Development of Refractory Silicate-YSZ Dual Layer TBCs

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Research Area

- Materials (TBC)

Objective

- Improve TBC durability by incorporating an environmental barrier with low oxygen conductivity and high hot corrosion resistance.

Relevance to ATS

TBC's with enhanced environmental resistance provide longer lifetime and higher temperature capability, which in turn increase the efficiency and performance of gas turbine engines.

Approach

1. Selection of Ceramic Environmental Barrier
   - Mullite, Glass Ceramics, Rare-Earth Silicates
2. Application of Coatings
   - APS, Sputtering, SPPS
3. Testing and Data Analysis
   - Thermal Cycling, Na_2SO_4 Hot Corrosion
   - XRD, SEM.

Selection Of Barrier Coatings

- Low Oxygen Conductivity
- Hot Corrosion Resistance
- Chemical Compatibility
- Thermal Expansion Coeff.

Barrier	Mullite BAS, CAS	CeAS	La_2SiO_5, SmAS, SLB
CTE ($10^{-6}/^{o}C$)	3 ~ 5	7 ~ 8	9 ~ 12

CTE (YSZ) : **9~10** $10^{-6}/^{o}C$

Application Of Coatings

Barrier

- Sputtering, SPPS (oxygen barrier)
  - on top of bond coat
  - thin coating (1~10 μm)
- APS (hot corrosion barrier)
  - on top of YSZ
  - thick coating (50~75 μm)

Bond Coat

- LPPS
  -NiCrAlY (5 mil)

Top Coat

- APS
  -YSZ (10 mil)

Substrate

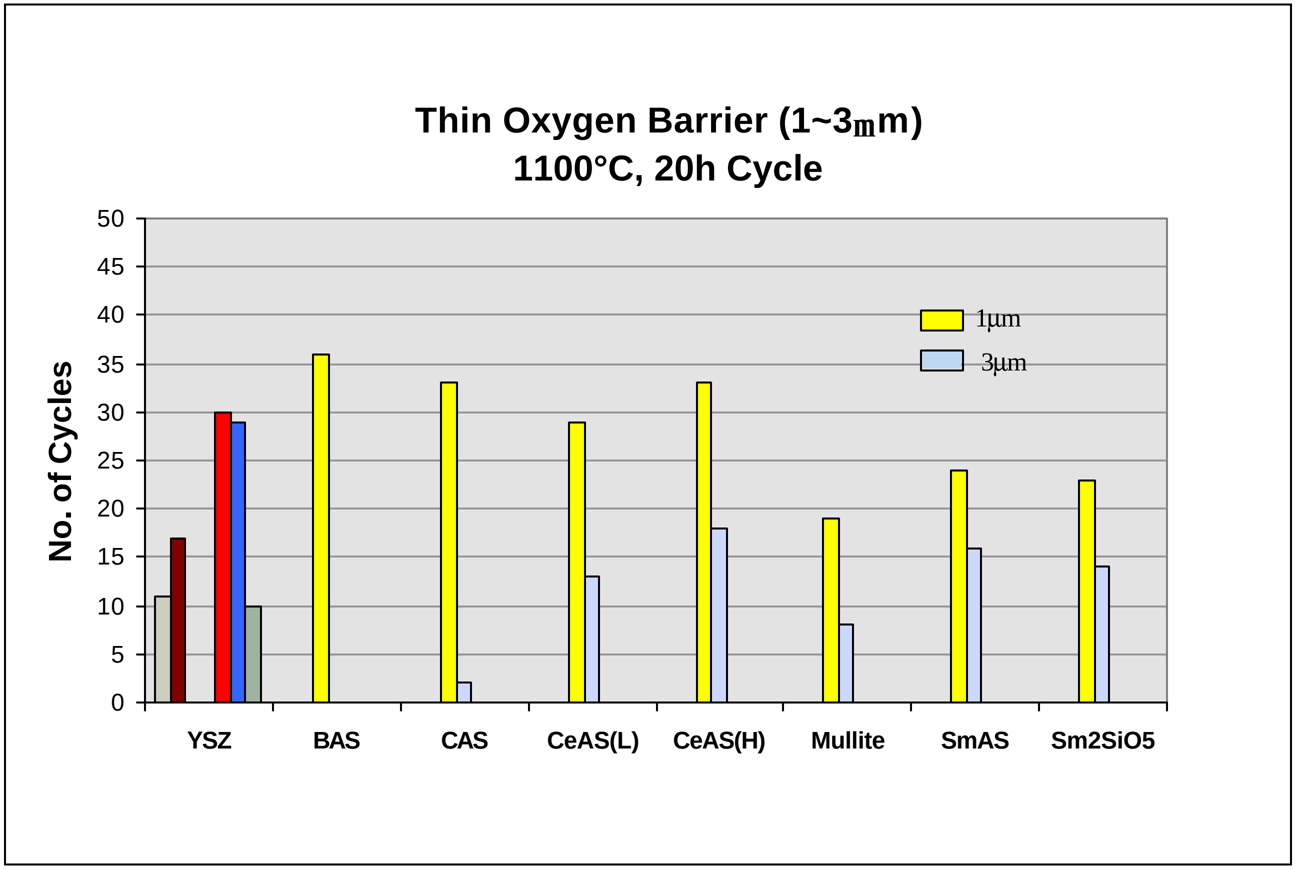
- CMSX4+Y
  - 1” Dia., 1/8” thick
  - all coatings on one face

Testing & Data Analysis

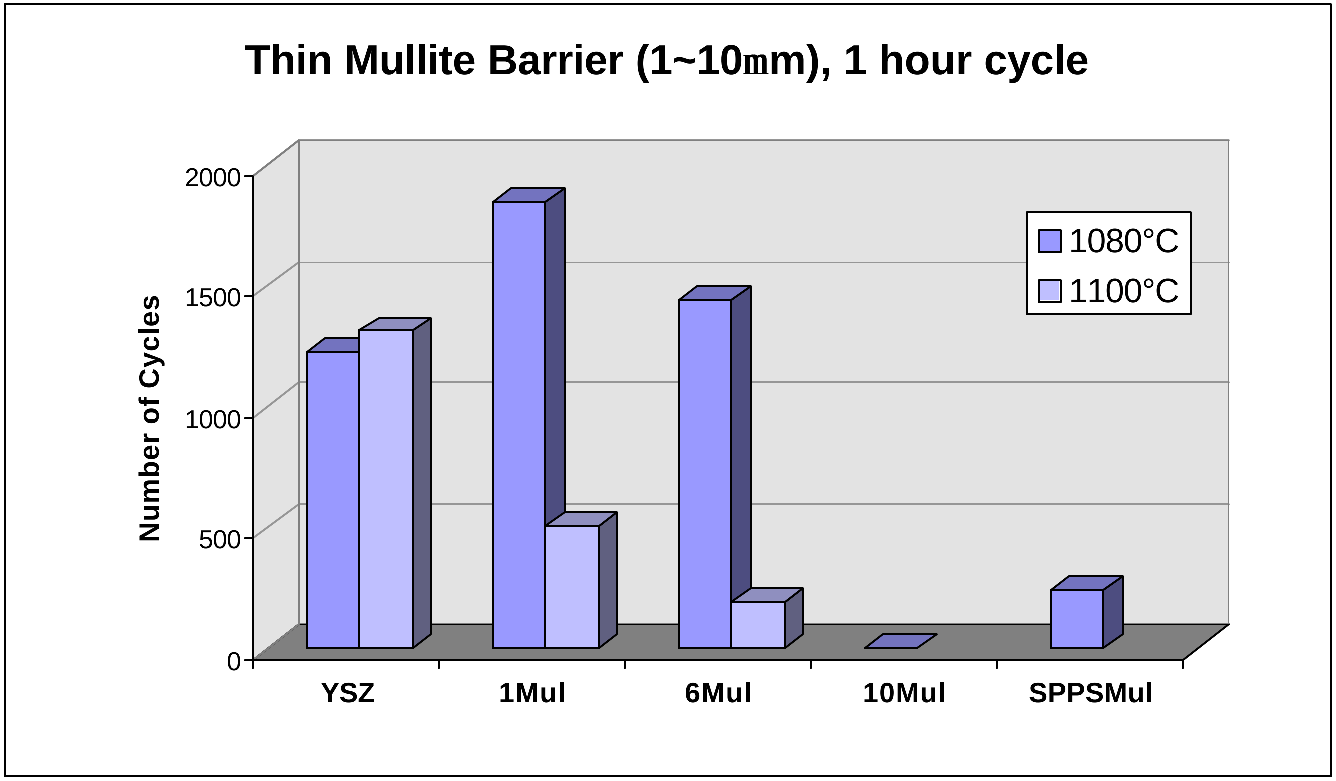
- Annealing: 4h in Ar-5% H_2, 1100^oC
- Cyclic Oxidation: 1h & 20h cycle @ 1080-1100^oC
- Hot Corrosion : 900°C, O_2/100ppm SO_2,
  3 mg/cm^2 Na_2SO_4 film
- Post-Test Characterization: XRD, SEM

Results

- Oxygen Barrier Coatings by Sputtering
  - *Applied at the bond coat/YSZ interface*
  - Low CTE: Mullite, BAS, CeAS (L)
  - High CTE: CeAS (H), SmAS, Sm_2SiO_5

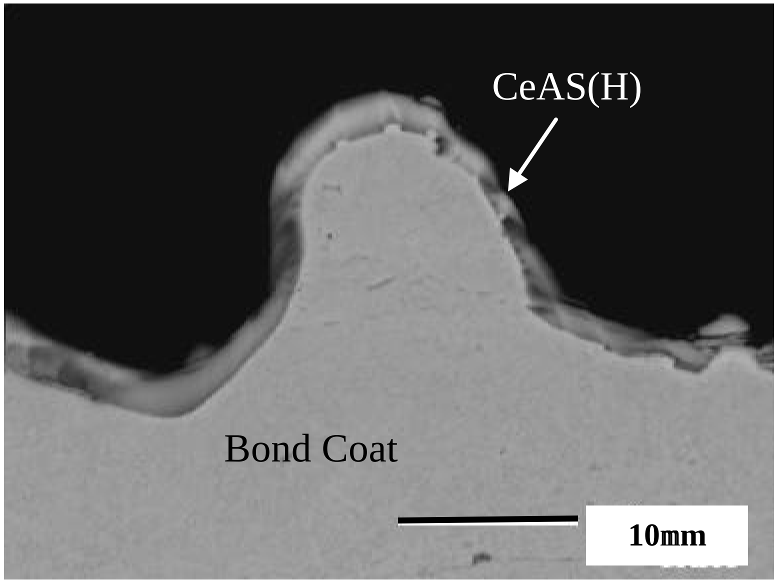


- **1 ㎛ oxygen barrier shows the best durability**
  - presumably due to enhanced compliance
- **No clear evidence of reduced TGO thickness (Except for mullite)**
  - similar TBC life to standard YSZ TBC
  - low coating quality is an issue (porosity, discontinuity)

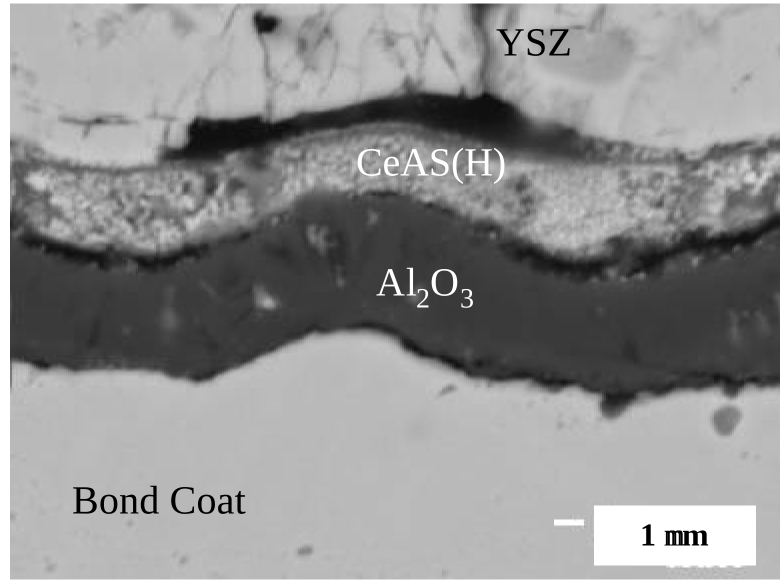


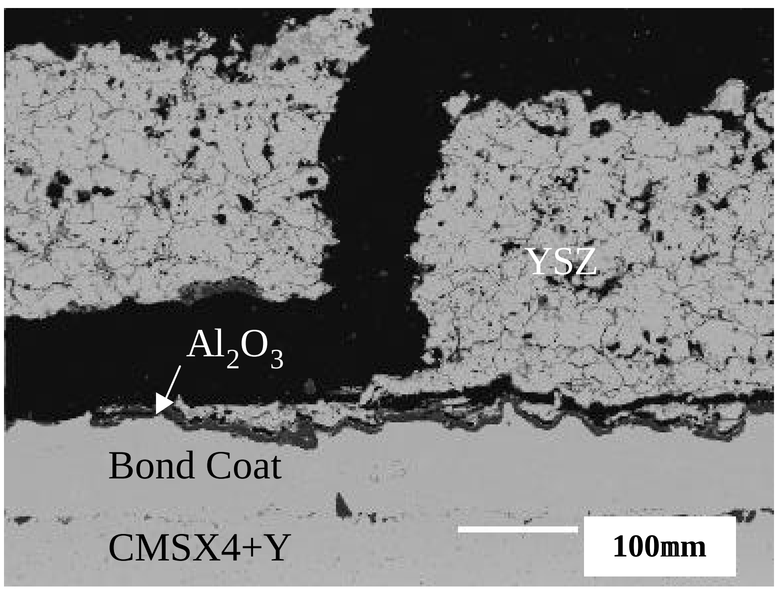
- **Similar TBC life to standard YSZ TBC at 1080°C**
  - despite reduced TGO thickness by a factor or two
  - presumably due to high modulus

- **Significantly reduced life at 1000°C**
  - not understood at this point (duplicate test is underway)

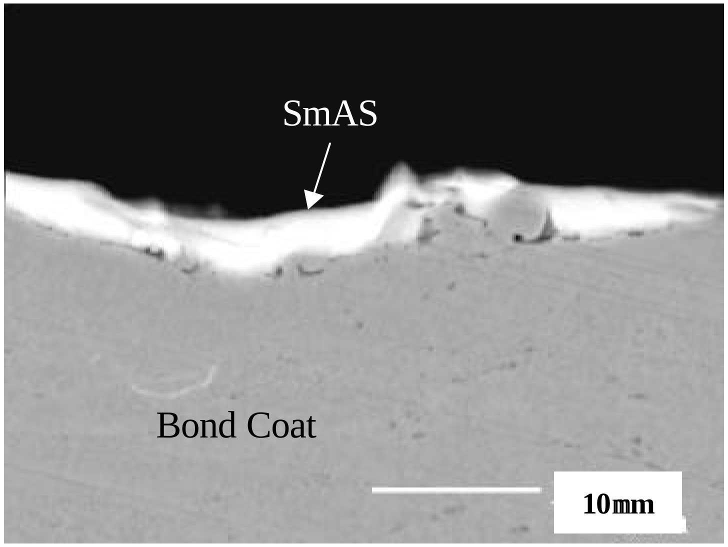


As-sputtered 3mmCeAS(H)

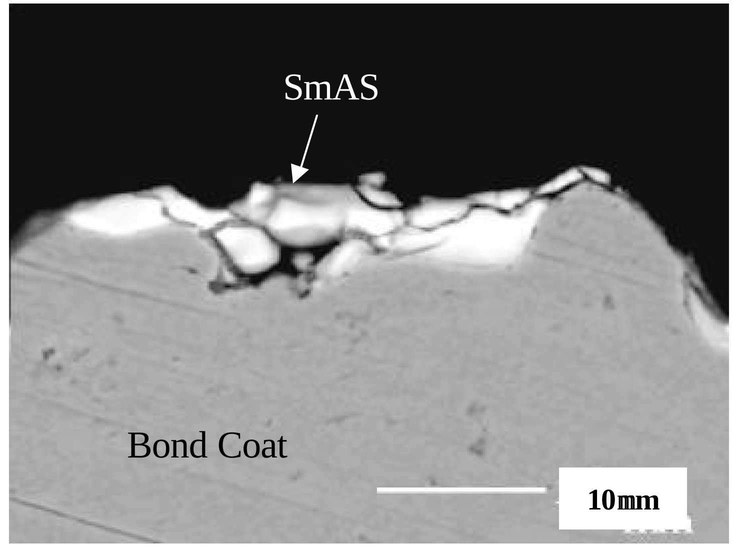




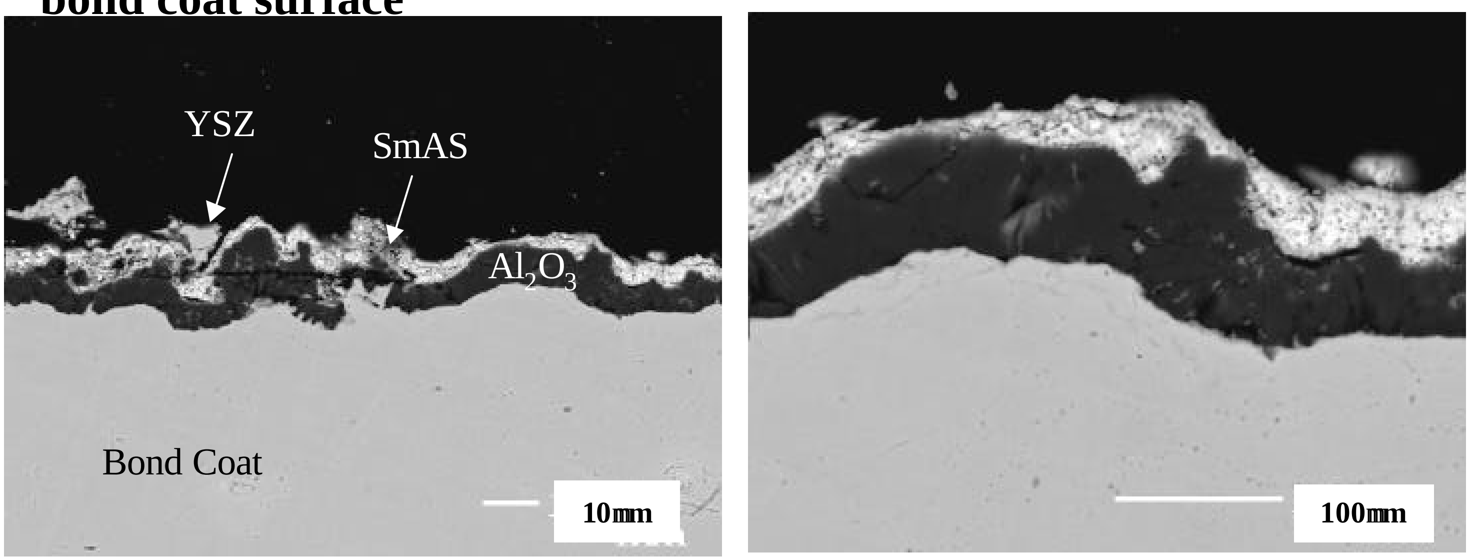
3mm CeAS(H)/YSZ after 18 cycles of 20h cycle test at 1100°C



As-sputtered 3mm SmAS on flat bond coat surface

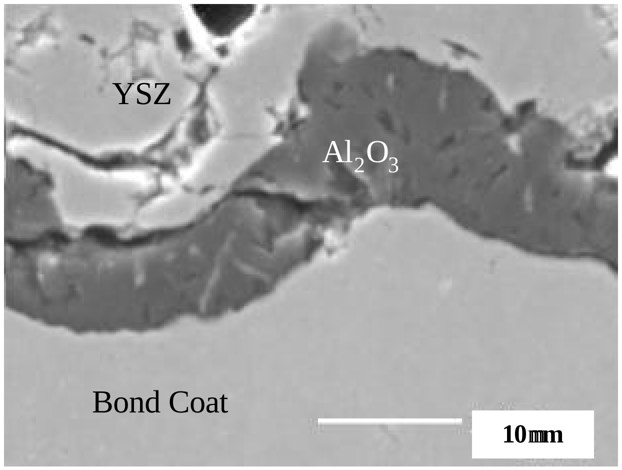


As-sputtered 3mm SmAS on rough bond coat surface

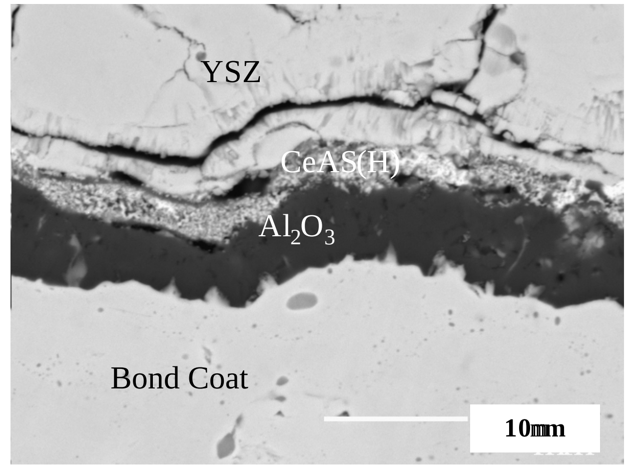


3mm SmAS/YSZ after 16 cycles of 20h cycle test at 1100°C

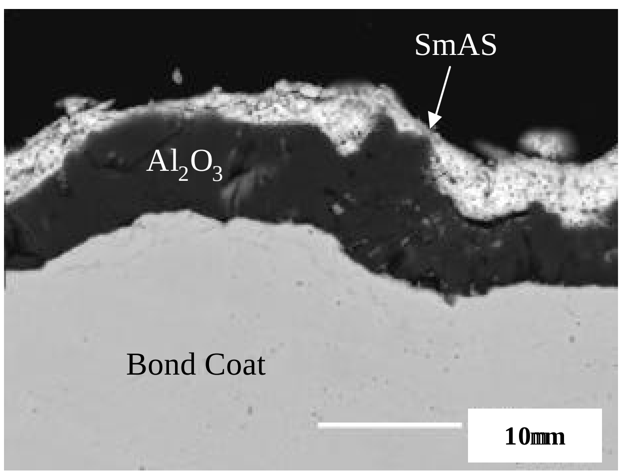
Comparison of TGO thickness (20h cycle, 1100°C)



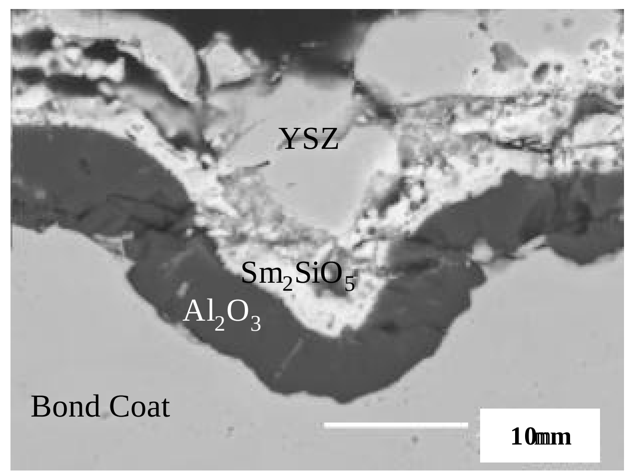
Standard YSZ after 17 cycles



3mm CeAS/YSZ after 18 cycles



3mm SmAS/YSZ after 16 cycles



3mm Sm_2SiO_5/YSZ after 14 cycles

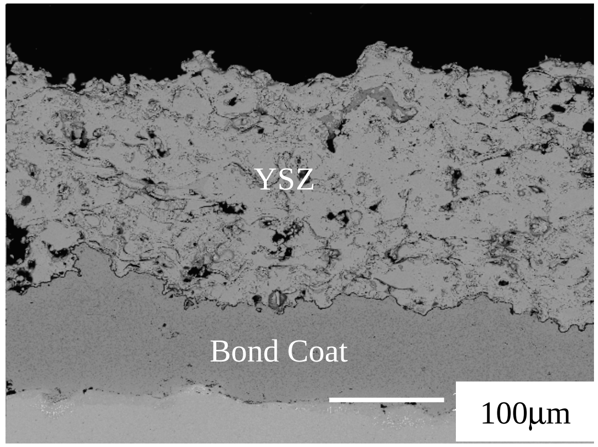
Conclusions
(Oxygen Barrier)

- Thin oxygen barrier (1μm) performs better than thick oxygen barriers (> 3 μm)
  - presumably due to enhanced compliance of thinner coatings
- No clear evidence that oxygen barrier reduces TGO thickness (Except for mullite oxygen barrier)
  - similar TBC life to standard YSZ TBC
  - key issues (limitations)
    - low quality coating (porosity, discontinuity, phase instability)
    - high modulus

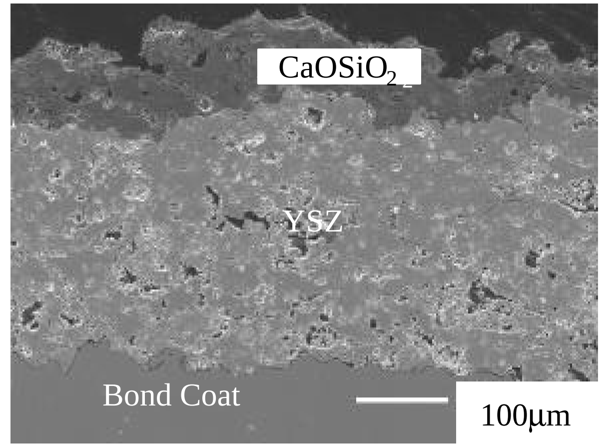
Results

- Hot Corrosion Barrier Coatings by APS
  - *Applied on top of YSZ*
    - $CaOSiO_2$
    - Mullite
    - BAS
    - SmAS
    - La_2SiO_5
    - SLB
    - CeAS
    - ZTY

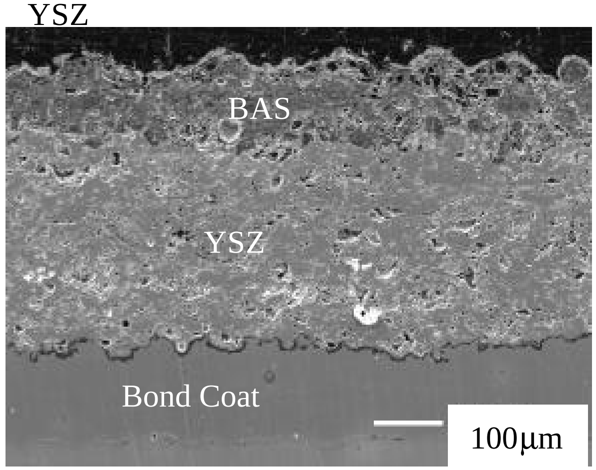
48 Na_2SO_4 Hot Corrosion at 900°C



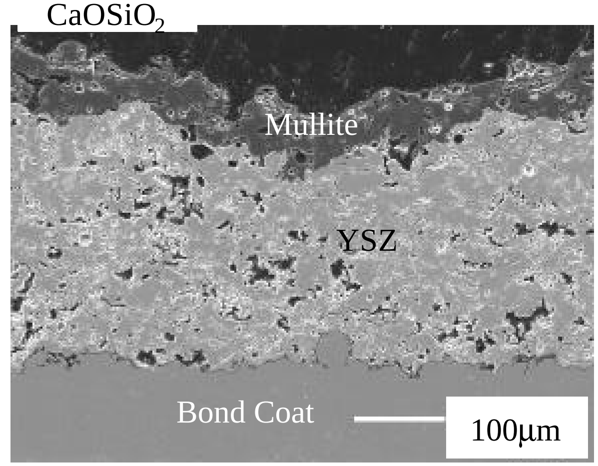
YSZ



$CaOSiO_2$



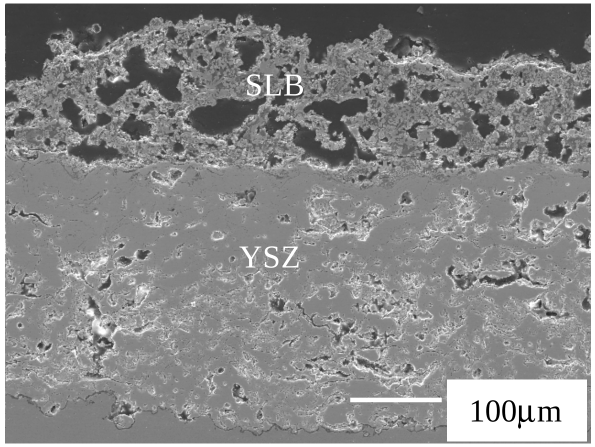
BAS



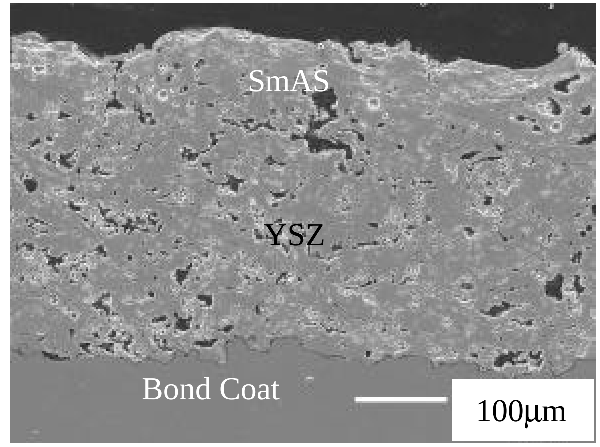
Mullite

- **$CaO{\cdot}SiO_2$, BAS, Mullite**:
  - dense, continuous overlay coating
  - no chemical degradation, cracking or spallation

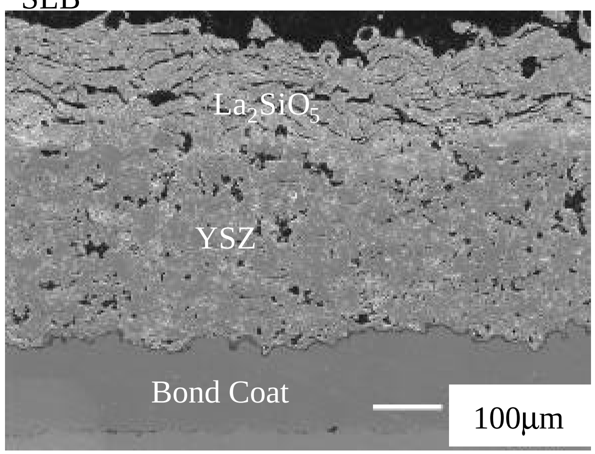
48 h Na_2SO_4 Hot Corrosion at 900°C



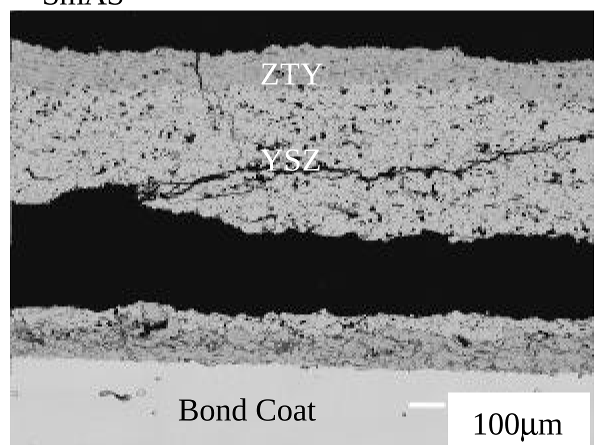
SLB



SmAS



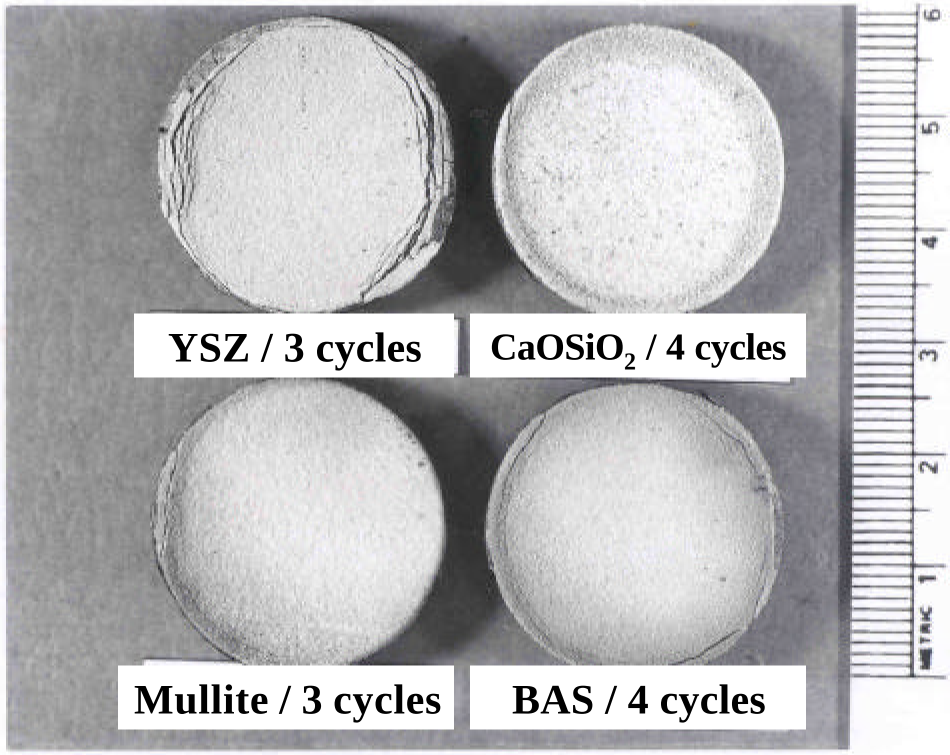
La_2SiO_5



ZTY

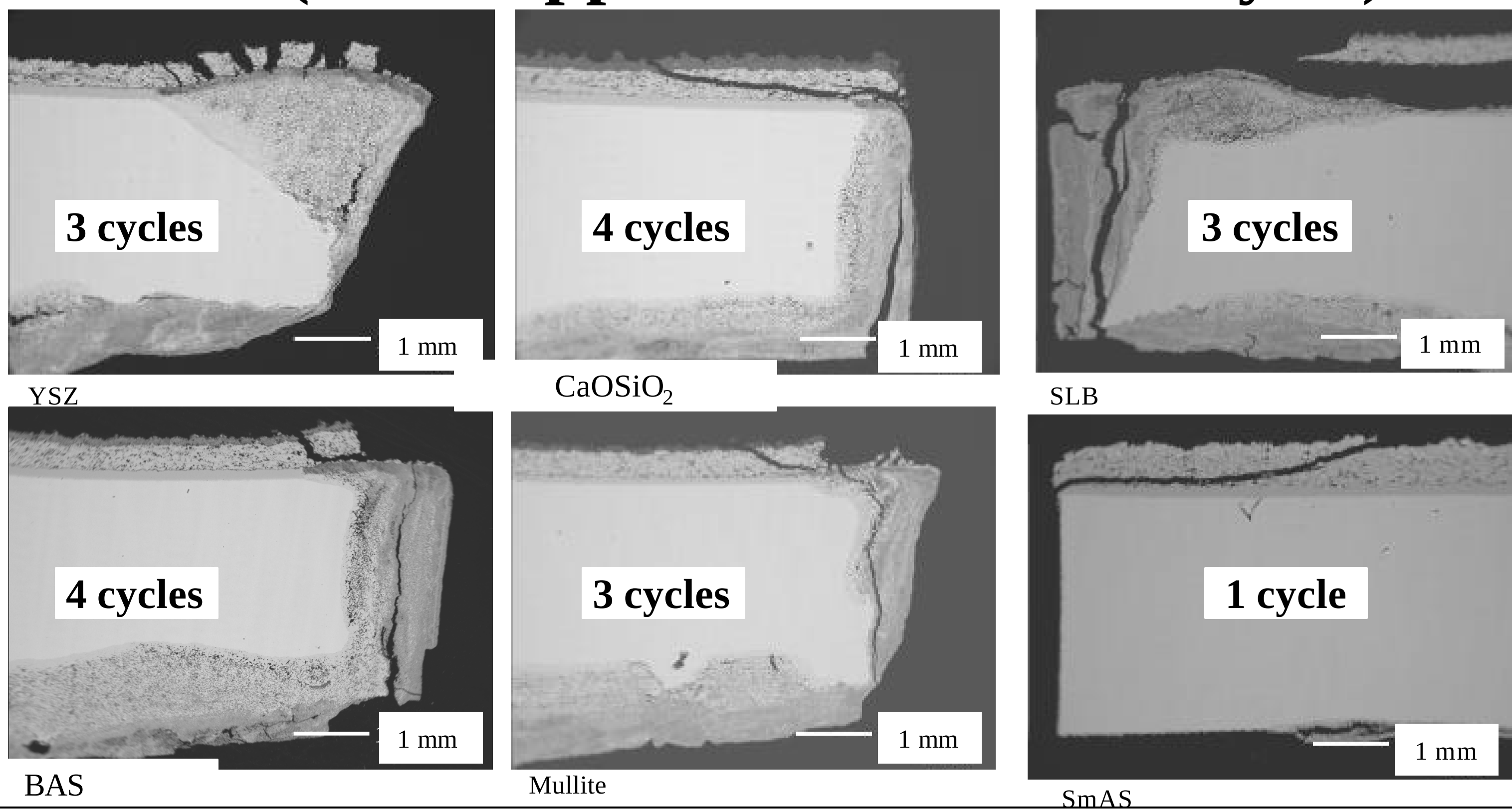
- **SLB**: high porosity
- **La_2SiO_2** : severe cracking
- **ZTY**: caused cracking in YSZ

Repeated 48h Na_2SO_4 Hot Corrosion at 900°C
(salt reapplied between each cycle)



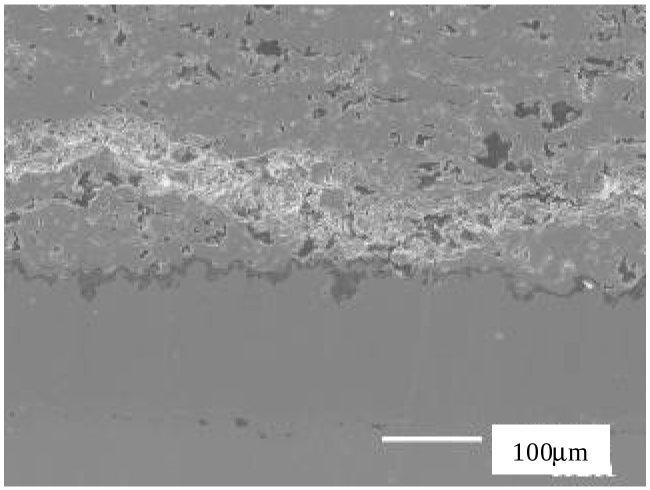
- **CaO·SiO_2, BAS, Mullite:**
  - significantly enhanced hot corrosion resistance compared to YSZ
  - need to eliminate edge effect for accurate assessment of hot corrosion durability

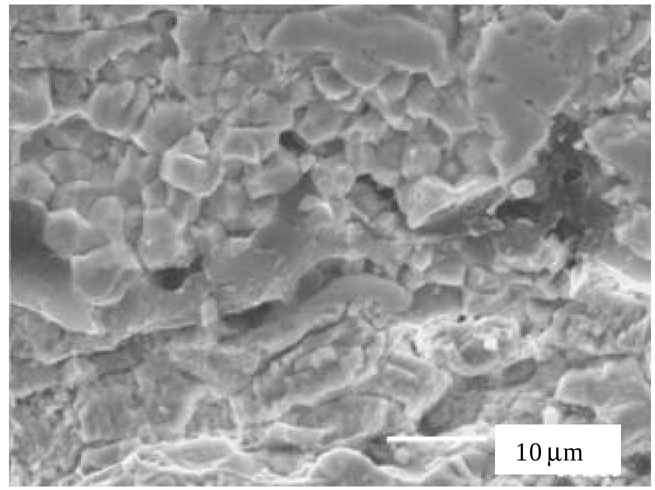
Repeated 48h Na_2SO_4 Hot Corrosion at 900°C
(salt reapplied between each cycle)



- **Standard YSZ TBC:** severe degradation of both YSZ and substrate
- **$CaO{\cdot}SiO_2$, BAS, Mullite:**
  - significantly enhanced hot corrosion resistance compared to YSZ
  - some cracks around the edge (edge effect needs to be eliminated in future test)
- **SLB, SmAS:** severe cracking of the entire coating

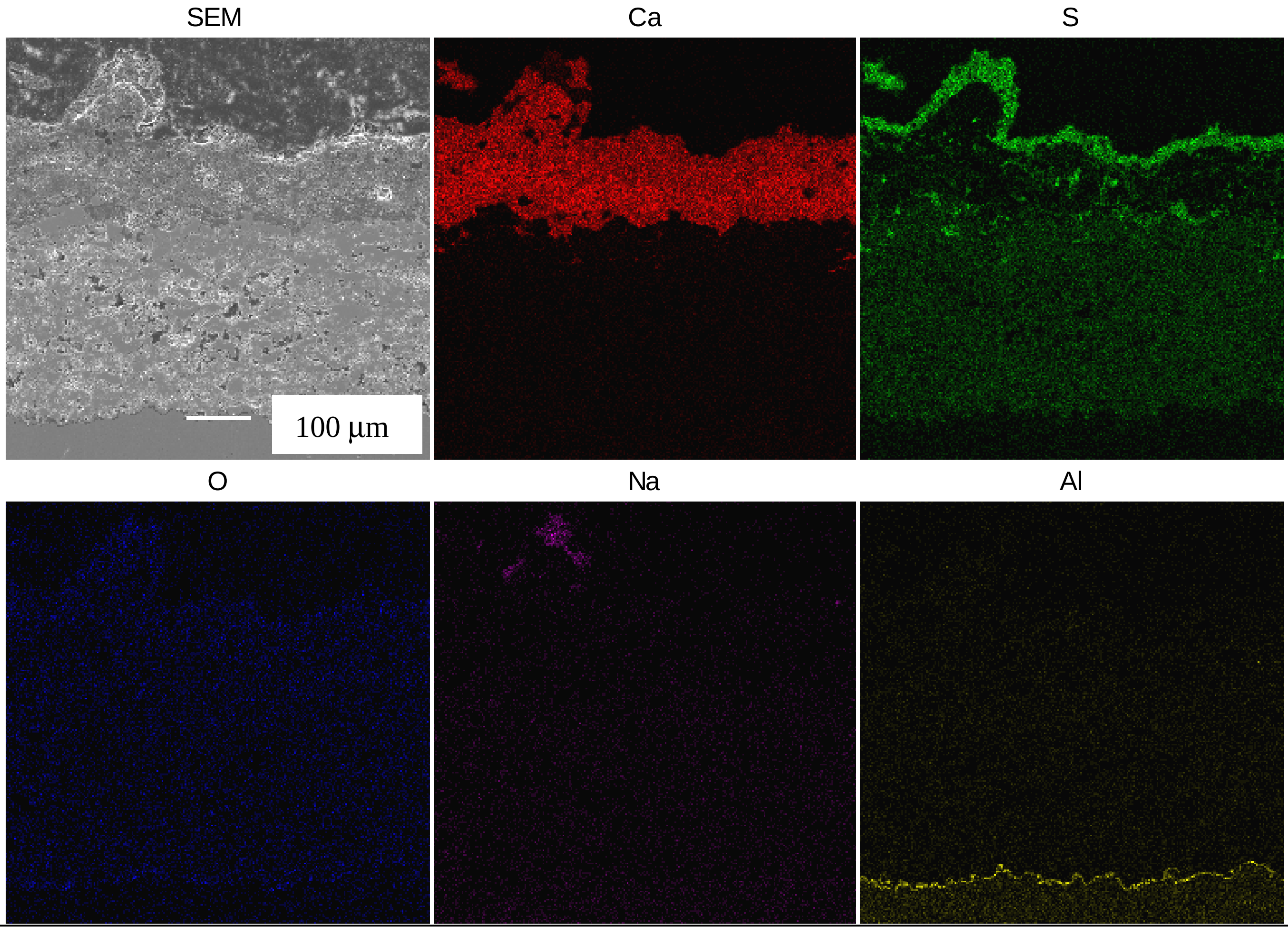
Standard YSZ TBC after 3 cycles of 48h Hot Corrosion at 900°C





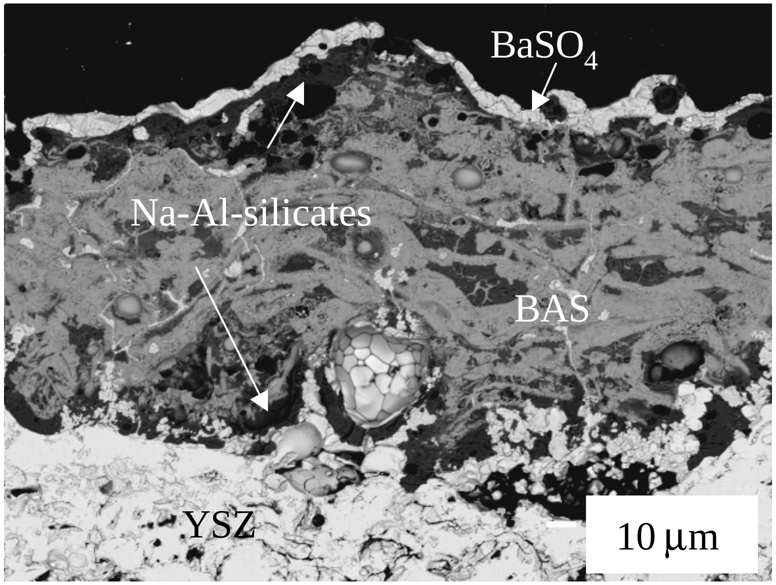
- **Degradation of YSZ near the bond coat/YSZ interface where YSZ TBC typically fails under thermal cycling**
  - YSZ grains readily come off during the polishing
  - this type of degradation disappears in the presence of overlay coatings
  - combination of **salt attack & high stress**?

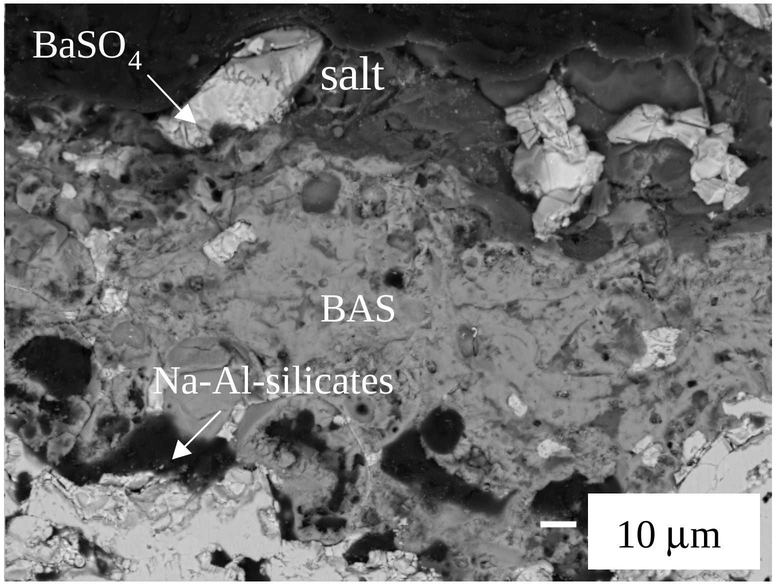
$CaO \cdot SiO_2$/YSZ TBC after 4 cycles of 48h Hot Corrosion at 900°C



- A continuous layer of $CaSO_4$ & some residual salt on the surface
  - solid $CaSO_4$ is expected to limit further reaction

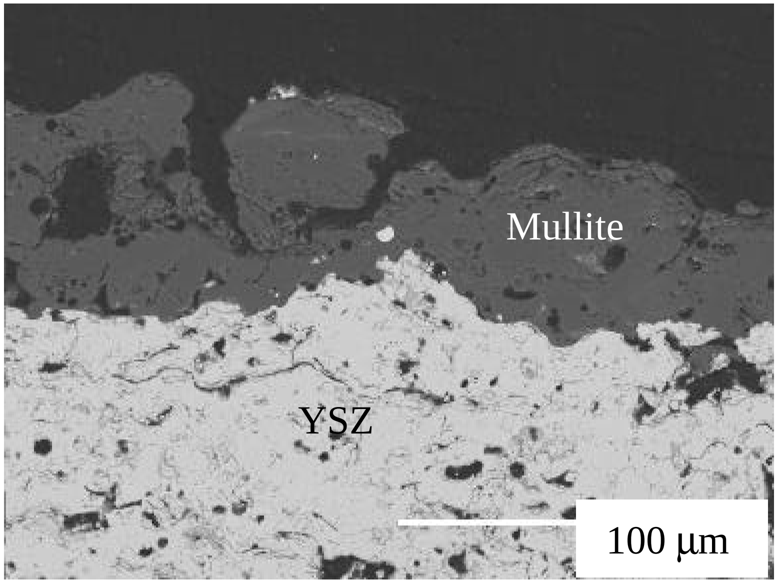
BAS /YSZ TBC after 4 cycles of 48h Hot Corrosion at 900°C

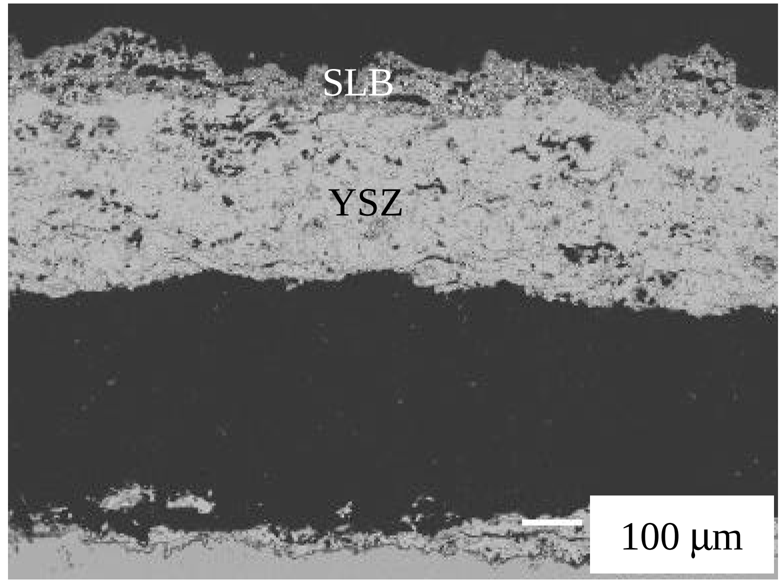




- Multiple phases in the BAS coating
- A continuous layer of $BaSO_4$ & some residual salt on the surface
  - solid $BaSO_4$ is expected to limit further reaction
- Some Na-Al silicates detected in the coating

Mullite/YSZ and SLB/YSZ TBCs after 3 cycles of 48h Hot Corrosion at 900°C





- No evidence of chemical reaction
- cracking is an issue
  - plasma sprayed mullite prone to cracking
  - process optimization necessary

- Entire coating spalled
- Unstable phase?

Conclusions
(Hot Corrosion Barrier)

- **CaO·SiO$_2$, mullite and BAS** show the best potential as a hot corrosion barrier coating
  - significantly improved hot corrosion resistance
  - high density, good adherence and crack-resistance
  - CaO·SiO$_2$ & BAS show limited chemical reaction in Na_2SO_4
  - mullite shows no chemical reaction in Na_2SO_4
- **Rare earth silicates, SLB and ZTY** show cracking
  - cracking in rare earth silicates is due to phase instability
  - cracking of SLB and ZTY is under investigation

Collaboration

- **Industry (Solar Turbines, Westinghouse, GEAE)**
  - provided some superalloy substrates and guidance on testing and evaluation
- **NASA Glenn Research Center**
  - provided plasma spray and sputtering facilities

Future Activities for FY00

- Process and characterize thin oxygen barrier coatings of Ge-doped silica and mullite
- Process optimization of hot corrosion barrier coatings.
- Investigate long-term hot corrosion and air thermal cycling of hot corrosion barrier coatings
- Burner rig test of selected dual layer coating systems
- Make recommendation of dual layer coating systems for scale up.