Development of EBCs with Enhanced Durability and Temperature Capability

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Environmental Barrier Coatings Workshop
November 18-19, 2003
Gaylord Opryland Resort & Convention Center, Nashville, TN

This work is supported by:
NASA Ultra Efficient Engine Technology (UEET) Program

Co-workers

Dennis Fox - water vapor thermogravimetry

Craig Robinson - high pressure burner rig test

Narottam Bansal - fabrication of hot pressed EBC

Jeff Eldridge - phase stability/stress measurement

Dongming Zhu/Robert Miller - thermal conductivity

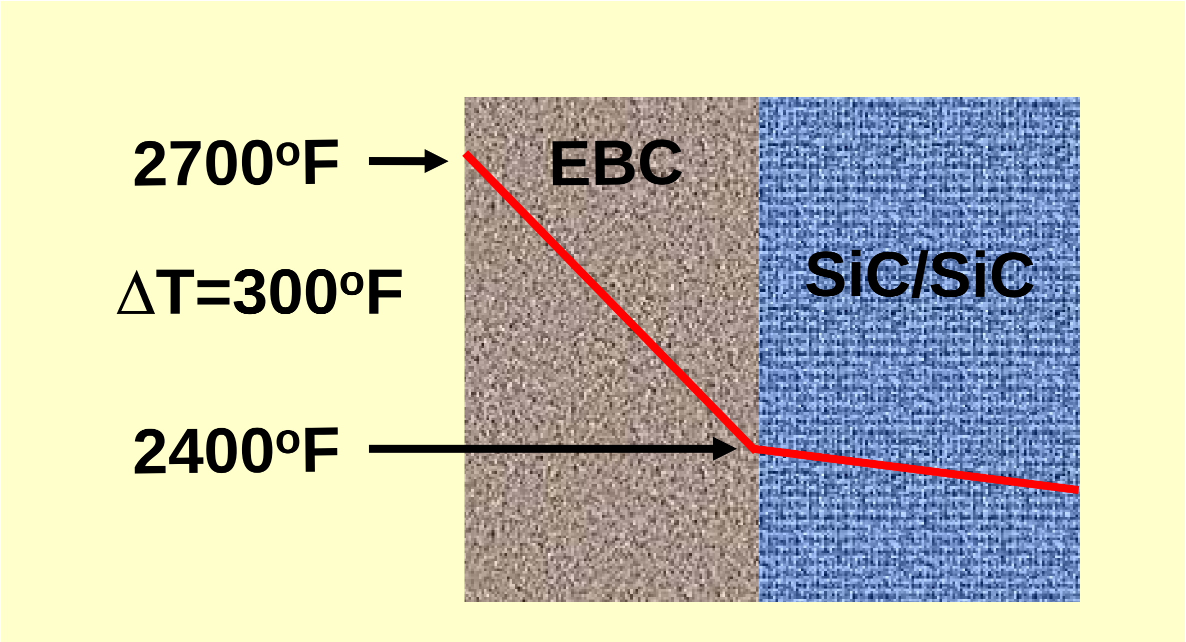
Outline

- **Objective**
- **Approach**
- **Results (SiC/SiC, Si_3N_4)**
- **Conclusions**

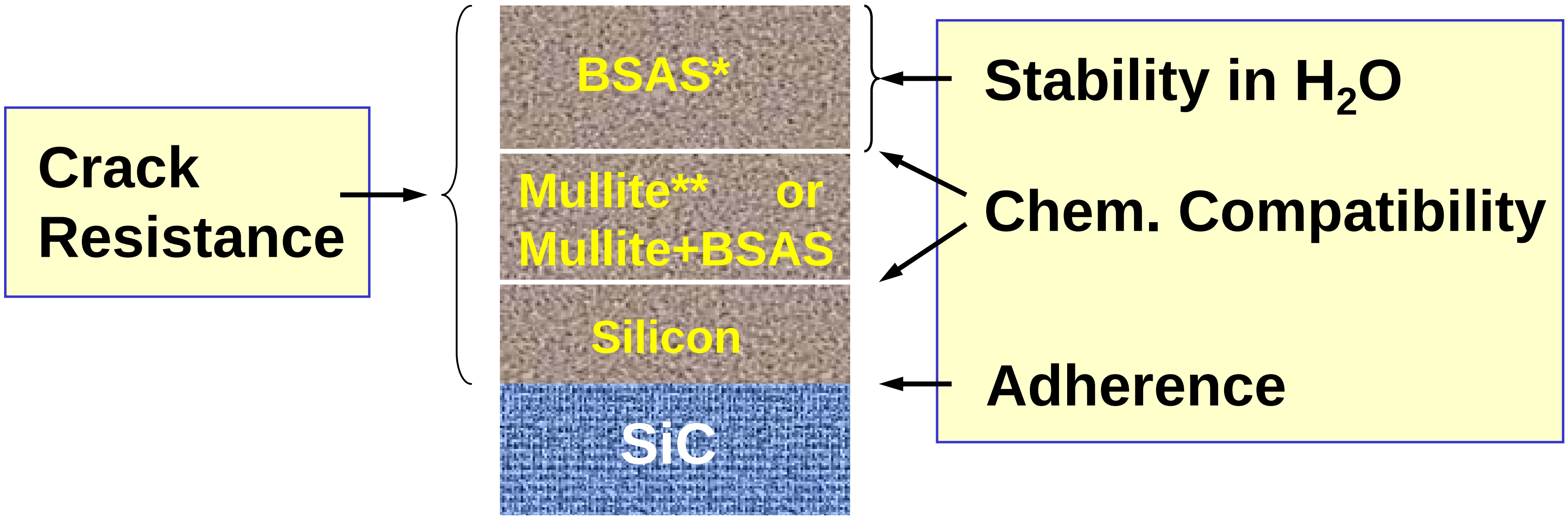
Objective

Develop advanced EBCs:

>1000 hr life at 2700°F (1482°C) EBC temp and 2400°F (1316°C) CMC temp



Current EBCs



* $xBaO \cdot (1\text{-}x)SrO \cdot Al_2O_3 \cdot 2SiO_2$

** $3Al_2O_3 \cdot 2SiO_2$

- Developed in the NASA HSR-EPM Program in joint research by NASA-GE-PW (2001 R&D 100 Award)
- Successful 15,000h engine test in Solar Centaur 50s SiC/SiC combustor liners under the DOE-CSGT Program (scaled up by Pratt & Whitney)

Current EBC Issues - Recession

Projected BSAS Recession

(1000 hr, 6 atm, v_{gas} = 24 m/sec)

1300°C : 28 μm
1400°C : 67 μm
1500°C : 268 μm

Silica Volatility Model (Smialek et al)

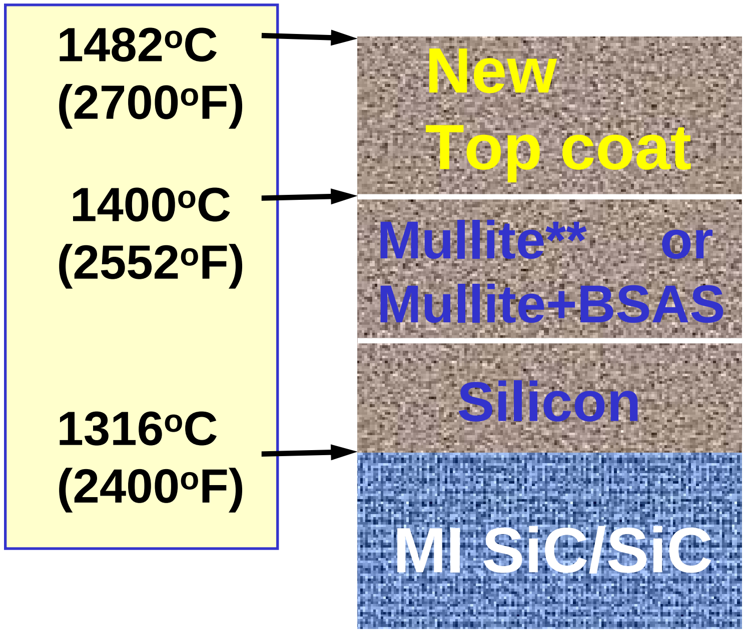
$$\textbf{Volatility} \propto \frac{v^{1/2} \times P(H_2O)^2}{(P_{TOTAL})^{1/2}}$$

ν : gas velocity
$P(H_2O)$: water vapor pressure
P_{TOTAL} : total pressure

Assumptions
- Observed weight loss is due to silica loss only
- $Si(OH)_4$ is the major volatile species

Approach to Develop New EBC Systems

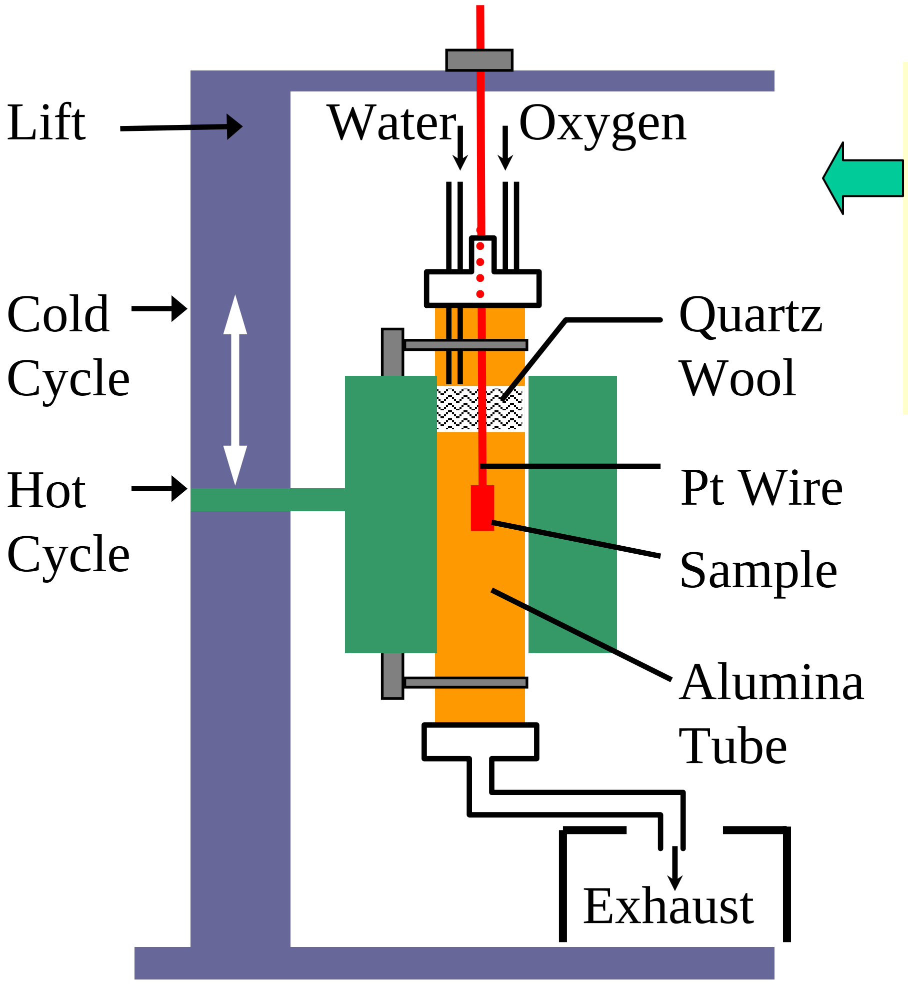
Temp goals



- **Identify new top coats**
  - water vapor stability @ T>1482^{o}C
  - chemical compatibility @ T>1400^{o}C
  - mechanical compatibility

- **Water vapor TGA test**
  - **Water vapor stability of top coat @ 1500^{o}C**
- **High steam thermal cycling test**
  - **Chemical & Environmental durability @ 1300 - 1400^{o}C**

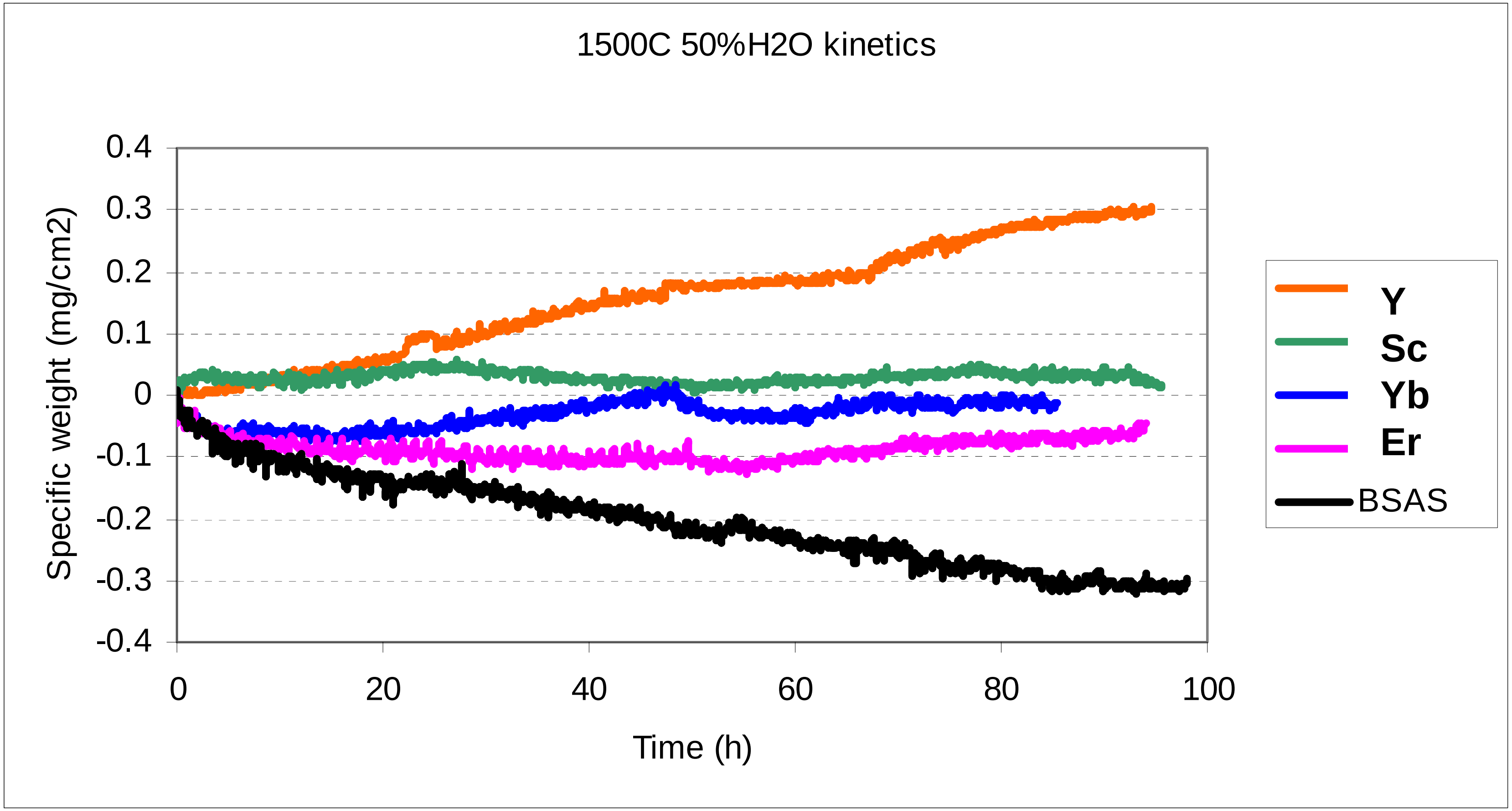
High Steam Thermal Cycling Rig (HSTC)



- **HSTC Rig**
  - **simulate fuel lean environment**
    (pH_2O = 0.9, V_{gas} = 2.2 cm/sec)
  - **environmental durability**
  - **chemical stability**

- **Water vapor TGA**
  - **volatility**

Rare-Earth Silicate EBC Identified



US PATENT PENDING

Rare Earth Silicate CTE

Material	CTE ($10^{-6}/^oC$)
Y_2SiO_5	5 ~ 6*
Er_2SiO_5	5 ~ 7
Yb_2SiO_5	3.5 ~ 4.5
Sc_2SiO_5	5 ~ 6

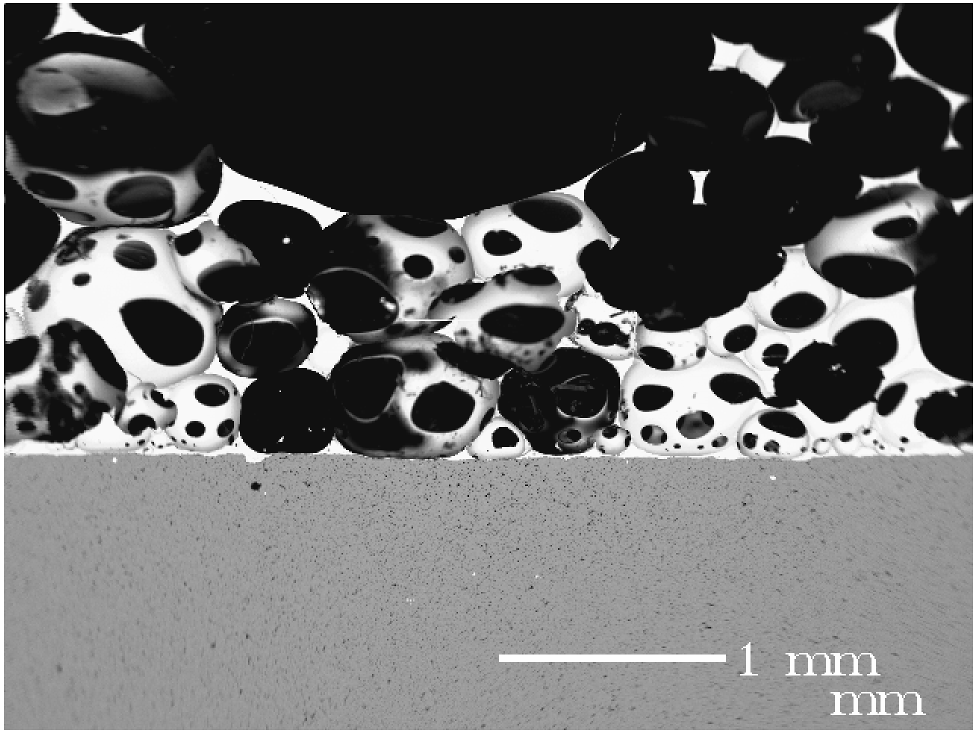
Material	CTE ($10^{-6}/^oC$)
SiC**	4.5 ~5.5
Si_3N_4**	3 ~ 4
Si**	3.5 ~ 4.5
BSAS (celsian)	4 ~ 5
Mullite	5 ~ 6

* Ogura et al.

** Touloukian et al, "Thermophysical Properties of Matter"

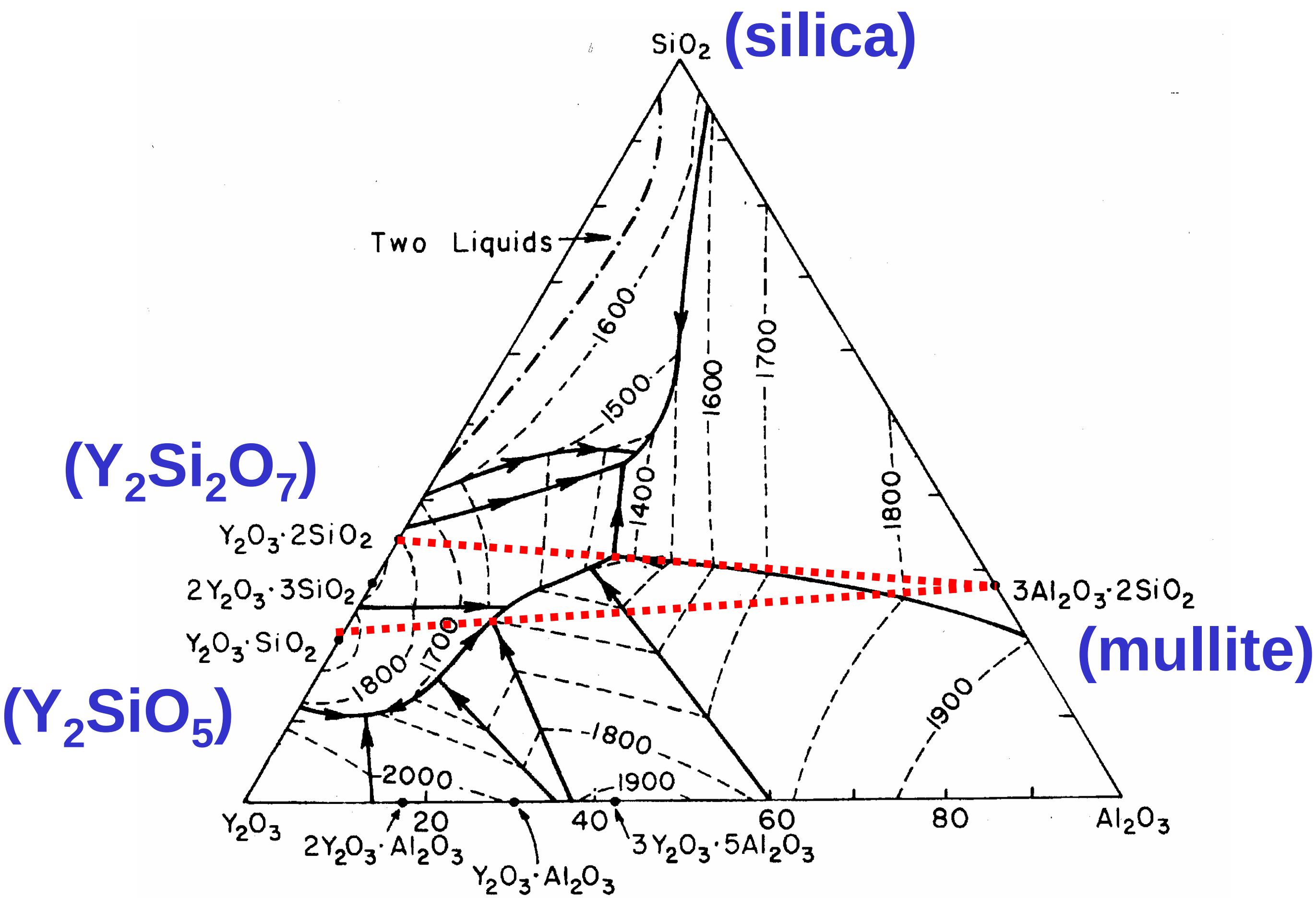
Mullite/Y_2SiO_5

1400°C- 46 hr, 1h cycles, HSTC



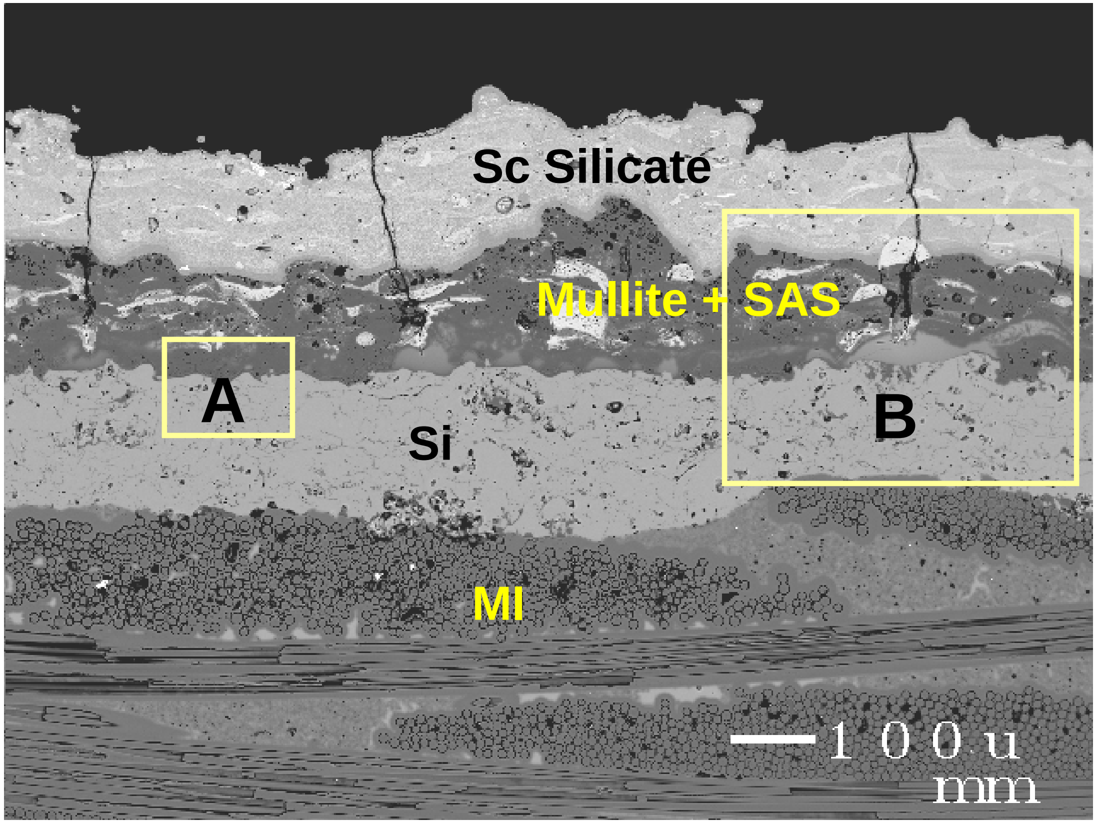
- Coating turned into Y-Al-Silicate bubbles

Y_2O_3-Al_2O_3-SiO_2 Phase Diagram



Si/Mullite+SAS/Sc Silicate

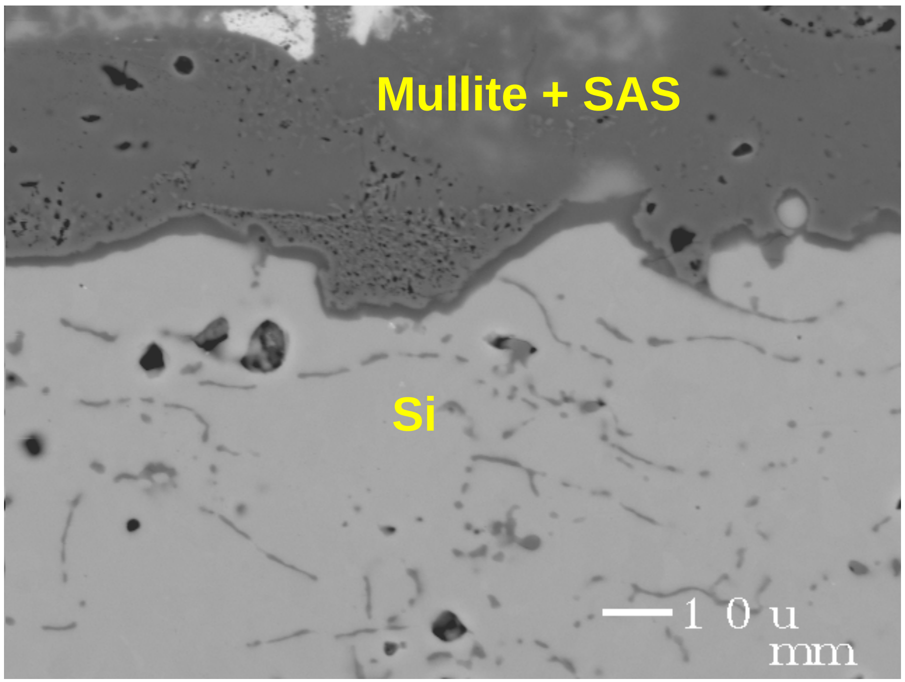
1380^{o}C- 300 hr, 1h cycles, HSTC

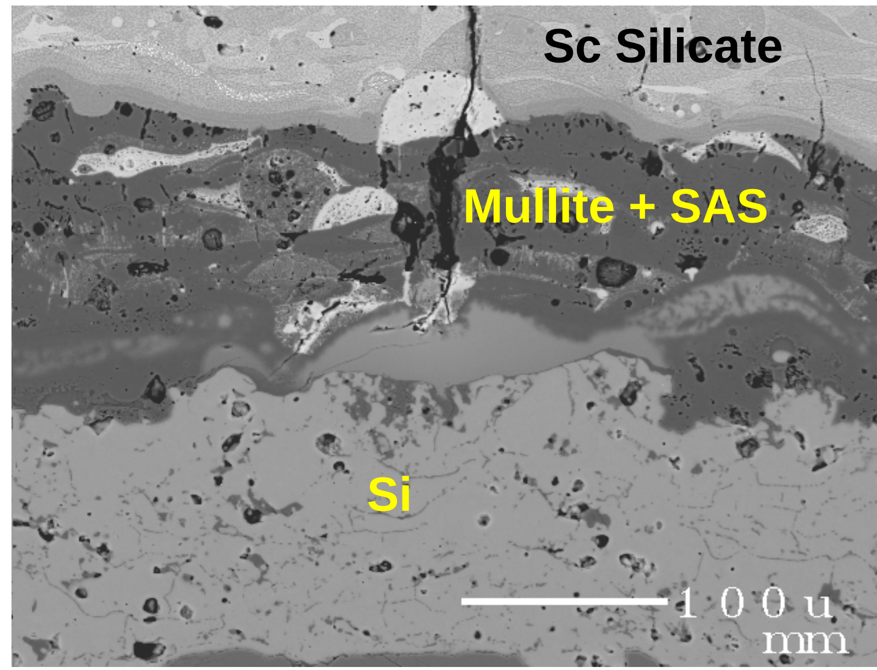


- Through-thickness cracks in ceramic layers
  - CTE mismatch, phase instability?, etc.
  - relax stress

Si/Mullite+SAS/Sc Silicate

1380°C- 300 hr, 1h cycles, HSTC



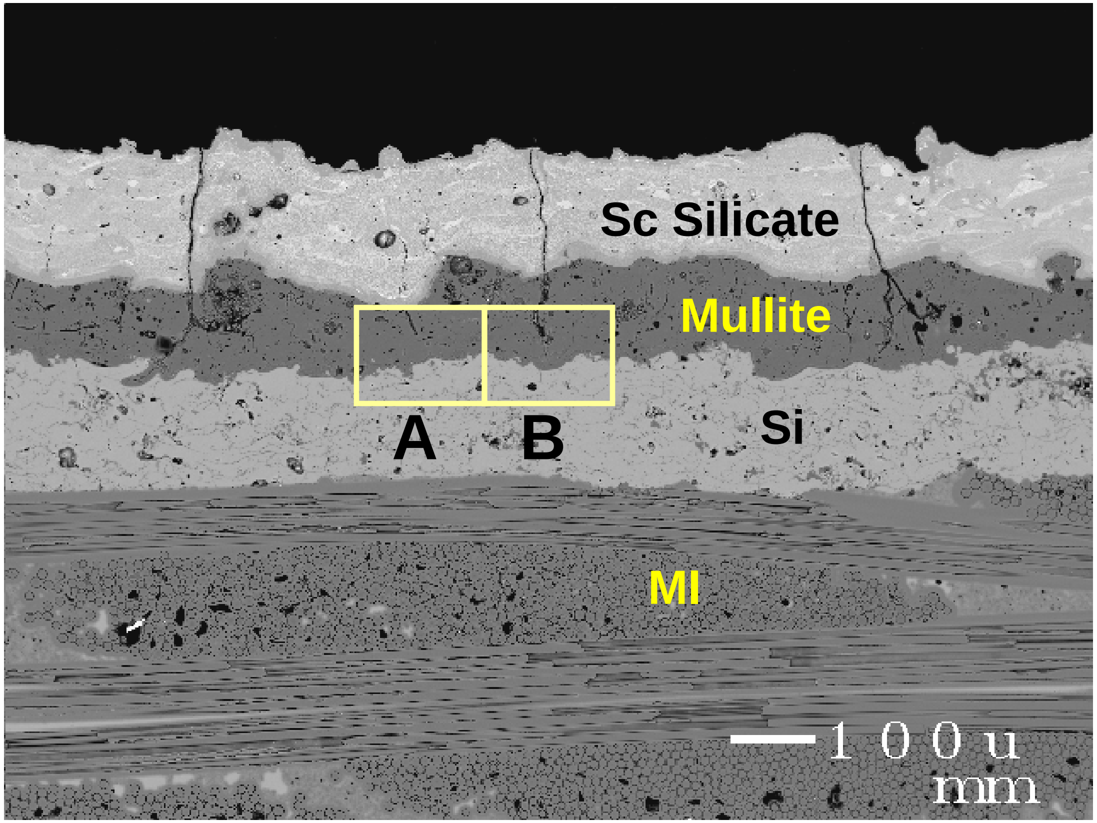


A: Minimal oxidation

B: Enhanced oxidation at the crack tip
- glass formation

Si/Mullite/Sc Silicate

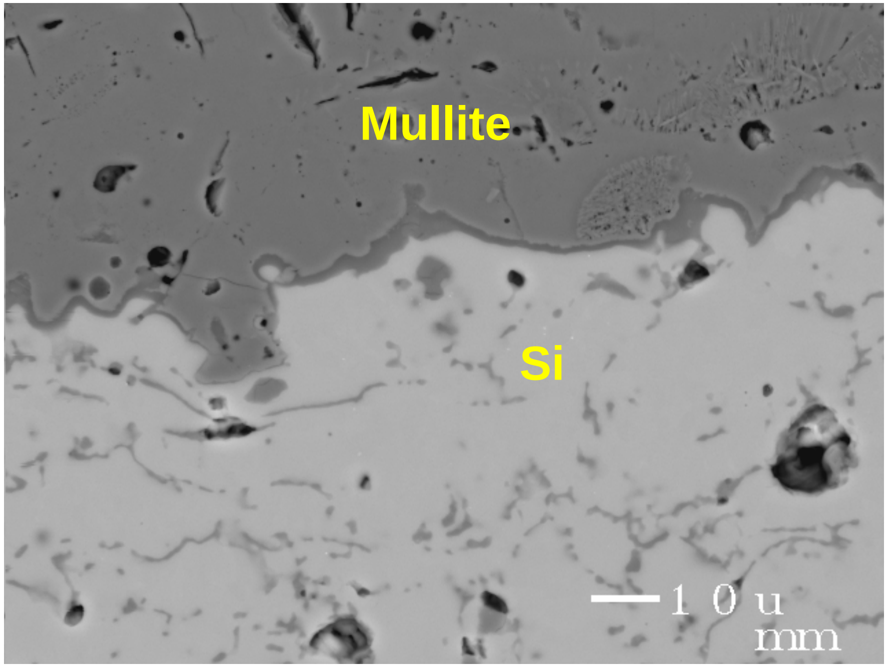
1380ºC- 300 hr, 1h cycles, HSTC

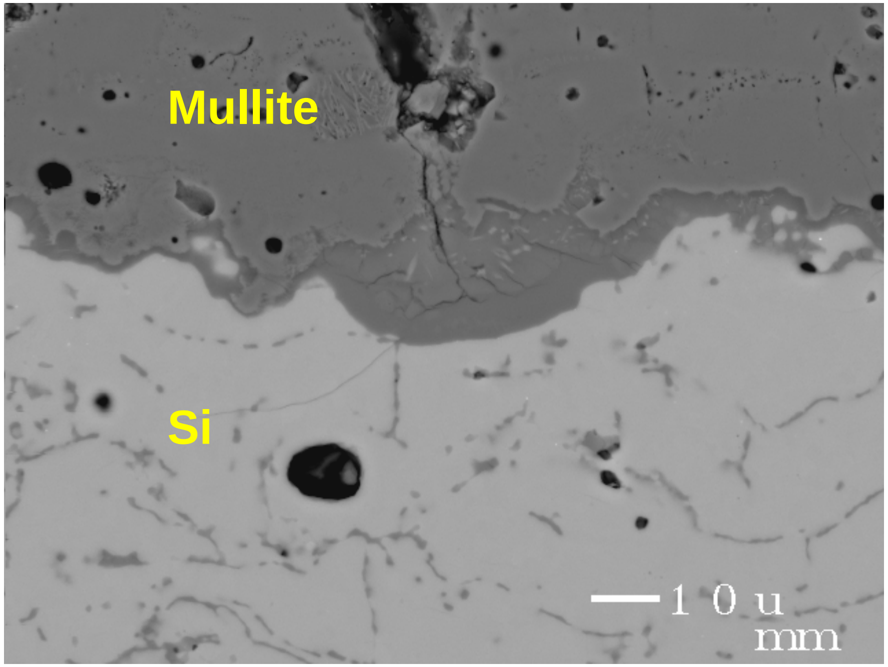


- Through-thickness cracks in ceramic layers
  - more prone to cracking with mullite intermediate layer

Si/Mullite/Sc Silicate

1380°C- 300 hr, 1h cycles

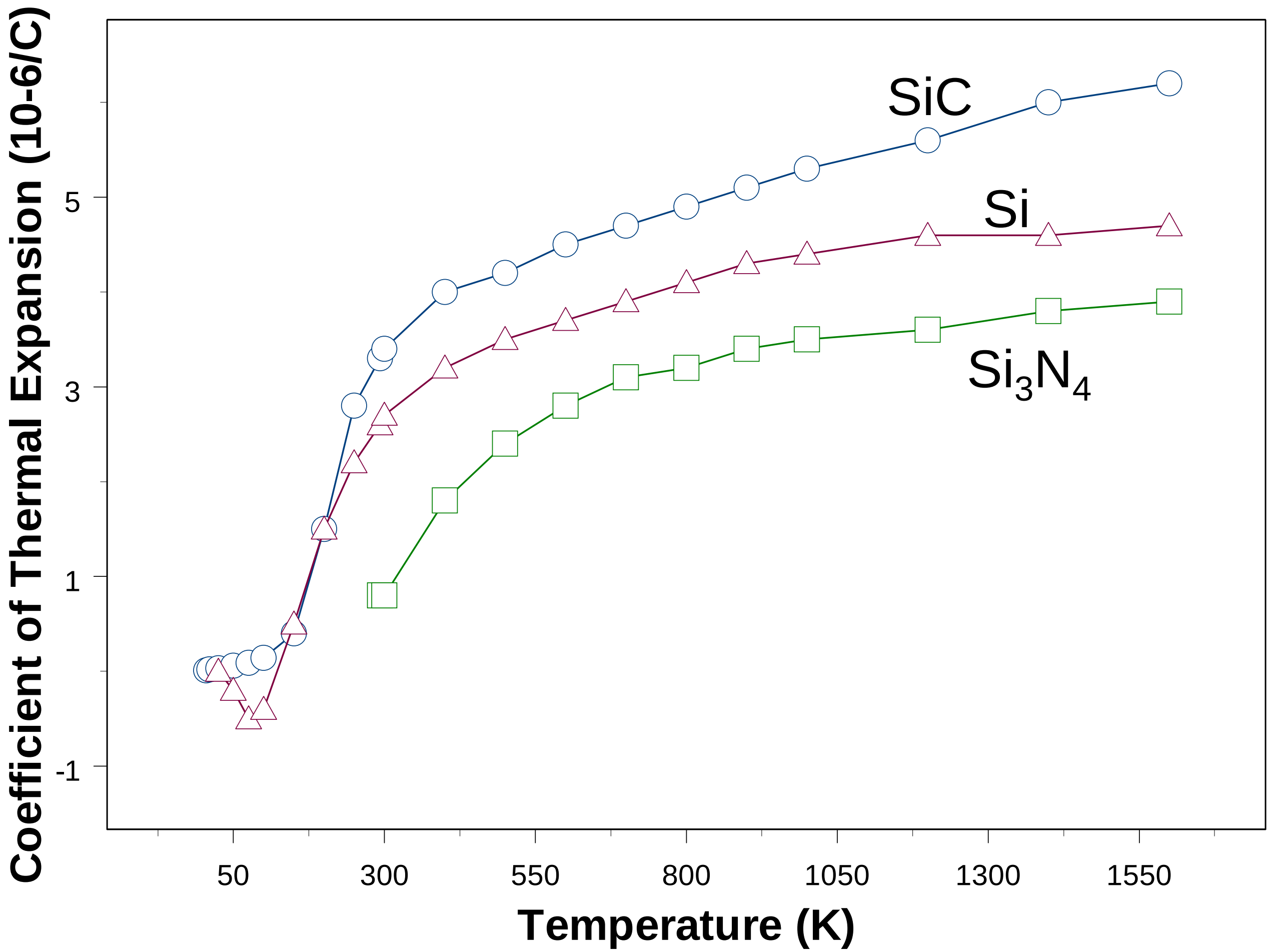




A: Minimal oxidation

B: Enhanced oxidation at the crack tip
- no glass formation

CTE of Si, SiC and Si_3N_4

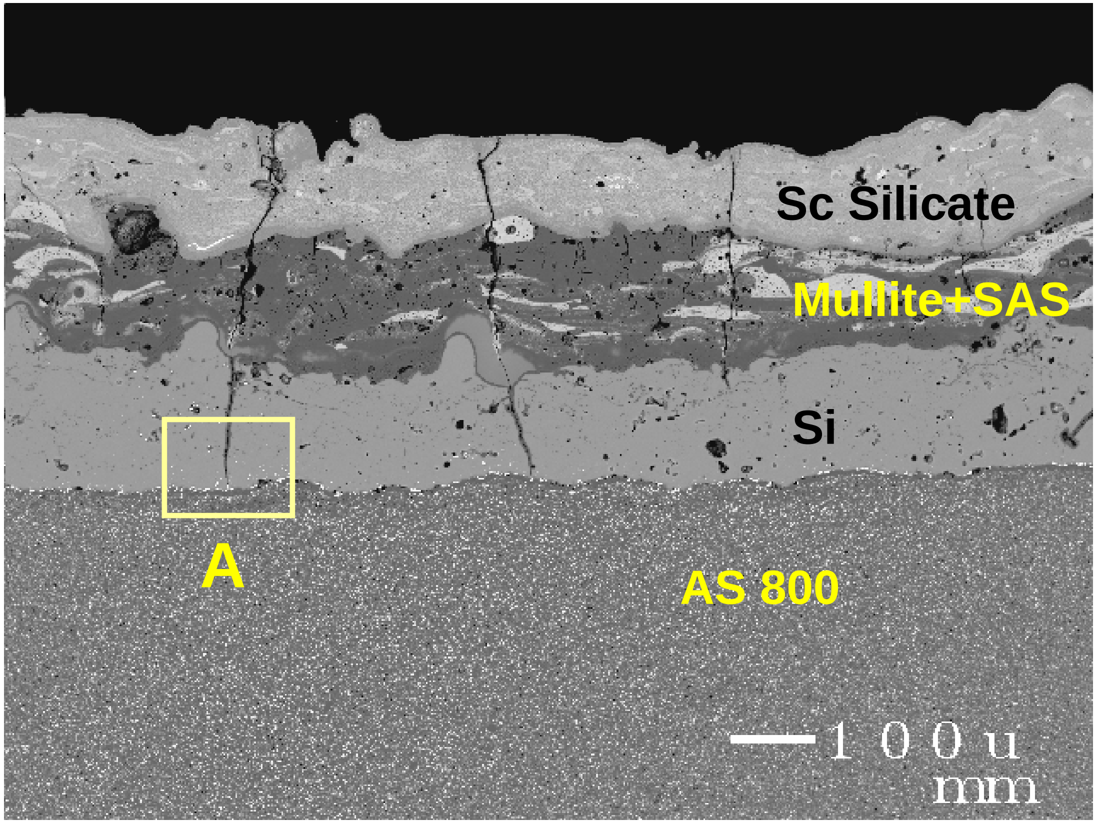


- Lower CTE of Si_3N_4 causes bigger CTE mismatch

Touloukian et al, “Thermophysical Properties of Matter”

Si/Mullite+SAS/Sc Silicate

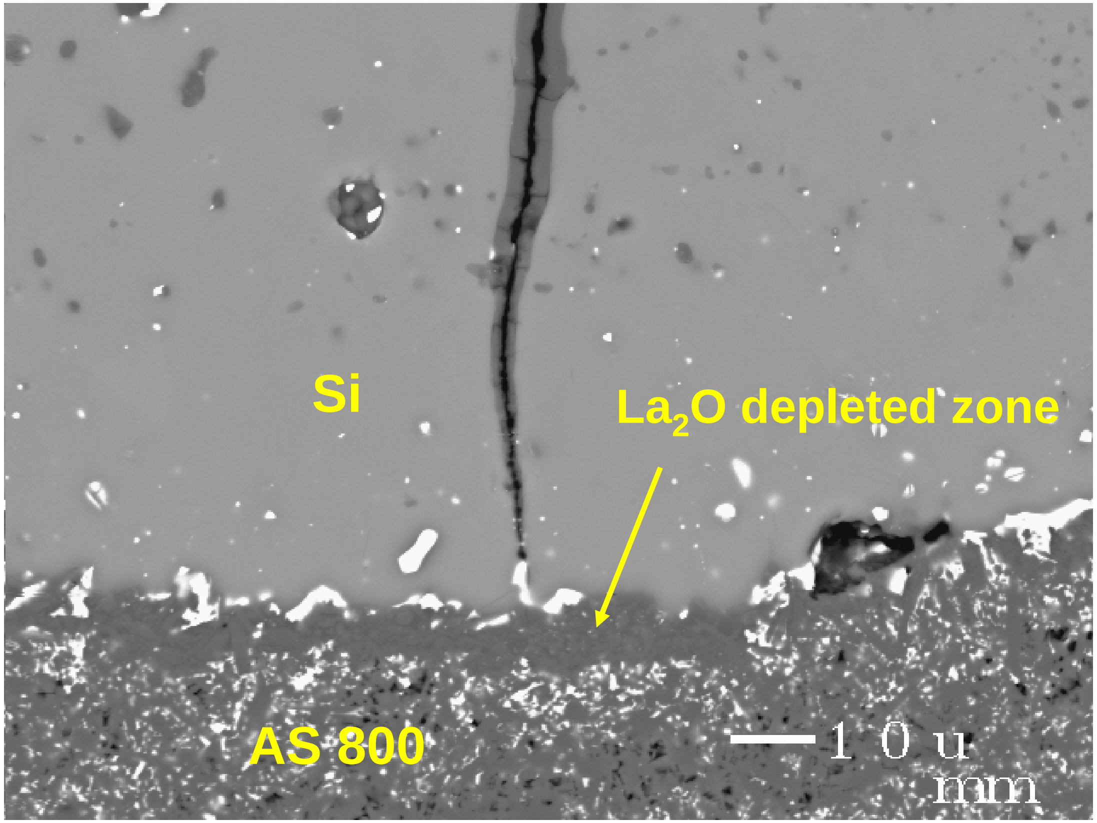
1380^{o}C- 200 hr, 1h cycles, HSTC



- Through-thickness cracks in all three layers (Si bond coat in tension)

Si/Mullite+SAS/Sc Silicate

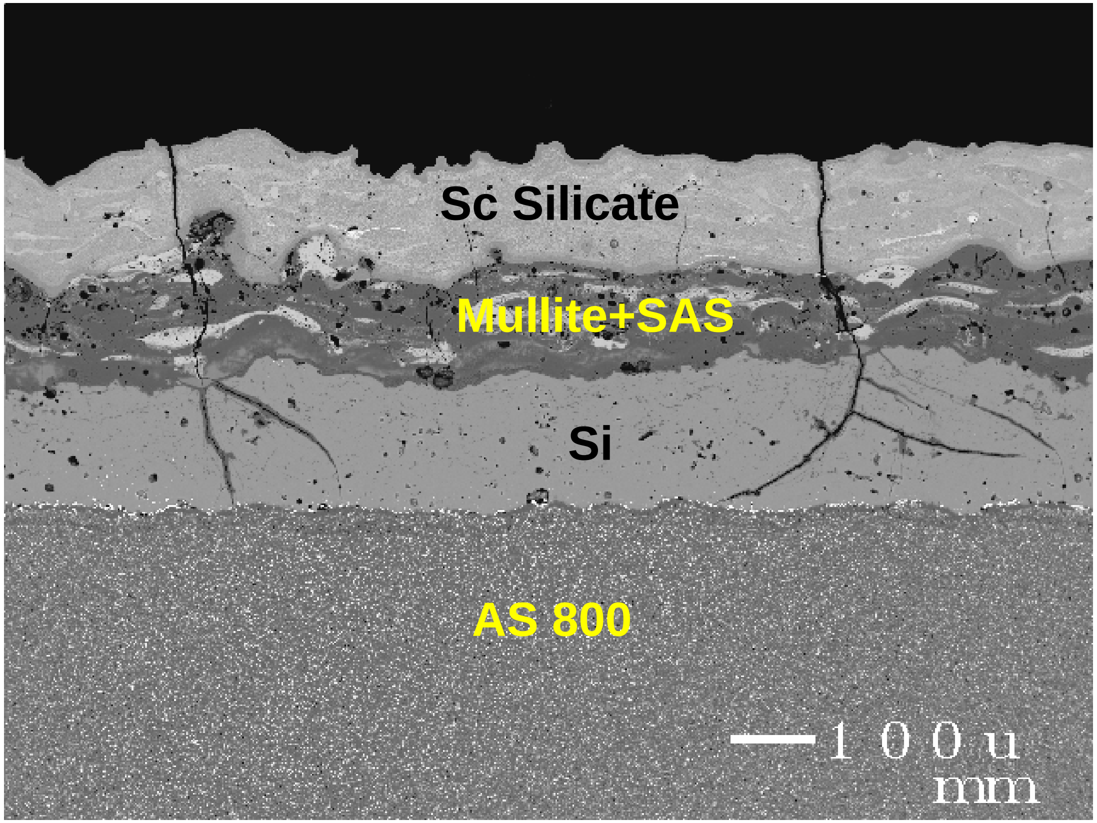
1380°C- 200 hr, 1h cycles, HSTC



A: Cracks provide path for water vapor which can rapidly oxidize Si bond coat

Si/Mullite+SAS/Sc Silicate

1380^{o}C- 200 hr, 1h cycles, HSTC



- some cracks branch laterally
  - can cause coating delamination

Conclusions

- Rare earth silicates (Sc, Yb, Lu) are promising as 2700°F EBC top coat
  - Low CTE ($4 \sim 7 \times 10^{-6}/^{o}C$)
  - Superior water vapor stability compared to BSAS
  - Superior chemical compatibility compared to BSAS
  - Low thermal conductivity (equal to or better than YSZ)
- Issues with rare earth silicates
  - Through-thickness cracks
    - What is the effect on long-term durability?
  - Economy (high cost of Sc, Lu)

Conclusions (cont)

- Si_3N_4 EBC issues
  - Cracks into Si bond coat can rapidly oxidize Si bond coat

    - should not be as severe in infrequent cycling (industrial turbines)
  - Cracks branching laterally can cause delamiantion
  - Adherence on as processed surface?

- Selection of EBC system depends on operating conditions
  - EBC surface temperature (*BSAS vs. RE silicates*)
  - Substrate temperature (*Mullite+BSAS vs. Mullite*)
  - Life goal
  - Thermal cycling frequency

    - Aero or industrial gas turbines?