

### Anode Material Degradation Mechanisms

#### Thermo-Mechanical Degradation

- Stresses exist in SOFC anode can cause micro-cracks formation
- Material aging affects YSZ at high temperature and reduce its strength

#### Redox/Thermal Cycle Effects

- Anode dimensional changes can build up over many redox cycles
- Generates internal stresses
- Loss of performance and structure integrity

#### Syngas Contaminants Effects

- Phosphorus and arsenic interact strongly with Ni
- Form secondary phases and cause grain growth
- Initiation of micro-crack within anode

### Anode Material Degradation Model

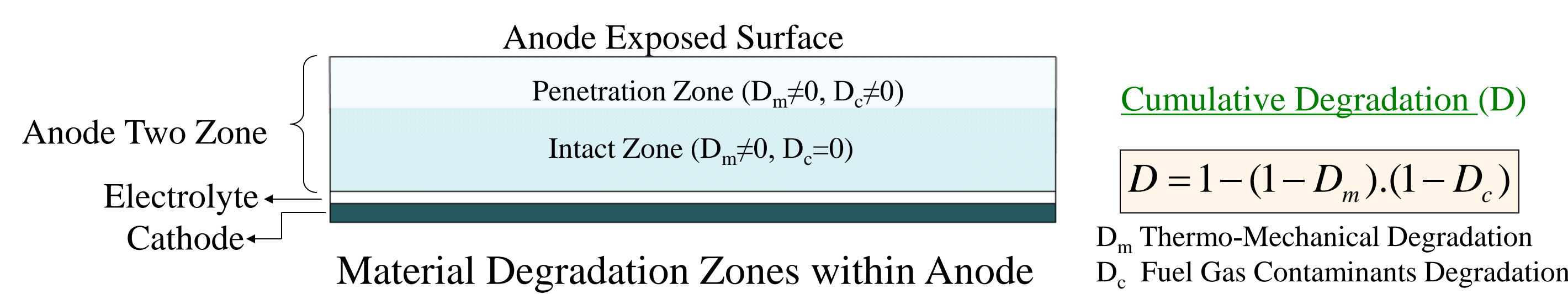
We proposed that degradation of anode material can be assigned in two different regions:

#### Intact Zone

The material degradation in the intact zone is due to thermo-mechanical

#### Penetration Zone

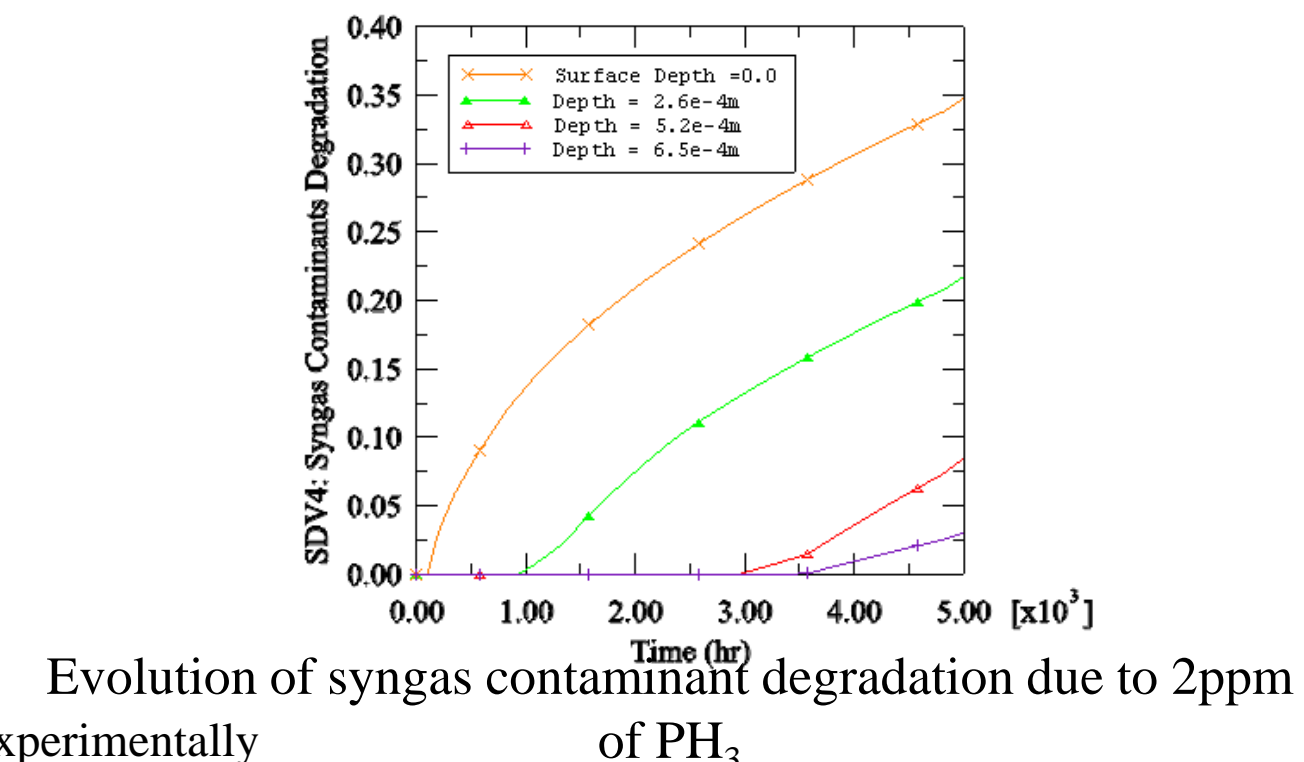
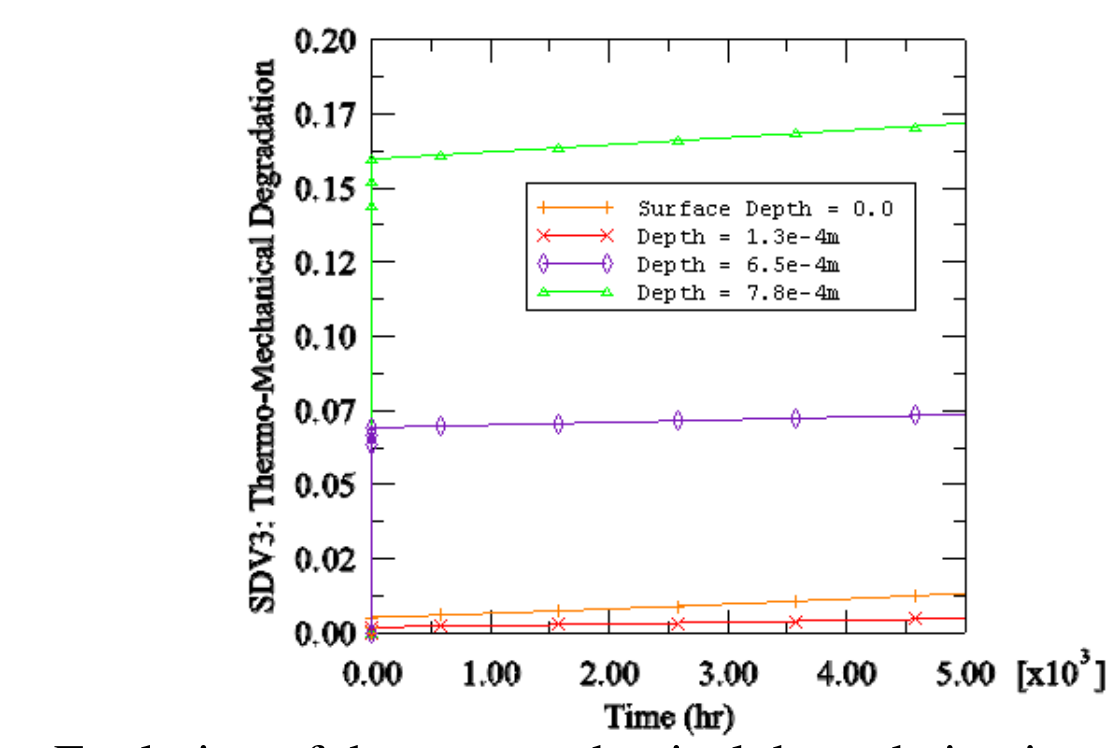
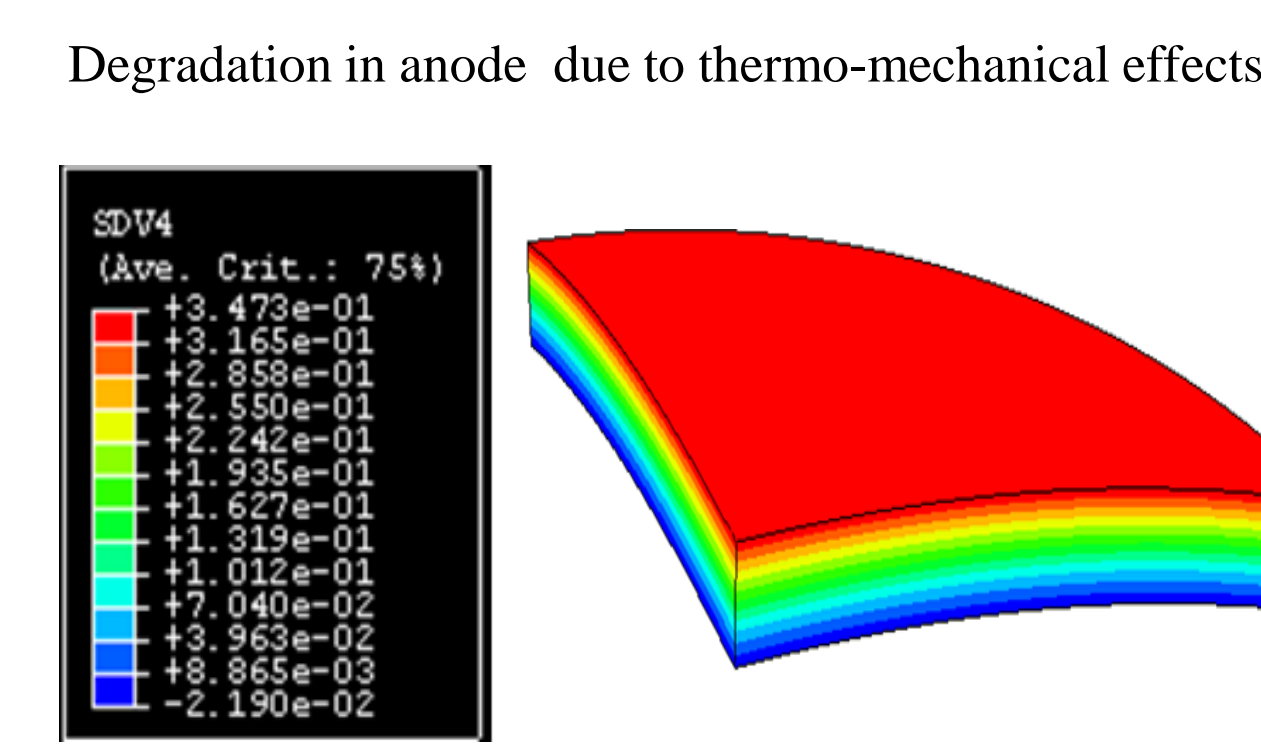
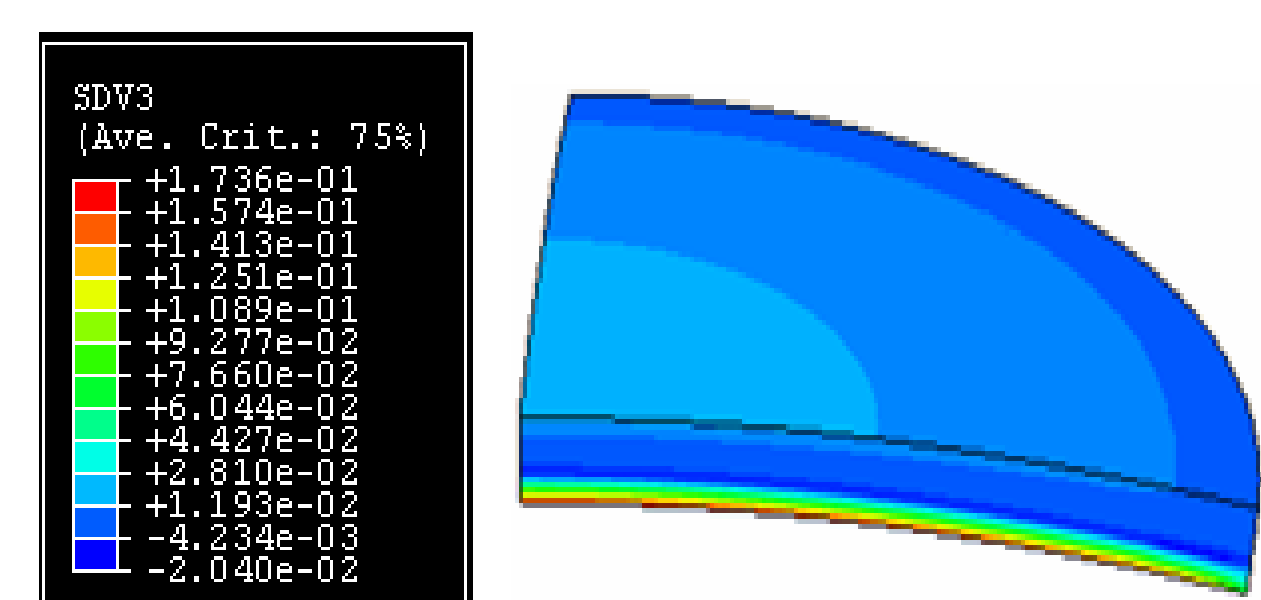
Fuel gas contaminants penetrate through anode surface and cause grain growth and form micro-crack



#### Stiffness Degradation

The stiffness degradation due to thermo-mechanical and fuel gas contaminants effects

$$K_{ijkl} = C_{ijkl}(1 - D_m)(1 - D_c) - \frac{Y}{2hY^e} \frac{\partial \sigma_{ij}}{\partial D} \frac{\partial F^d}{\partial Y} \frac{\partial Y}{\partial \epsilon_{ij}}$$



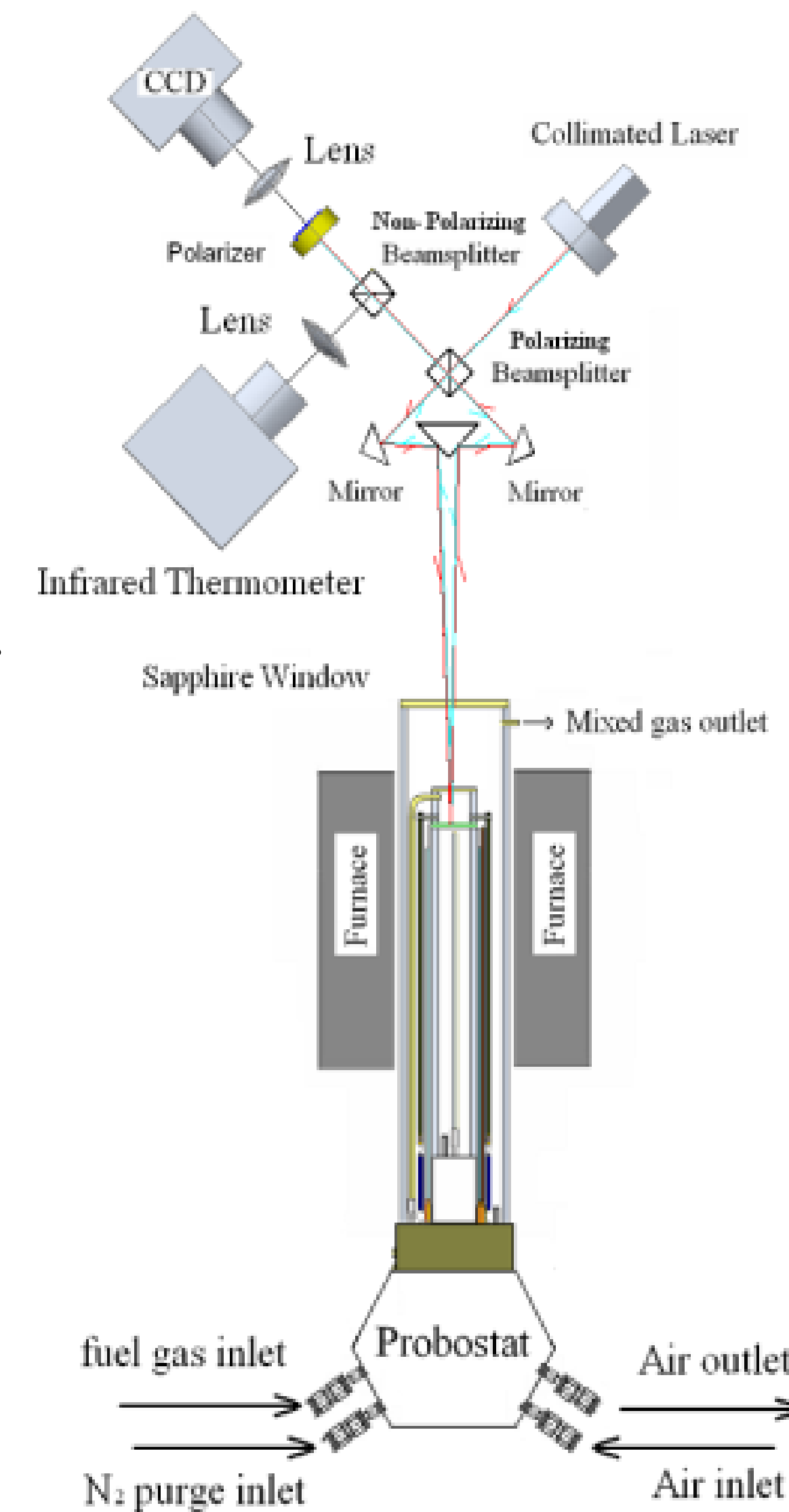
### SOFC Research Objectives and Experimental Setup

#### Objectives:

- To obtain anode surface deformation and temperature data experimentally for correlation/validation with SOFC electrochemical and structural models
- To investigate effects of  $PH_3$  on Ni/YSZ anode performance and microstructure under different testing conditions
- To develop anode structural durability model under thermo-mechanical and syngas contaminants effects on its microstructure

#### Capabilities:

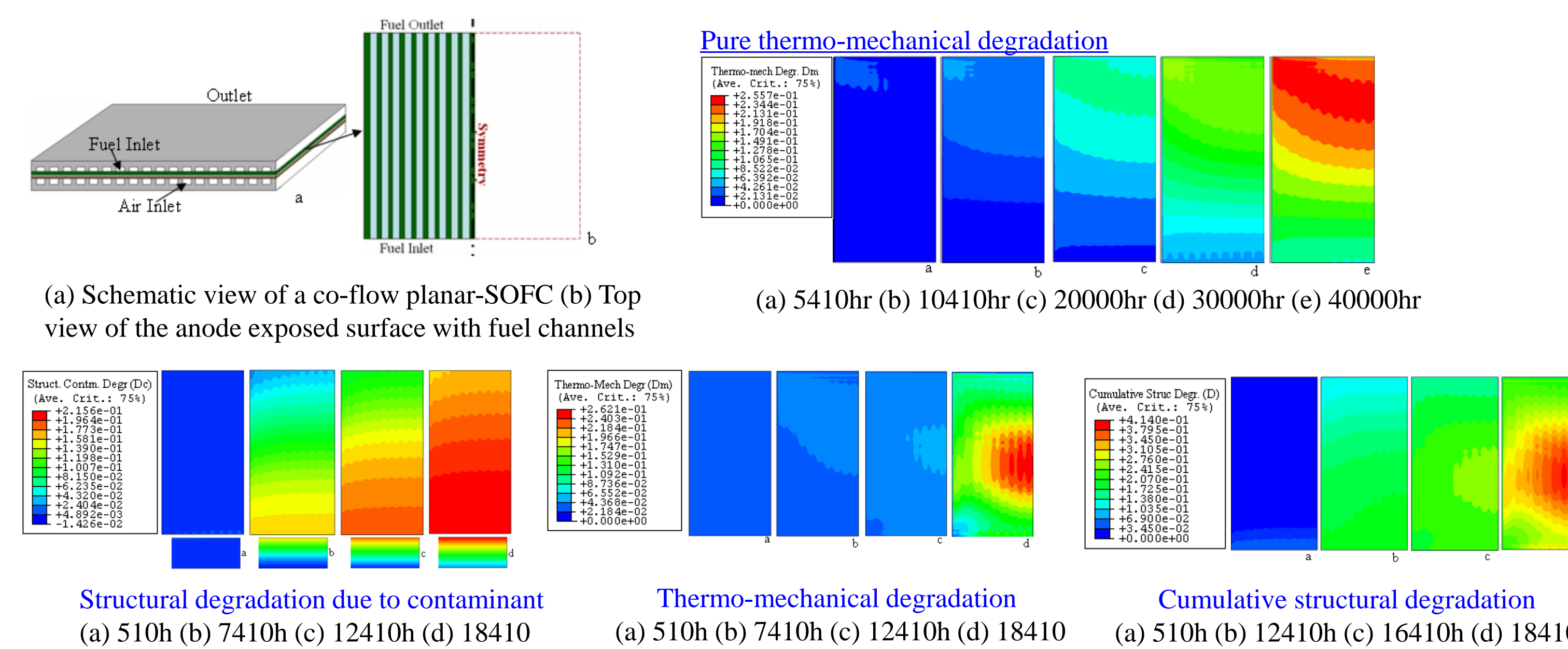
- In-situ surface deformation measurement
  - half wavelength measurement sensitivity
  - immune to system vibration and temperature fluctuation
  - the optical window does not affect the fringe formation
- In-situ surface temperature measurement
  - surface IR emission monitoring (transient and steady state) with SOFC in operation
- Electrochemical performance measurement



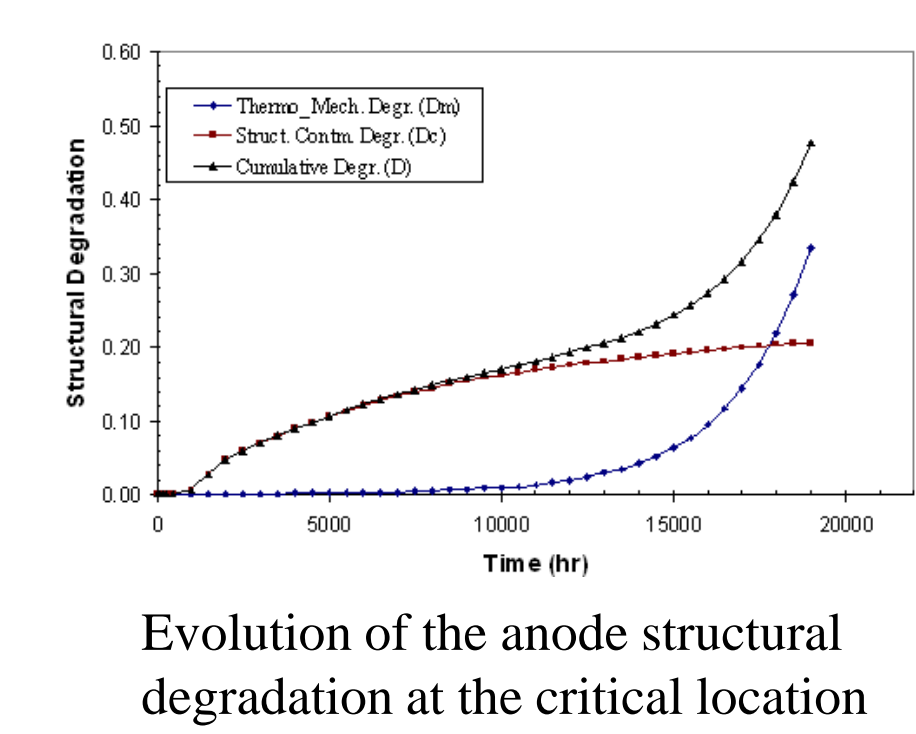
#### Experimental Setup:

Integration of NexTech Probostat™ SOFC button cell test apparatus with Sagnac interferometry optical technique and infrared thermometer

### Planar SOFC Anode Structural Degradation Model

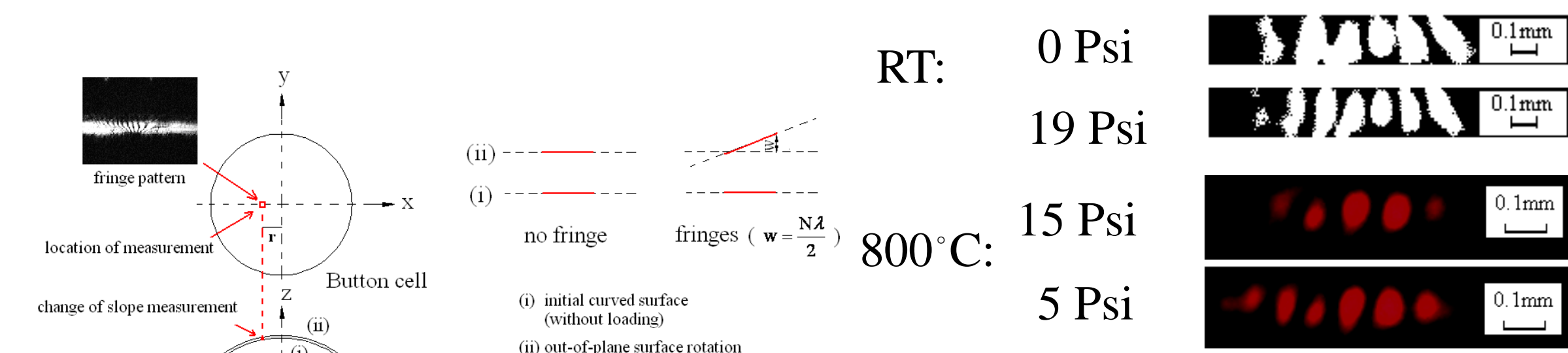


- Under pure thermo-mechanical effect, the critical location is for anode structural failure is near the fuel outlet corner
- When fuel contaminant effect on the anode structure are superimposed on the thermo-mechanical effect, the critical location shift near the middle of the cell



### SOFC Experimental Results

#### Surface Deformation Measurements



RT: 0 Psi  
19 Psi  
800°C: 15 Psi  
5 Psi

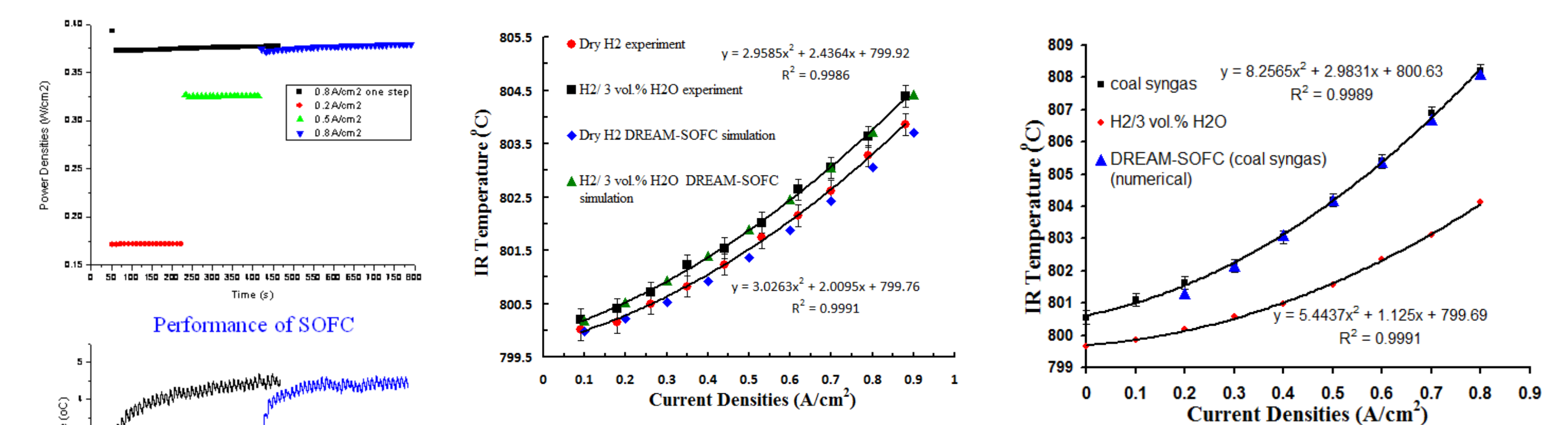
Fringe patterns on Ni mesh at  $r = 5.5$  mm from the center under different conditions

$$\lambda = 658 \text{ nm, Fringe sensitivity} = \lambda/2$$

#### Comparison among experimental, FE simulating and analytical results:

Applied Pressure (Psi)	temperature (RT)	Experimental Results		Simulation	Analytical
		Slope S	$\Delta S/\Delta P$	Result $\Delta S/\Delta P$	Result $\Delta S/\Delta P$
room	5	$4.038 \times 10^{-3}$			
10	5	$4.227 \times 10^{-3}$	$3.82 \times 10^{-5}$	$3.70 \times 10^{-5}$	$3.81 \times 10^{-5}$
	15	$4.420 \times 10^{-3}$			
	5	$3.877 \times 10^{-3}$			
800 C	10	$3.558 \times 10^{-3}$	$5.87 \times 10^{-5}$	$6.32 \times 10^{-5}$	$6.23 \times 10^{-5}$
	5	$3.290 \times 10^{-3}$			

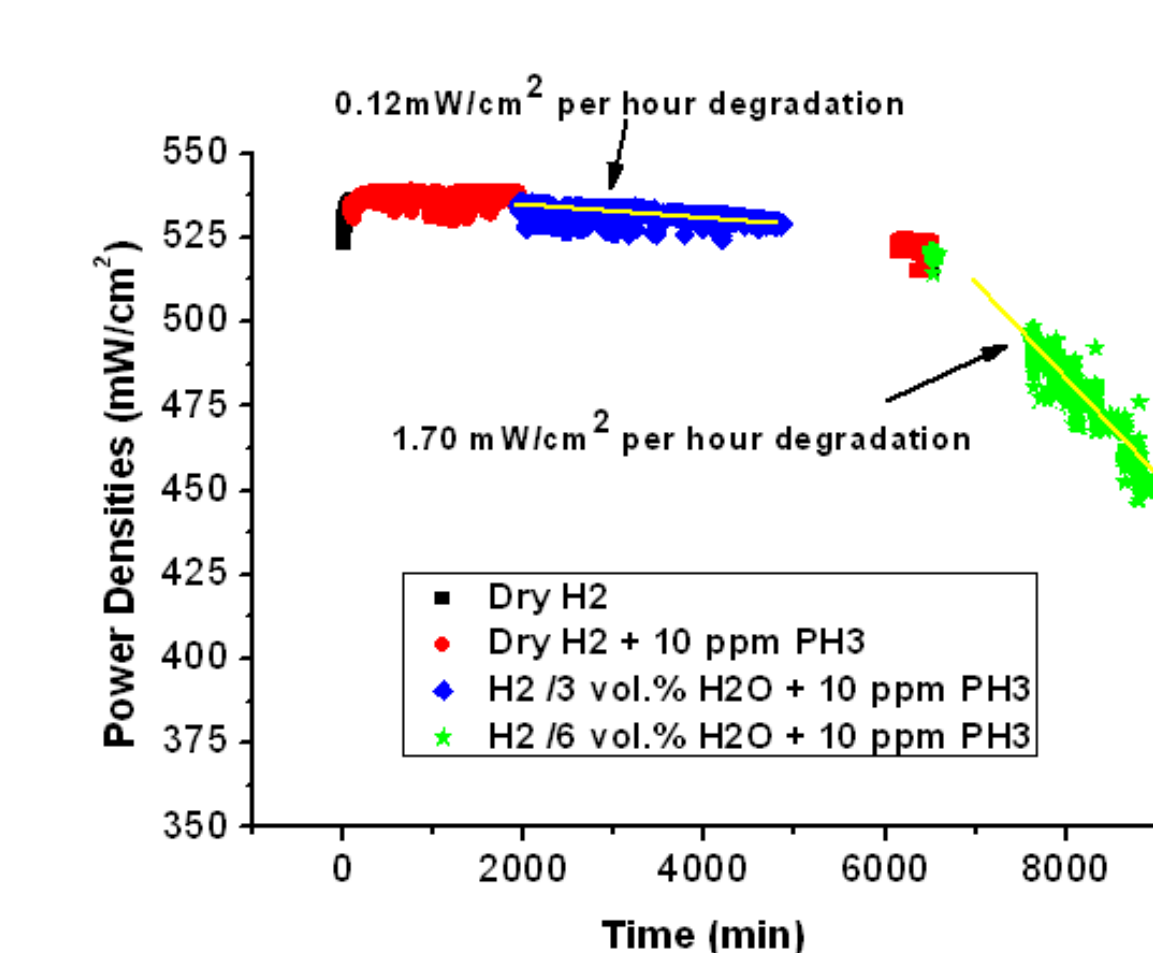
#### Surface IR Temperature Measurements



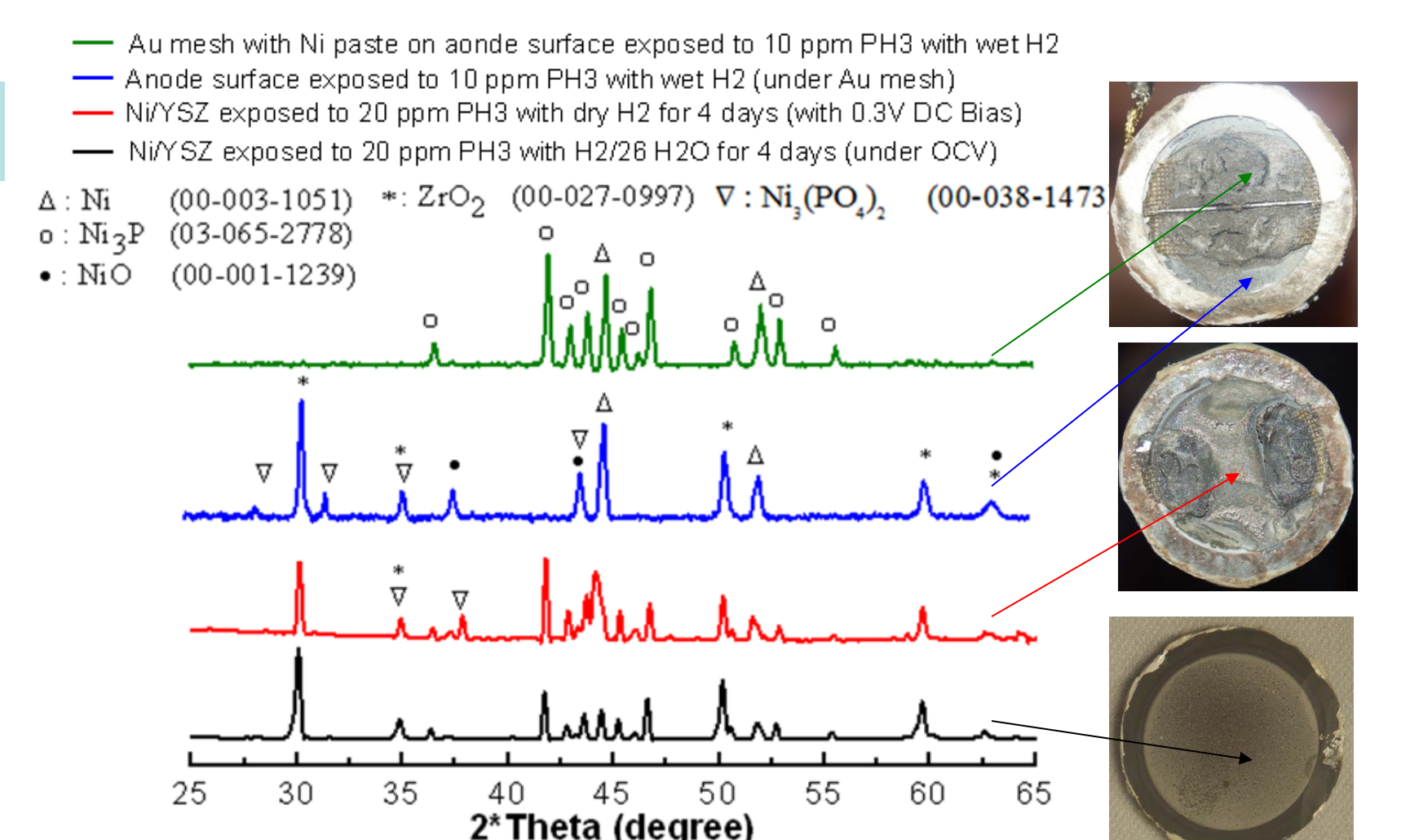
- > The major source of the temperature rise is entropic heating from fuel oxidation
- > A minor source is ohmic heating
- > water gas shift reaction provides negligible contributions

#### IR surface Temperature of SOFC

#### PH3 Effects on SOFC Performance



#### Performance Degradation History under Different Operating Conditions



- > SOFC anode is more susceptible to degradation due to  $PH_3$  in wet  $H_2$  than in dry  $H_2$ .
- > Under OCV condition,  $Ni_3P$  formation under either dry or wet  $H_2$  conditions.
- > Under cell operation, the potential bias drives  $O^{2-}$  to TPB of Ni/YSZ, Nickel Phosphate (such as  $Ni_3(PO_4)_2$ ) is preferred to be formed on the surface in the presence of steam
- > Nickel Phosphate has a deleterious effect on the SOFC performance.

### Acknowledgement:

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