2005 SECA Core Technology Review

High Temperature Strain Gages for SOFC Application

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Tampa, FL

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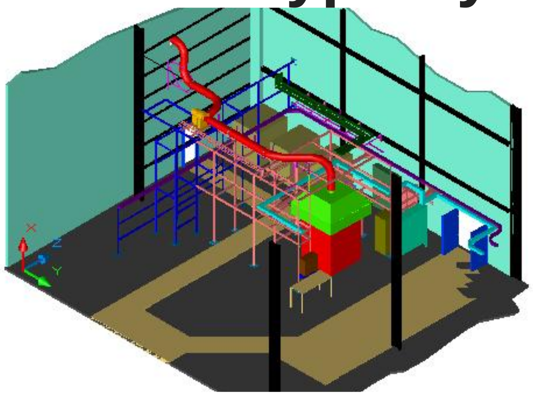
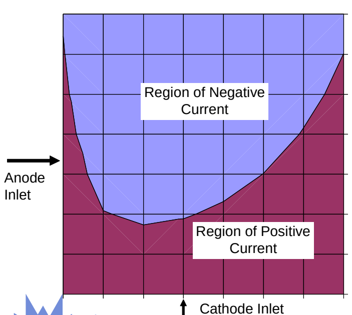
O. Gregory, T. You (URI)
Sponsor: SECA Program

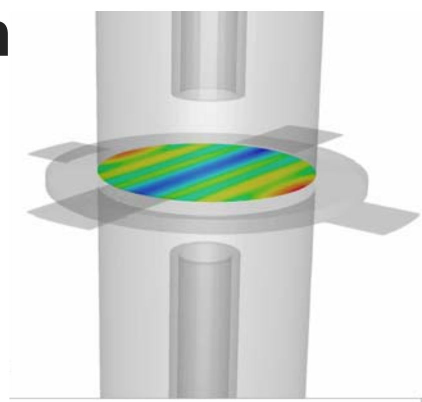
Overview of NETL SECA Support

- Independent Testing of SECA Prototype Systems

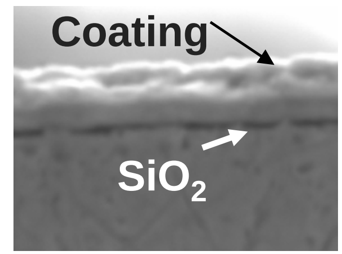


- Model Development and Application

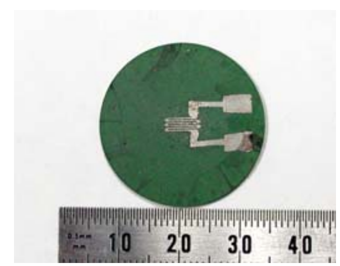




- Interconnect Development (coatings)



- Sensor Development



Sensor Development Review

- Technical Issues
- R&D Objective
- Approach
- Results
- Applicability to SOFC Commercialization
- Activities for next 12 months

Technical Issues / Challenges

- **Cell mechanical failure occurs frequently but is little understood**
  - Sudden event upon application of a load>critical strength (thermally or mechanically induced)
  - Can occur after numerous hours at a SCCG loading

- **There are few tools available for the engineer to employ**
  - ‘Integral’ strain measurements; Luna Innovations, Inc. (optical fiber; >800 deg. C)
  - Optical profilometry; Solarius Development, Inc. (optical access)
  - Acoustic emission for catastrophic failure detection

- **What is happening ‘inside the box’?**
  - Stack compression/creep?
  - Cell strain prior to failure?
  - Are FEA models working?

NETL

R&D Objective

Investigate/extend high temperature strain gage sensors to SOFC applications

- NASA (and others) have supported the development of high temperature strain sensors for in-situ turbine mechanical study
- Apply to prototype SOFC cells and subcomponents to assess feasibility as a new tool for engineering analysis
  - test in oxidizing & reducing environments—prove capability
  - measure fuel cell strain during start-up, shut-down, load changes, and fuel and oxidant concentration gradients

Approach

High Temperature Strain Sensors

- **Standards exist for resistive and capacitive gages**
  - ASTM E1319–98 (2003) Standard Guide for High-Temperature Static Strain Measurement
    - ***Prototype evaluation: gage + calibration device + hardware + instrumentation for system behavior checkout and qualifying installation procedures.***
- **Issues: good sensitivity (high gage factor), zero drift, sensitivity drift, repeatability, hysteresis, thermal response**

Gage factor:

$$K = ((R - R_{ref})/R_{ref}) \,/\, (L - L_{ref})/L_{ref}$$

$$= (\Delta R/R_{ref})/\varepsilon$$

$$K \sim 1.0 \text{ to } 20.0$$

Approach (cont.)

High Temperature Strain Sensors

- **Resistive ➔ suited for dynamic or short term static meas.**
  - Gage Factor; K ~ 2-6 for most metals (Fraden, 1993)
  - PdCr; K ~ 2
  - oxidation effects (not used for long tests)
  - 800 deg. C max
- **Capacitive ➔ suited for long term tests (creep)**
  - not affected by temperature, oxidation, phase change

Approach (cont.)
High Temperature Strain Sensors

- **Piezo-resistive Semiconductors ➔ suited for dynamic measurement**
  - Gage Factor; K ~ 10 @ 800 deg. C
  - indium-tin oxide (ITO); n-type ceramic
  - proven good thermal stability
  - oxidation resistance
  - good electrical response
  - used to study high cycle fatigue in jet engines (URI) up to 1500 deg. C (18-million cycle lifetime)

Thin Film Strain Sensors For SOFC

- **Benefits**
  - non-intrusive
  - small footprints
  - little thermal mass
  - sensitive for detecting small fluctuations associated with transient operation

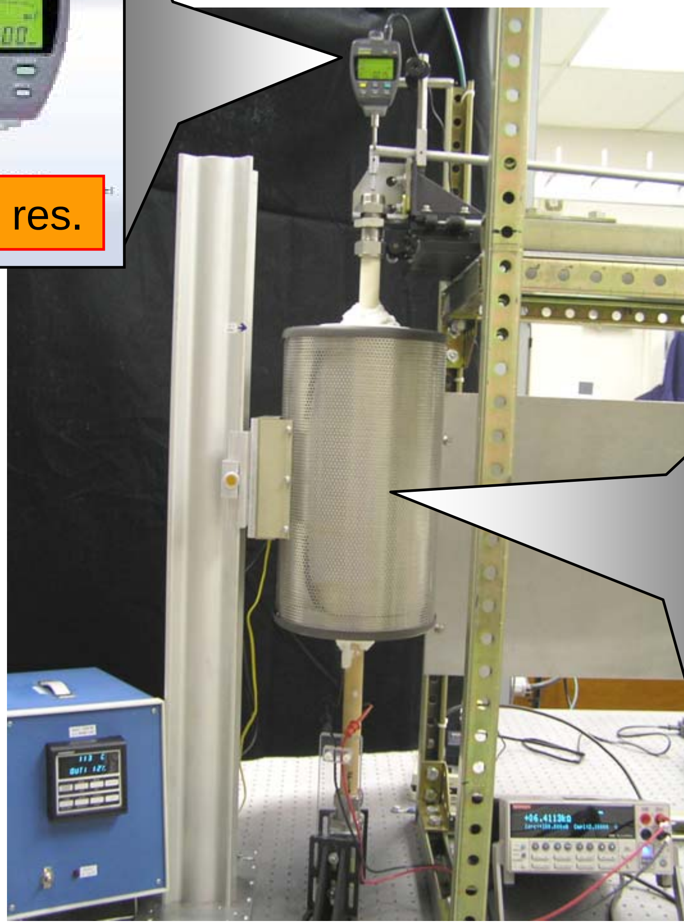
Thin Film Strain Sensors For SOFC
Pd-Cr/Indium-Tin Oxide

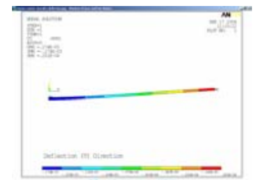
- **Fabrication:**
  - passivation / electrical isolation
  - patterning of the thin film leads using masks
  - patterning of the active strain sensor elements using photolithography
  - deposition of the thin film leads and bond pads as well as the active strain material using rf sputtering
  - lead wire attachment

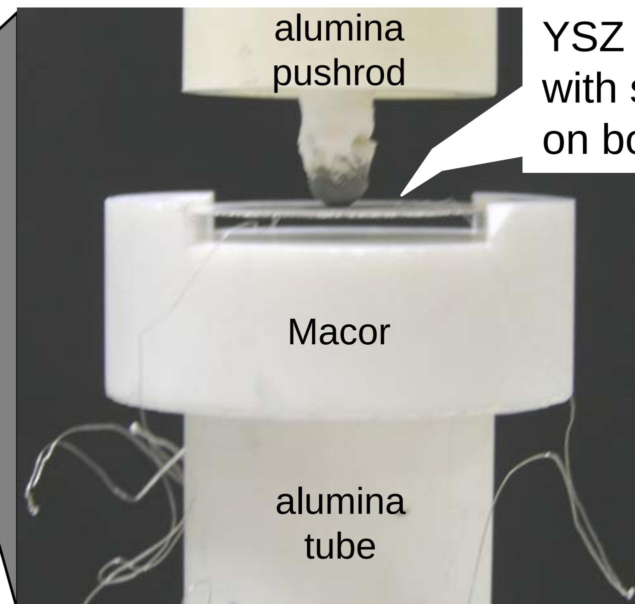
Experimental & Analysis Approach

Strain Gage CTR

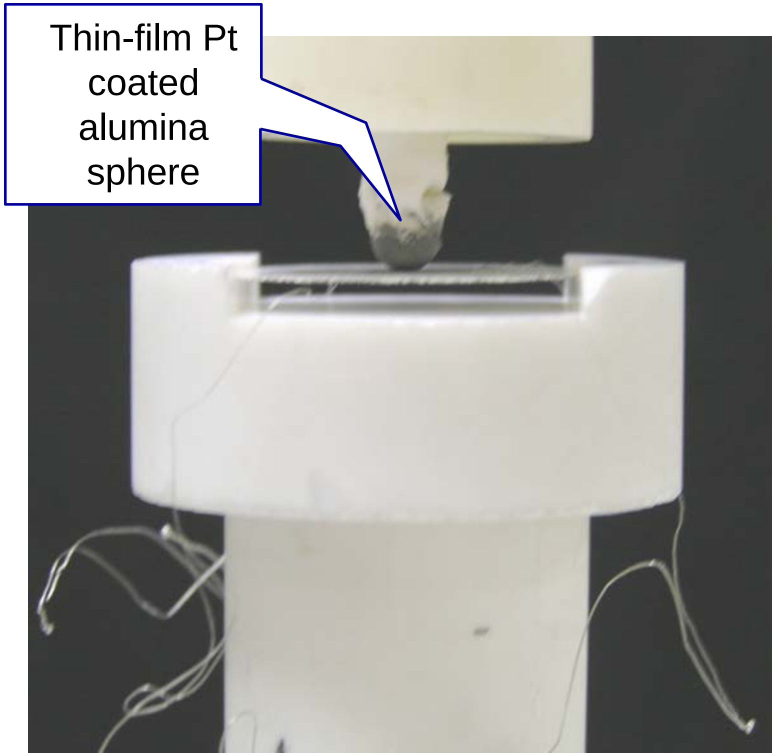
- **Initial bi-axial tests worked**
- **3-point measurements gave improved resolution**
- **ANSYS used to predict strain**

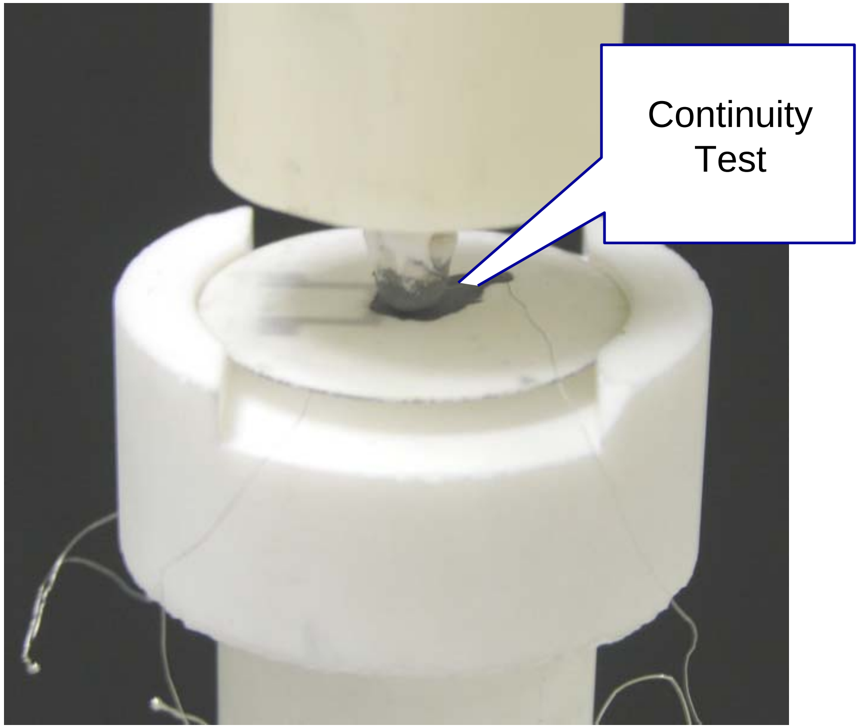






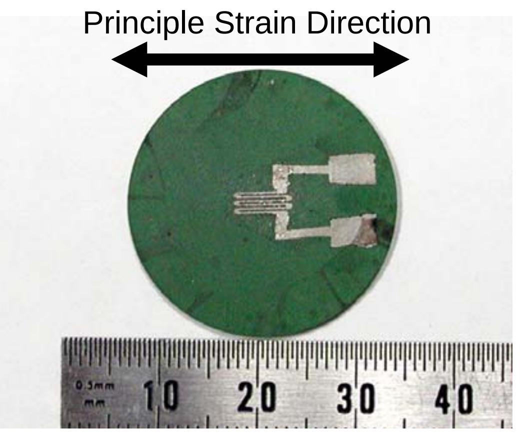
11/09/04 PdCr gage
(zero reference method for deflection)





Specimens Studied

- **PdCr**
  - 8YSZ wafer (191μm thick)
    - simplicity
    - ease of characterization
  - button cell
- **Indium-Tin-Oxide**
  - 8YSZ wafer (280μm thick)
  - button cell
- **Monoaxial design (see photo)**
- **Non-Temperature Compensated**



PdCr strain gage applied to SOFC anode

PdCr Results

Thermal Response

Gage Resistance (vs. T)

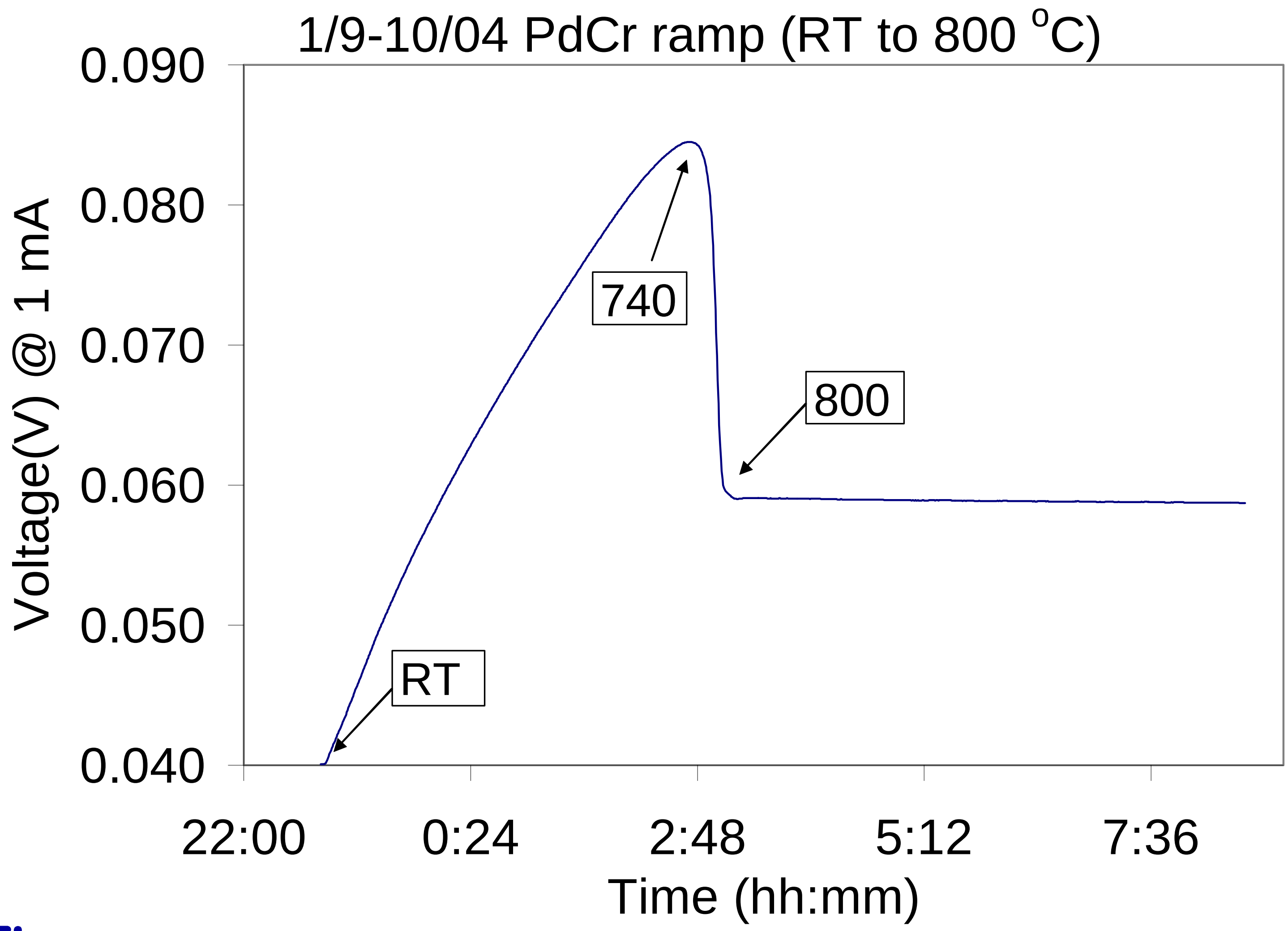
Stability (in Air)

Strain Response

Gage Factor

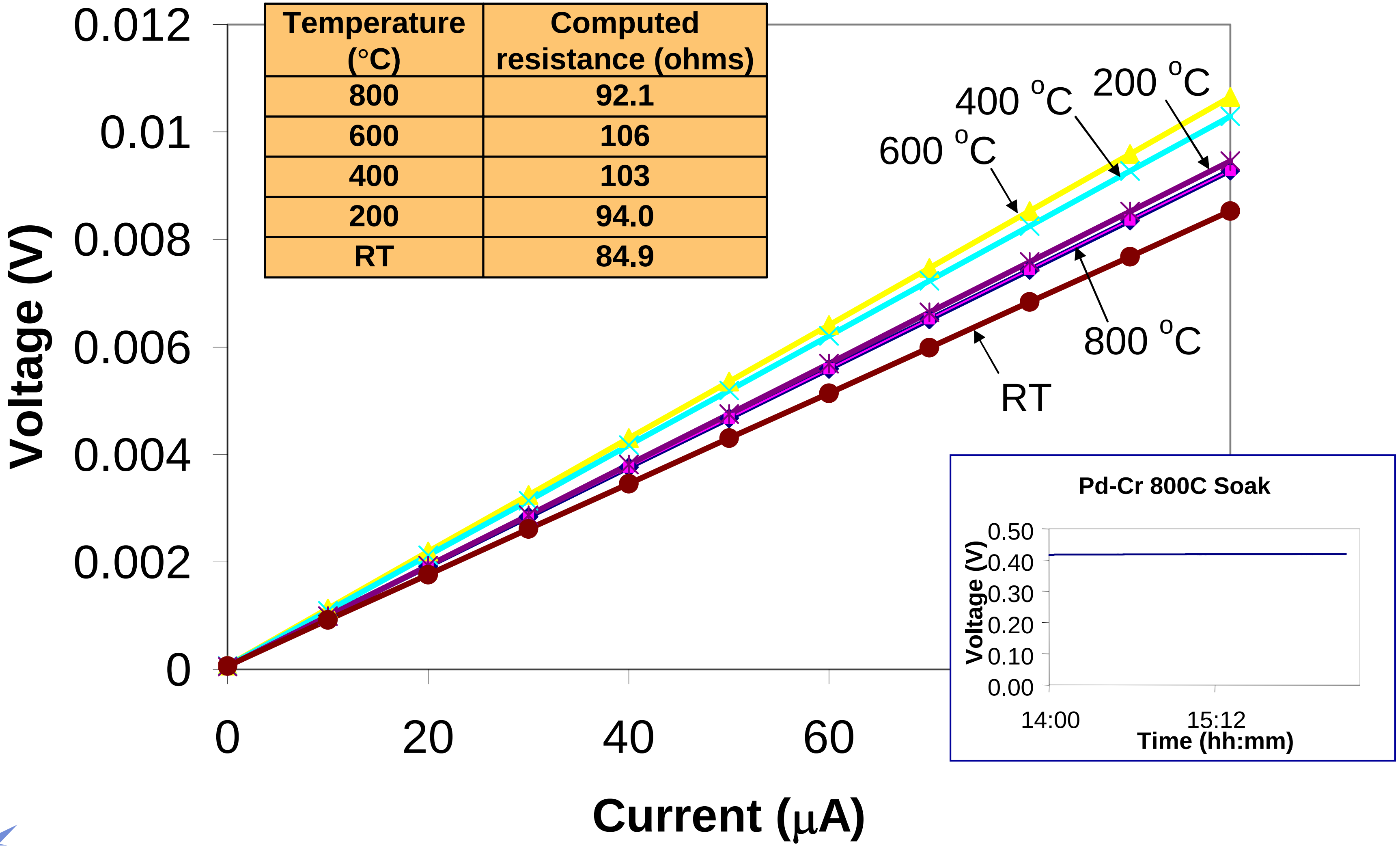
Pd-Cr Thermal Response

(8YSZ Wafer; Non-Temperature Compensated)



Pd-Cr Resistance

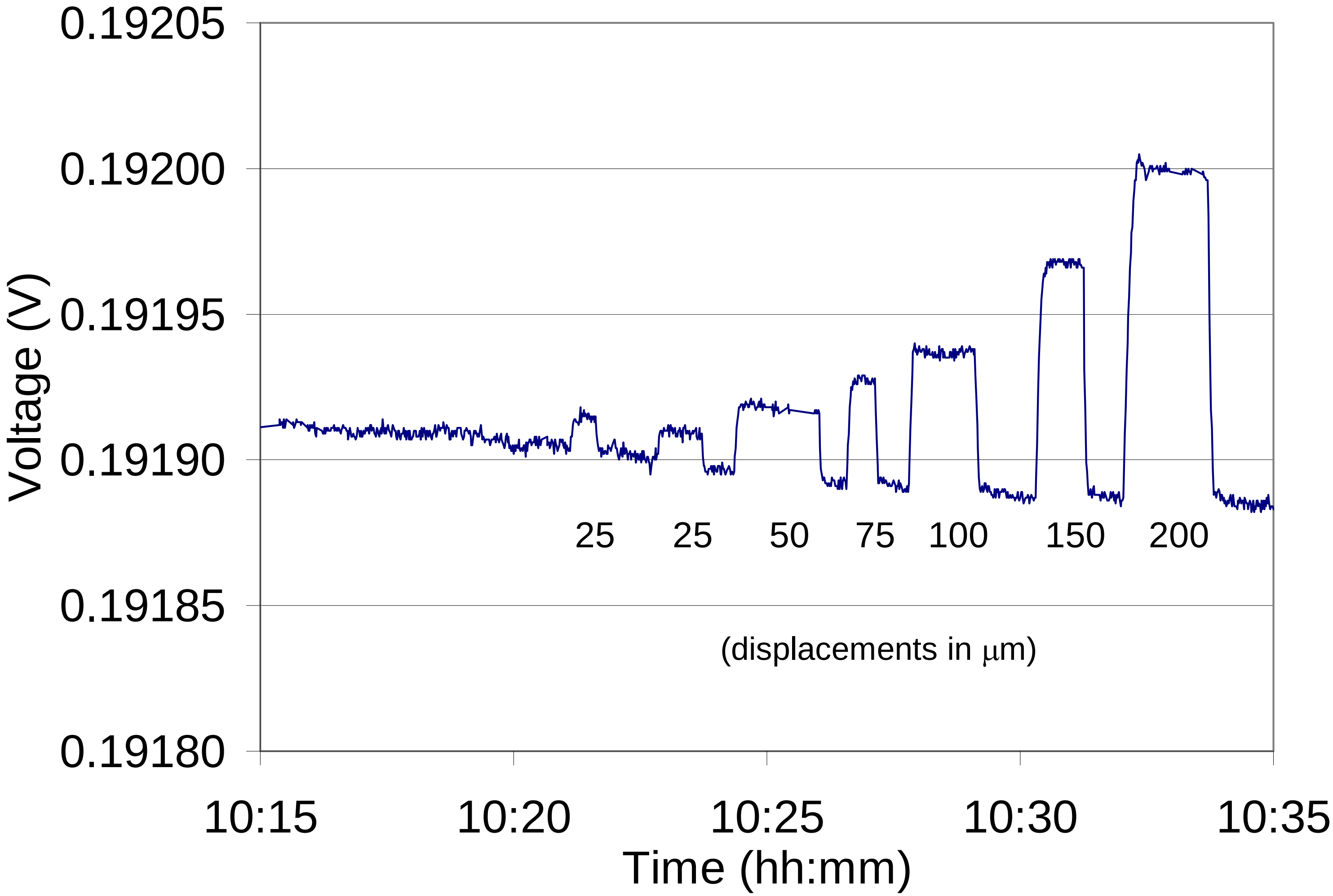
(8YSZ Wafer; Non-Temperature Compensated)



Temperature (°C)	Computed resistance (ohms)
800	92.1
600	106
400	103
200	94.0
RT	84.9

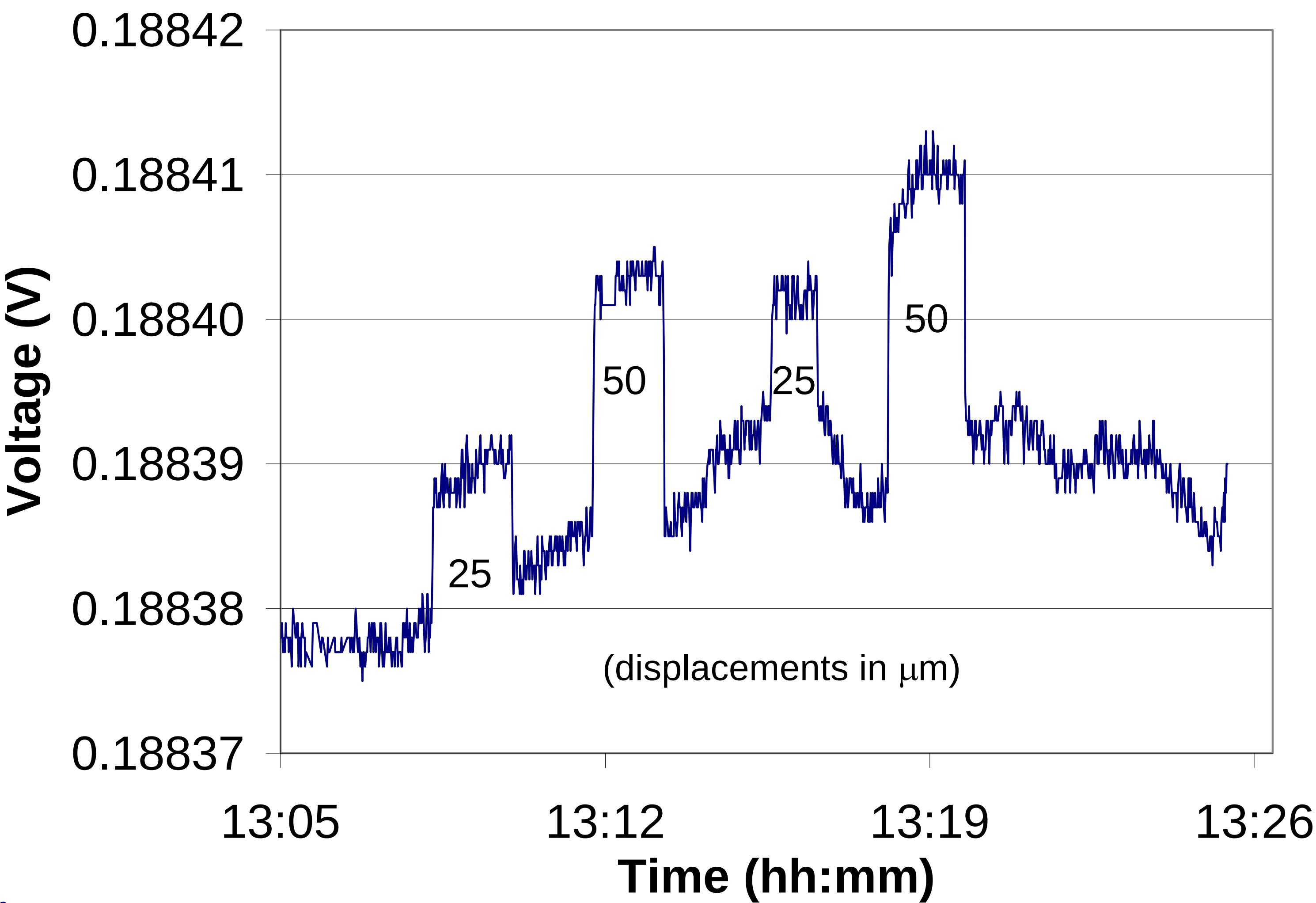
PdCr RT Strain Response

(8YSZ Wafer; Non-Temperature Compensated)



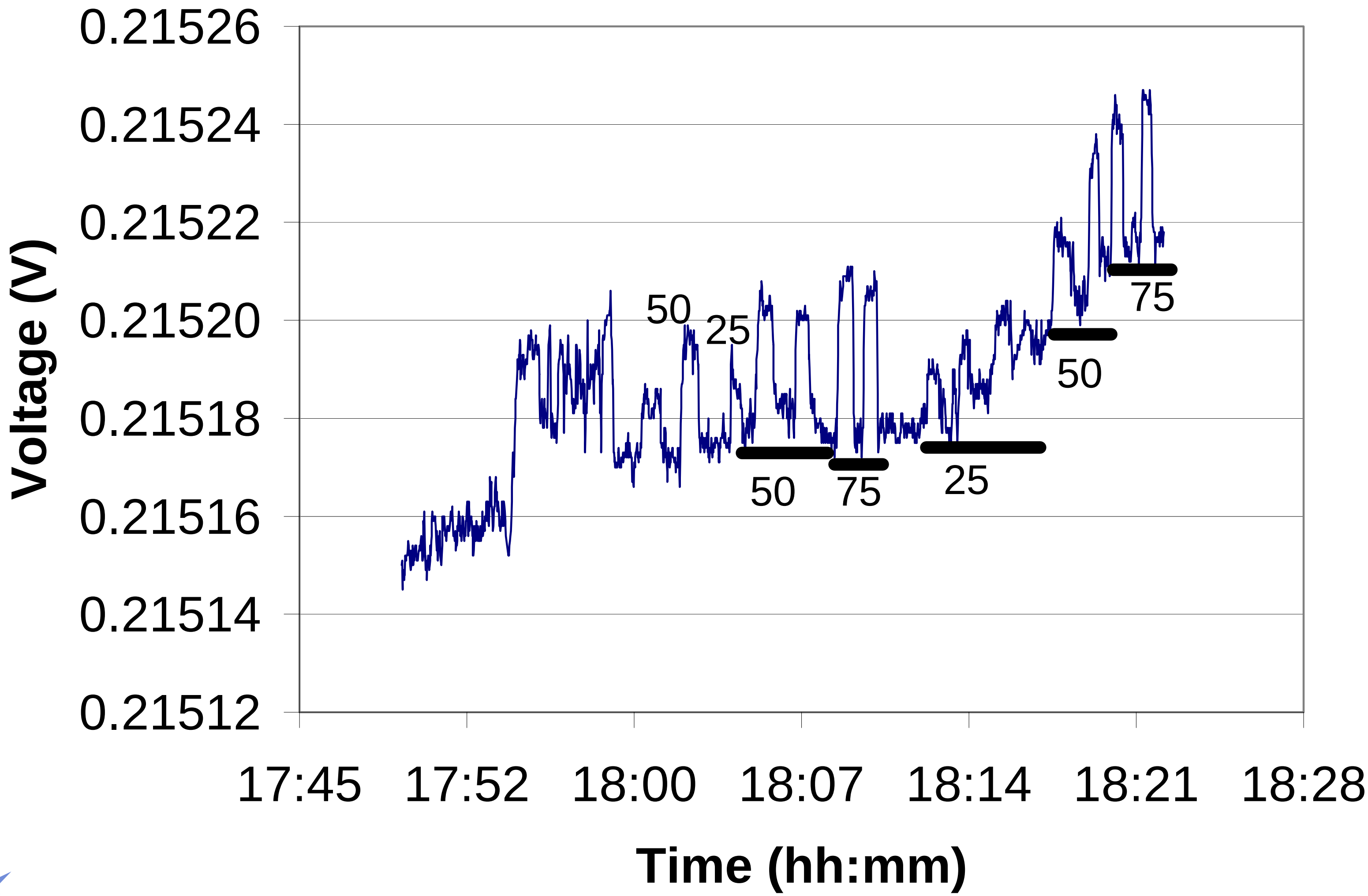
PdCr 50 ºC Strain Response

(8YSZ Wafer; Non-Temperature Compensated)



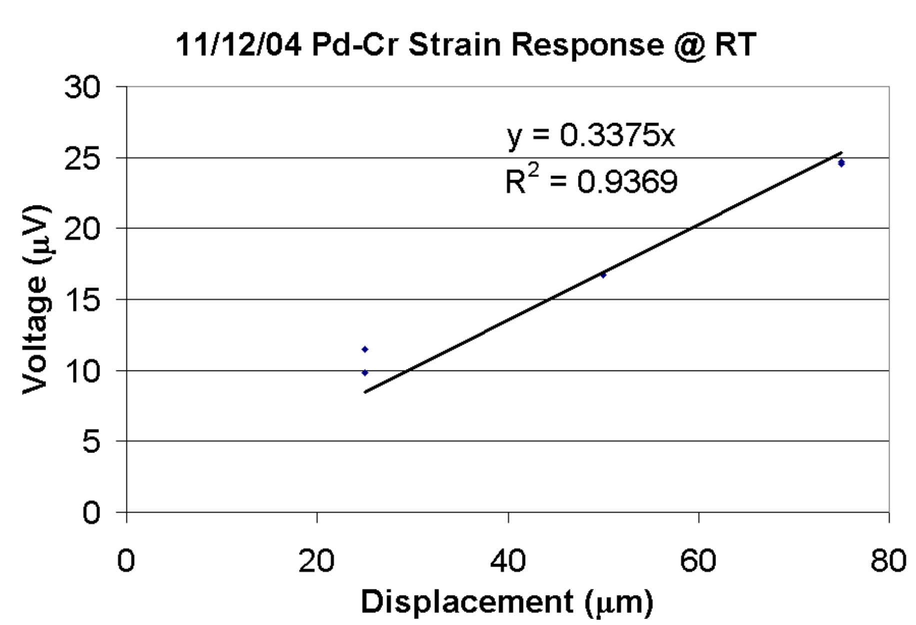
PdCr 550 ºC Strain Response

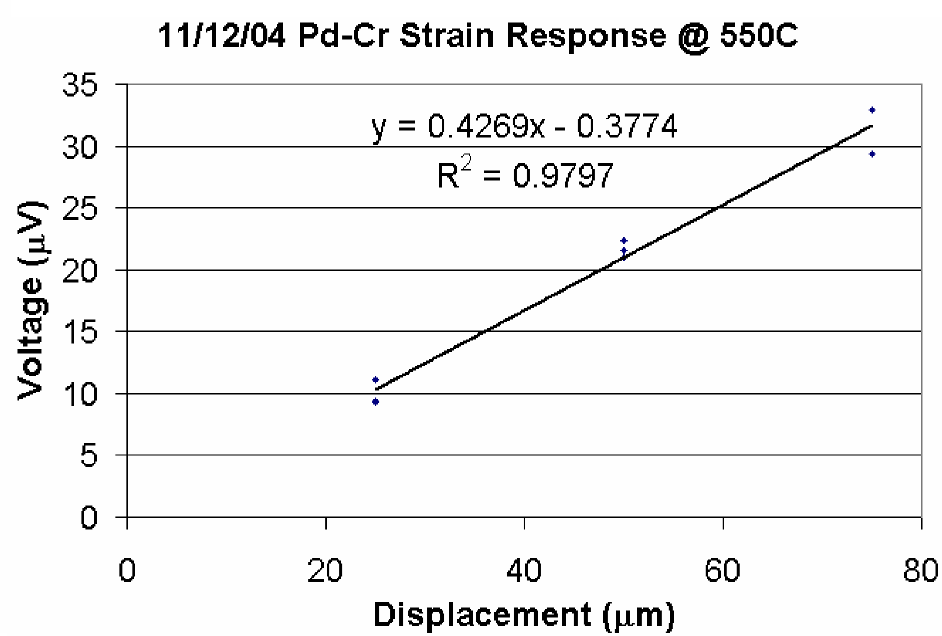
(8YSZ Wafer; Non-Temperature Compensated)



Pd-Cr Strain Response

(8YSZ Wafer; Non-Temperature Compensated)

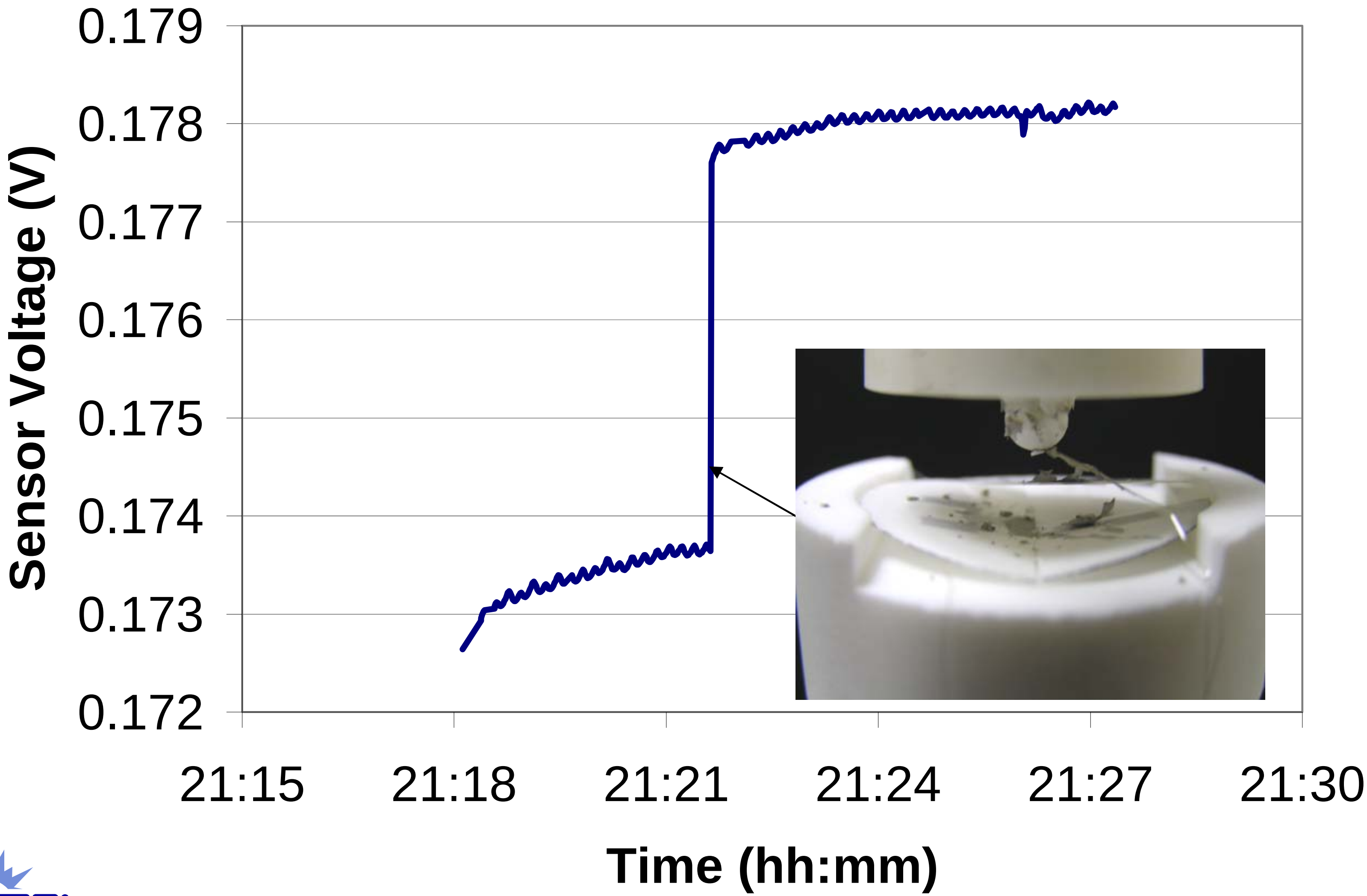




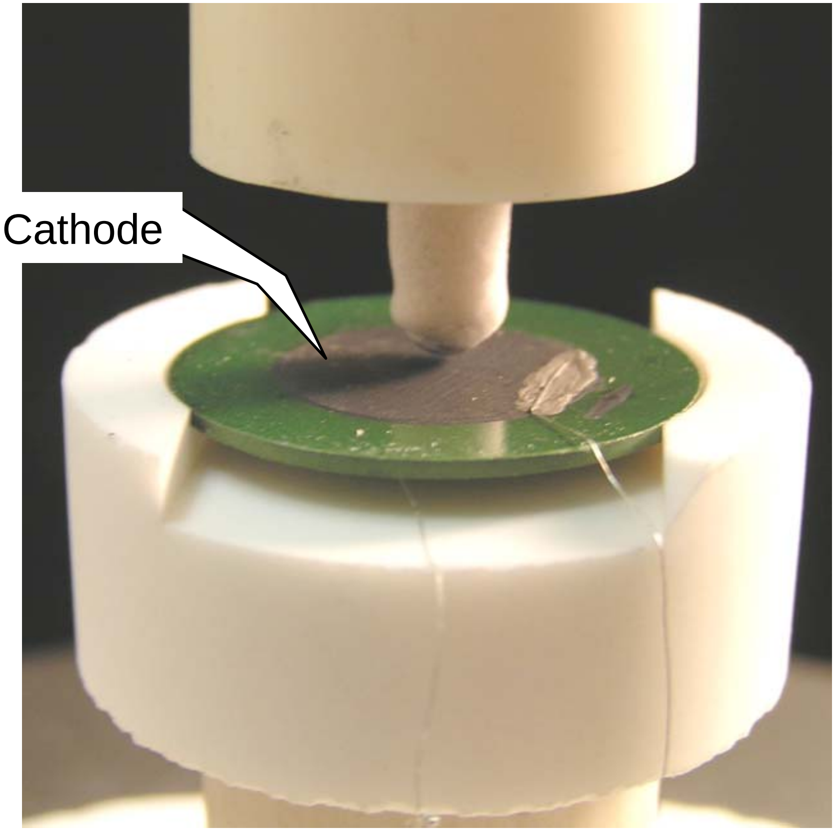
- **Good S/N Ratio at T<200 ºC**
- **Gage factor is slightly increased at higher temperatures**

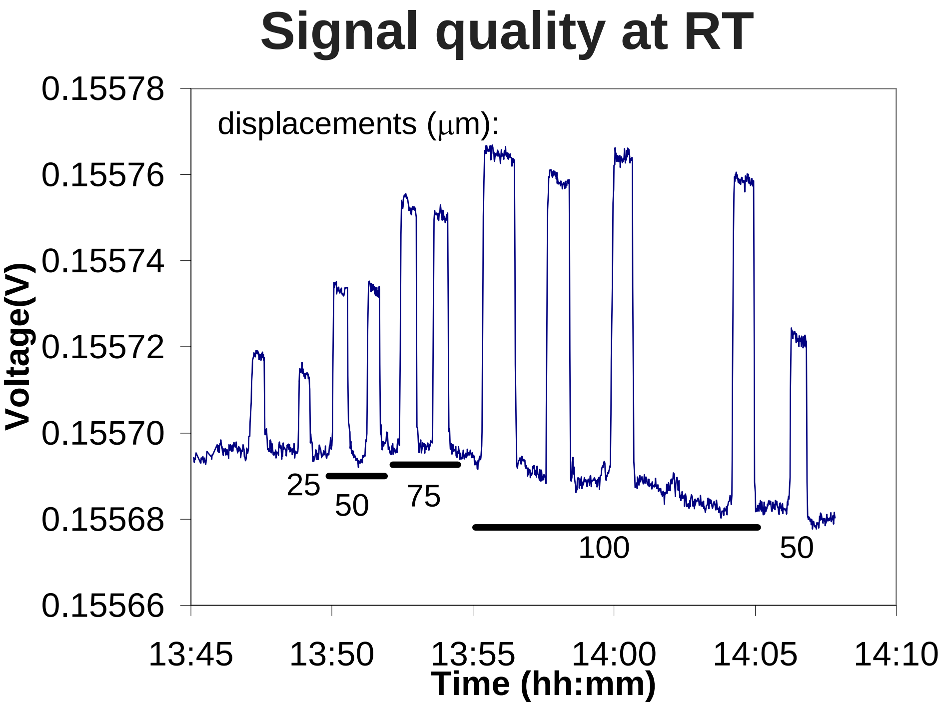
PdCr Fracture Signal (750 ^{o}C)

(8YSZ Wafer; Non-Temperature Compensated)

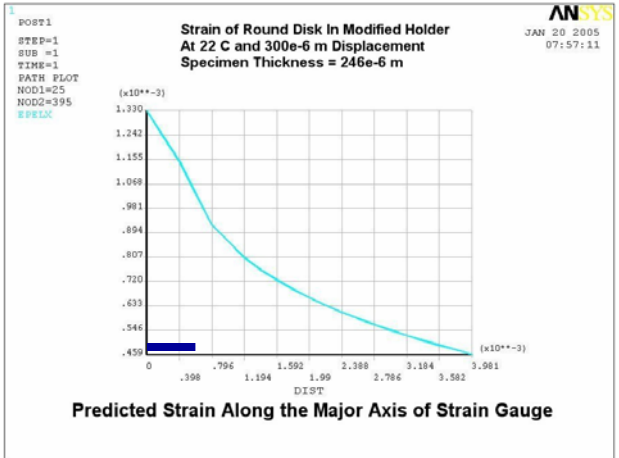


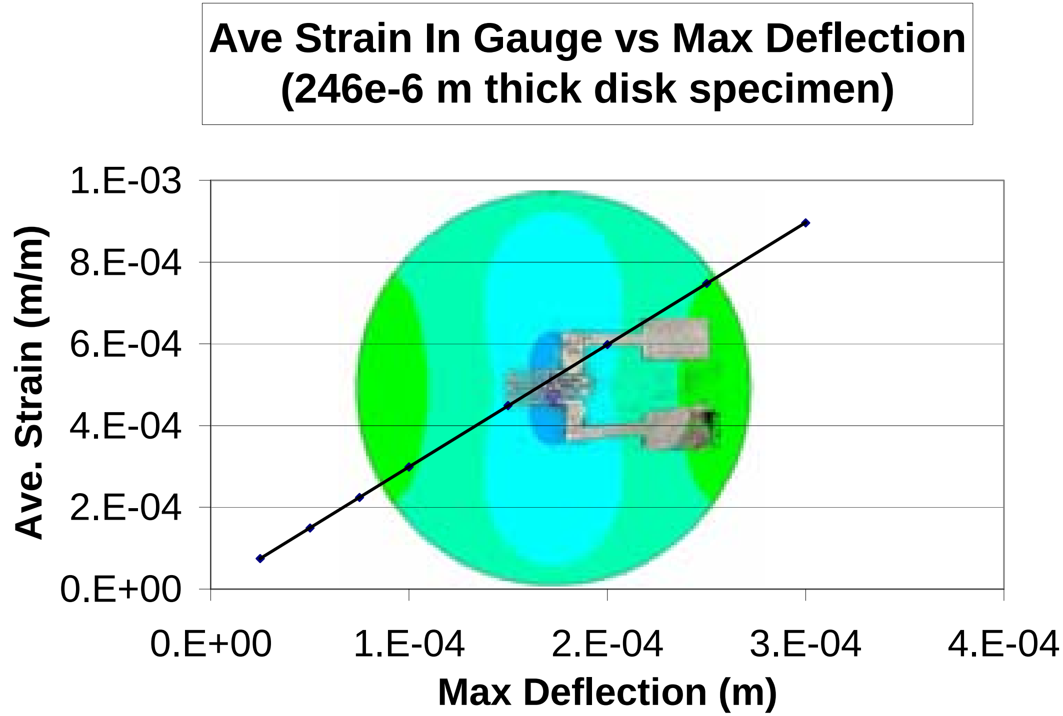
PdCr Sensor on 1-mm Anode Supported Cell





ANSYS





- **Calculated gage factor for PdCr sensor**
  - K=0.78 at RT
  - K=0.93 at 550 ^{o}C

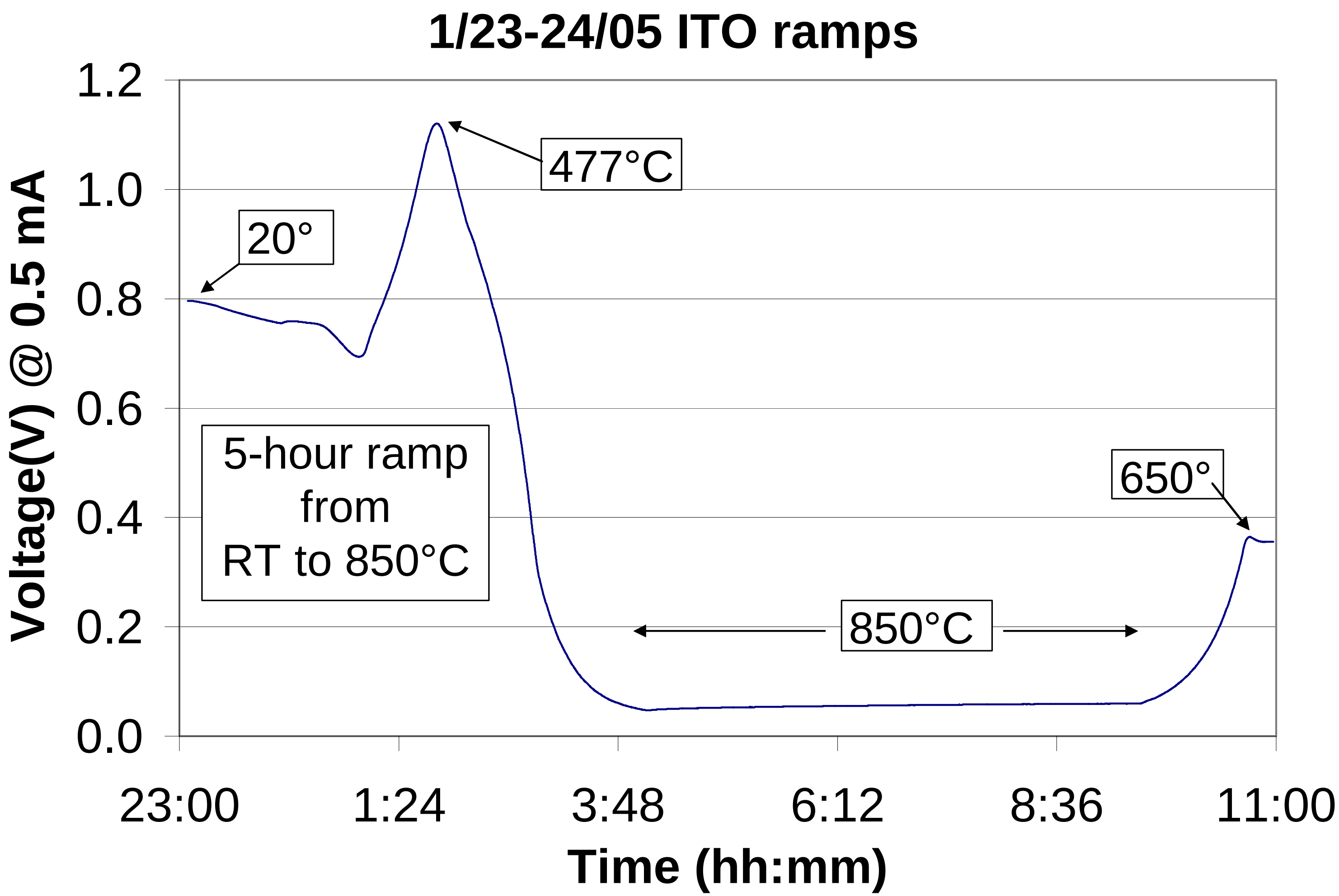
ITO Results

Thermal Response

Stability in Air

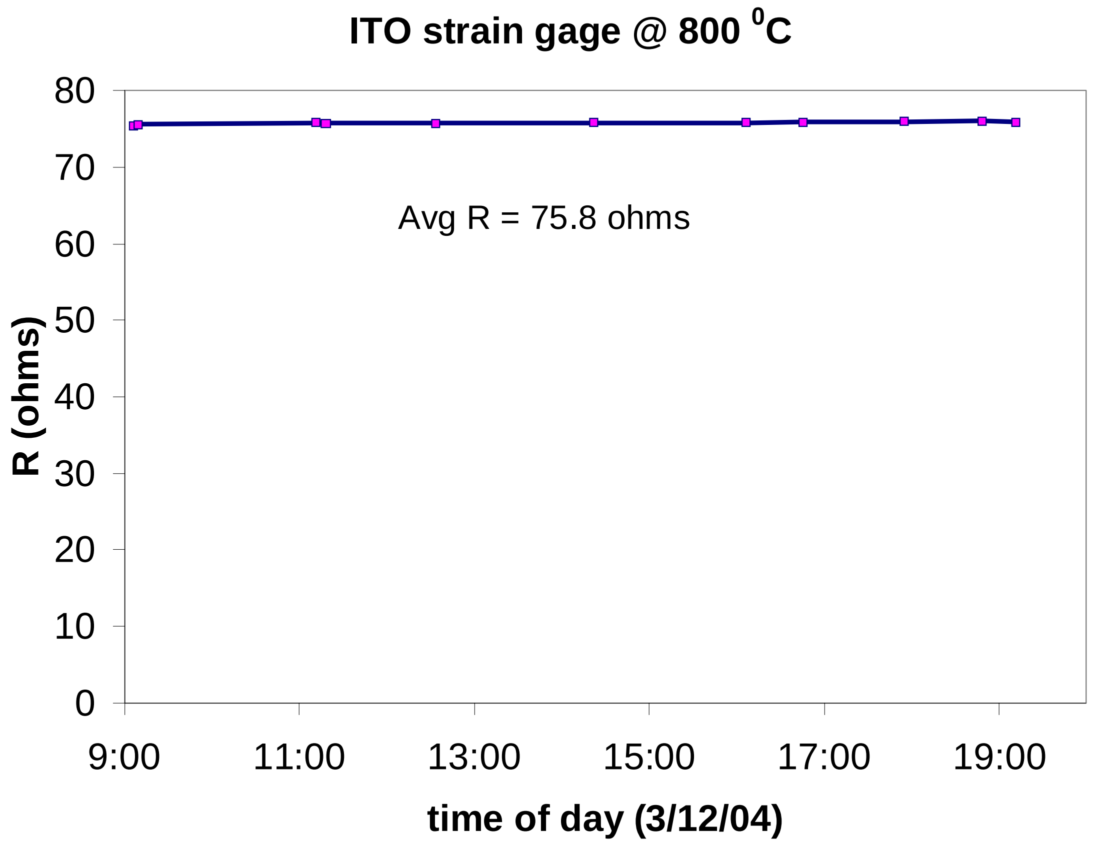
Strain Response

ITO Thermal Response



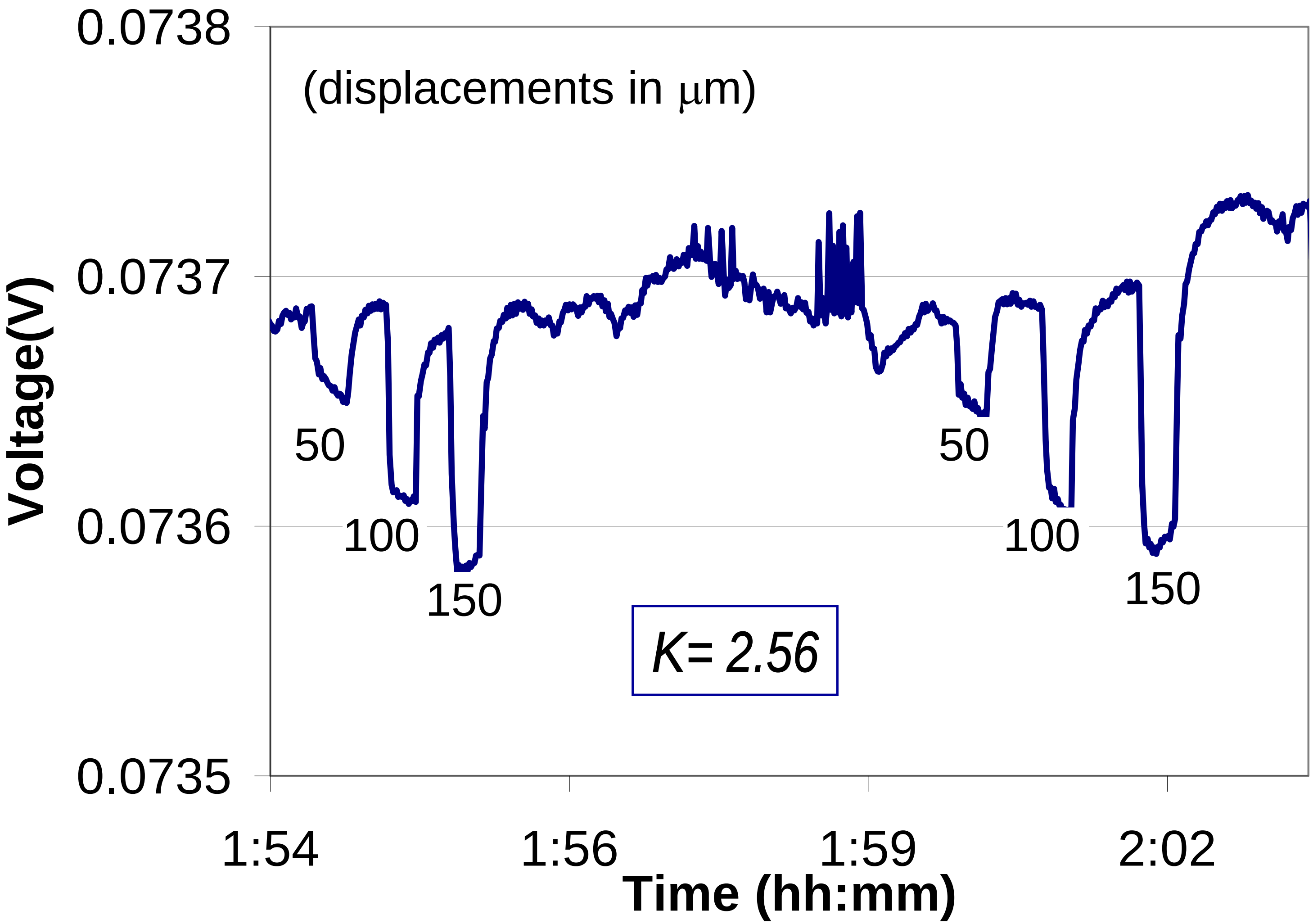
ITO Stability

- **ITO at 800 ^{o}C for one week with resistance measurements taken periodically**



ITO 650 ºC Strain Response

(8YSZ Wafer; Non-Temperature Compensated)



Summary

- **ITO strain gage has far better S/N ratio over PdCr**
- **Strain signal sufficient for detecting strain in SOFC materials**
- **Gage factors lower than typically cited**
  - PdCr ~ 0.93
  - ITO ~ 2.5

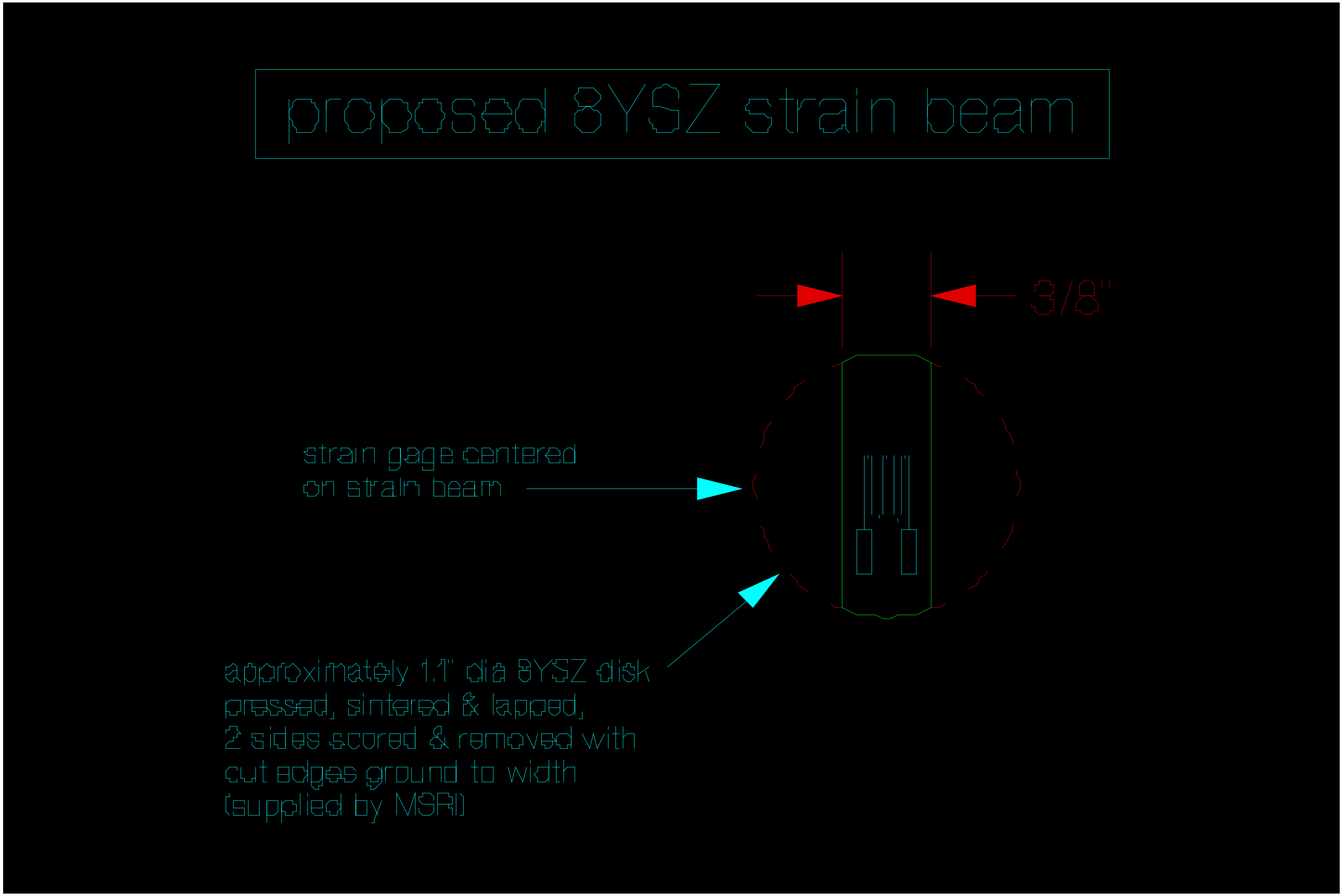
Application to SECA

- **High temperature strain gages may be of use in development of SECA cell and stack technology**
  - Diagnostic during stack assembly (stack compression)
  - Diagnostic for ensuring creep effects are not relieving/ removing desired compressive load for sealing
  - Diagnostic for stack state of stress
  - Diagnostic for on-cell state of stress
  - Experimentally validate models (e.g., GTech)

…and thereby improve our design capabilities through better modeling/prediction of mechanical performance

FY05-06 Project Tasks
(focus on ITO)

- **Task 1 –YSZ Substrates**
  - Confirm ITO sensor response (gage factor) at 200, 400, 600 and 800 deg. C.
  - Determine stability in reducing atmosphere
  - Characterize temperature-compensated sensor
- **Task 2 – Apply Sensor to Button Cell**
  - Evaluate in-situ response during cell operation
- **Task 3 – Model Experimental Conditions**
  - Apply models to experimental cases
  - Determine ability of model to follow strain (mechanically or thermally induced)
- **Task 4 – Journal Publications and Presentations**


proposed 8YSZ strain beam
3/8"
strain gage centered
on strain beam
approximately 1.1" dia 8YSZ disk
pressed, sintered & lapped,
2 sides scored & removed with
cut edges ground to width
(supplied by MSRI)

- Fraden J., *“AIP handbook of modern sensors: physics, designs and applications”*, AIP, New York, 1993.