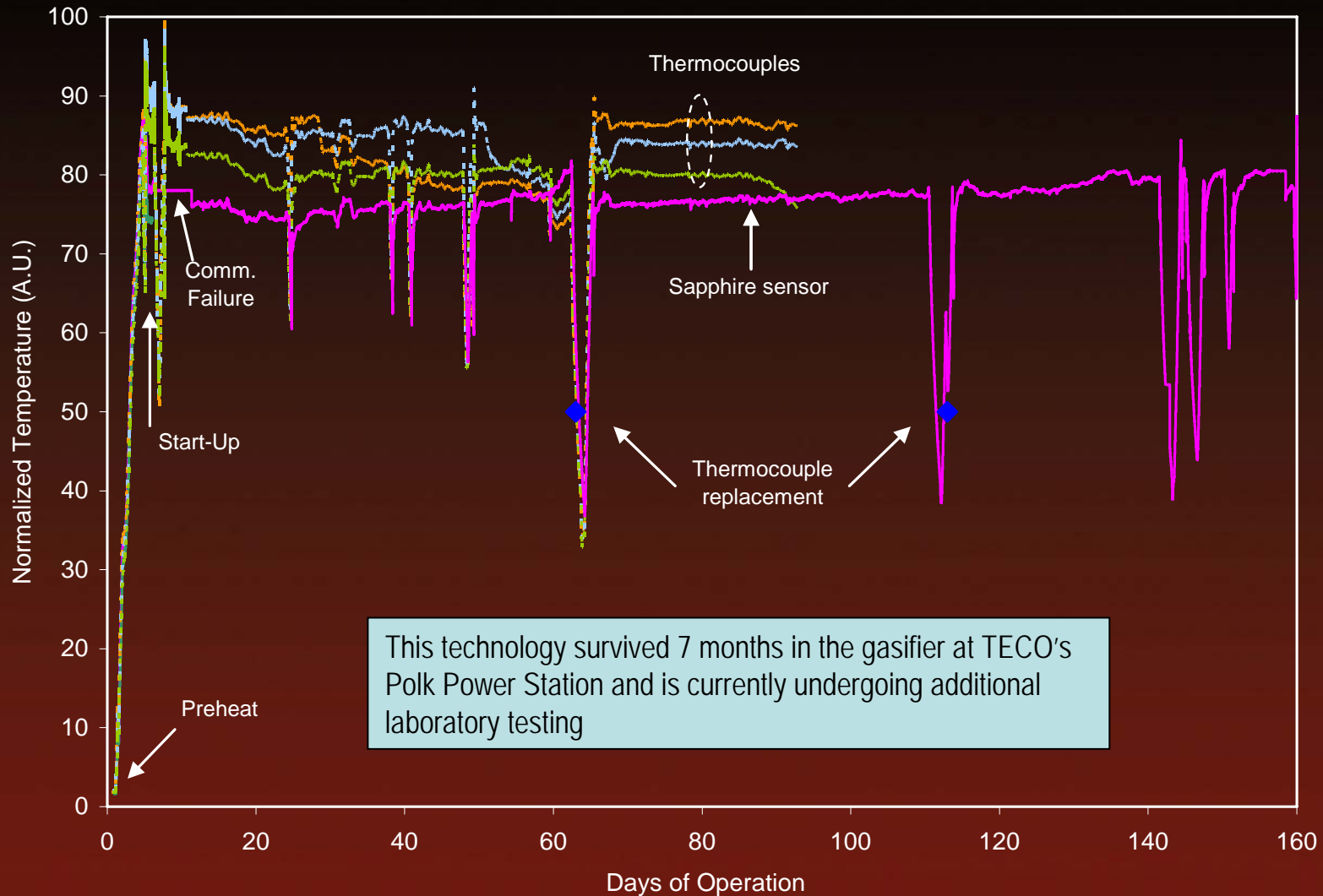
Future Work

- Testing thickness monitor at 1000°C
- Fabricating temperature probes for laboratory testing

- Software integration
- System calibration and testing