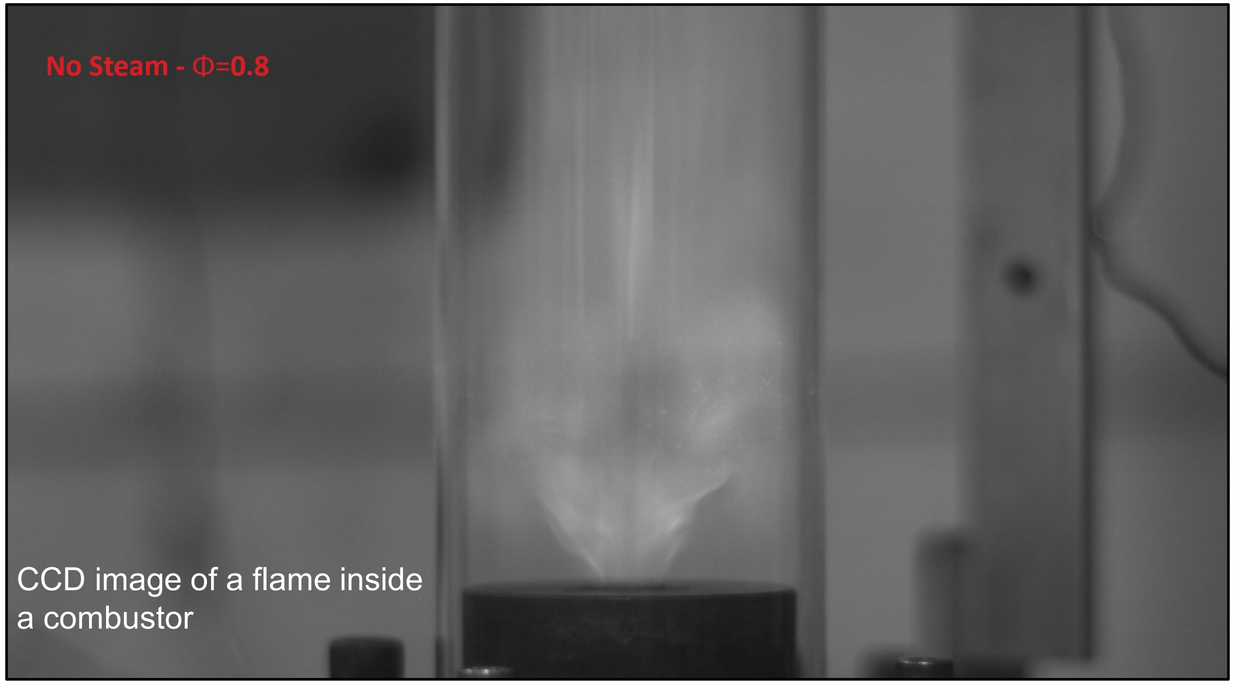
DEVELOPMENT OF HETERO-MULTILAYERED CERAMIC THERMAL BARRIER COATINGS FOR HYDROGEN TURBINES FOR STATIONARY POWER GENERATION



CCD image of a flame inside a combustor

Performing Organization(s): University of Maryland, College Park
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Project Summary

Timeline:

- Start date: May 1, 2023
- Planned end date: April 30, 2025

Key Milestones:

- Complete the initial co-design model on thermal, thermomechanical and ionic transport; July 31, 2023.
- Fabricate 1st generation of multilayer coating; October 30, 2023.
- Achieve a thermal conductivity 50% lower than conventional Yttria-stabilized Zirconia (YSZ), ionic conductivity 10 times lower than conventional YSZ; April 30, 2024.
- Complete the experimental demonstration of the multilayer coating in combustors with H2 enriched fuels; July 31, 2025.
- Achieve a 150 ^{o}C - 200 ^{o}C increase to the operational capabilities compared to conventional YSZ; April 30, 2025.

Budget:

Total Project $:

- DOE: $800,000
- Cost Share: $200,000

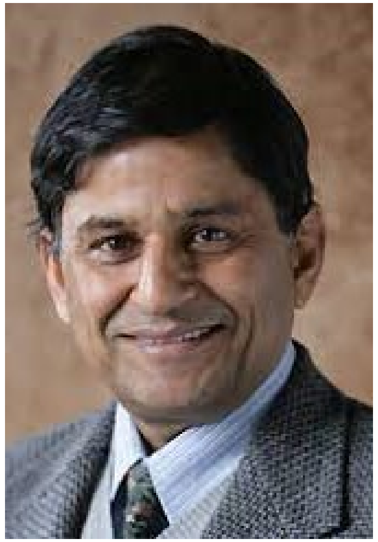
Key Partners:

- University of Maryland, College Park
- Aerojet Rocketdyne Inc. (Industrial Technical Advisor)

Project Outcome:

- This project will advance the fundamental understanding of advanced thermal barrier coating technology and its application in combustion of H2-enriched alternative fuels.
- This project will demonstrate the feasibility of developing the advanced multilayer YSZ/Alumina thermal barrier coatings that can withstand high moisture content and high temperature operation.
- This project aims to develop a prototype thermal barrier coating with a thermal conductivity 50% lower than current YSZ and an ionic conductivity 10 times lower than current YSZ, which is expected to provide a potential ~ 150-200 ^{o}C increase in temperature capability .

Team



Dr. Bao Yang is a Professor in the Department of Mechanical Engineering at the University of Maryland, College Park, and currently directs the Micro/Nanoscale Heat Transfer and Energy Conversion Laboratory at the Center for Environmental Energy Engineering (*CEEE*). He serves as Principal Investigator in this project and is responsible for the overall management and execution of the project.

Dr. Ashwani K. Gupta is a Distinguished University Professor in the Department of Mechanical Engineering at the University of Maryland, College Park, and currently directs the Maryland Combustion Laboratory. He is an internationally recognized expert in combustion, gas turbines, swirl flows, emission control, and serves as Co-PI in this project.

Dr. Michael Popp from Aerojet Rocketdyne Inc., serves as the technical advisor in this project.

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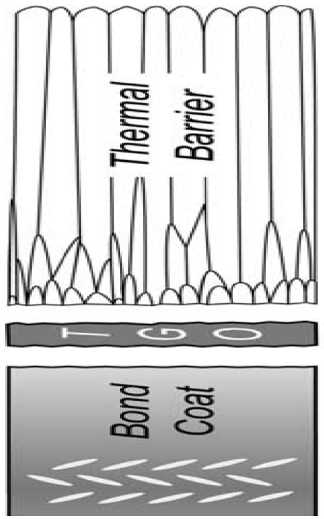
Challenge

- The alternative fuels with high hydrogen content have attracted considerable attention as a way to address the climate change and energy security issue.
- The combustion of the alternative fuels can produce higher flame temperature and more *water vapor content (up to 35%)* than the conventional hydrocarbon fuels (i.e., moisture content <<10%).
- State-of-the-art (SOTA) Thermal Barrier Coating (TBC):

  The SOTA TBC yttria stabilized zirconia (YSZ) has a relative small perpendicular thermal conductivity of 2 W/mk, but a high ionic conductivity at elevated temperature.
- Deficiency in SOTA: The SOTA TBC can not effectively protect the hot section of the combustor from moisture attack at elevated temperature.

State of the Art: Yttria-stabilized Zirconia (YSZ) Thermal Barrier Coating (TBC)

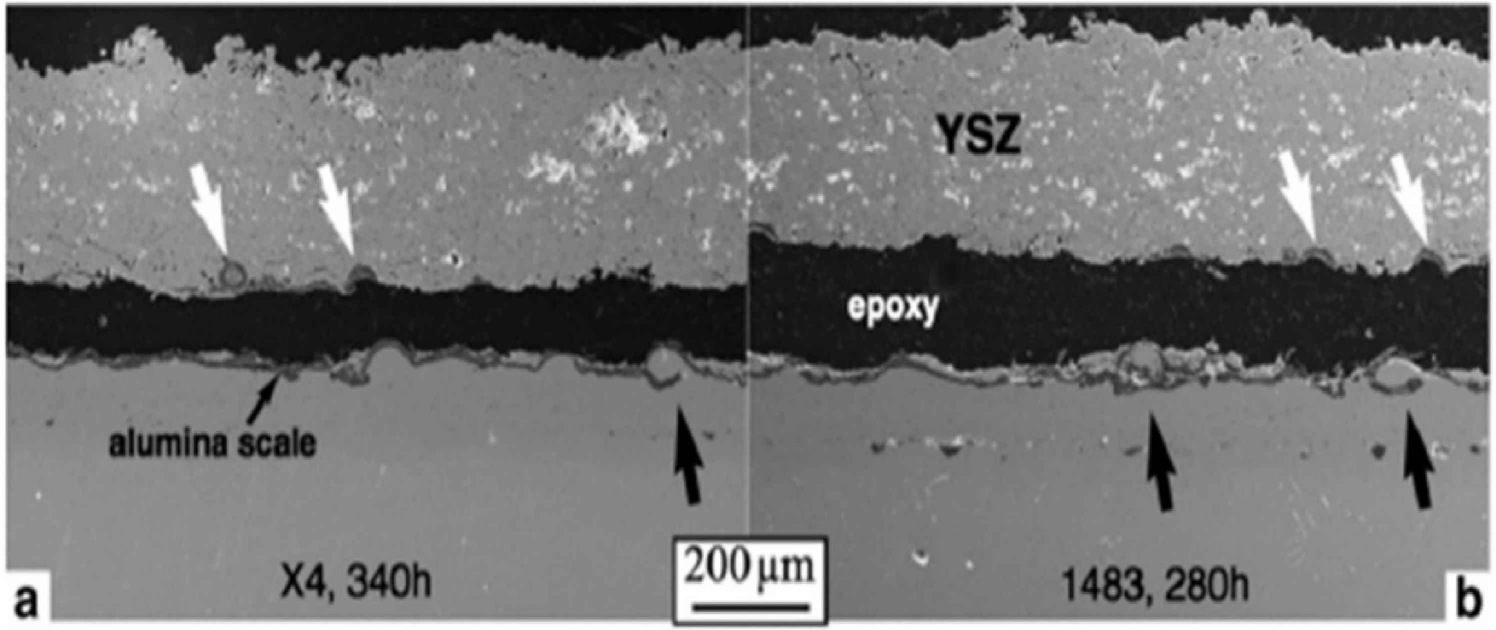


Low Thermal Conductivity ✓

High Ionic Conductivity ✗

Stability: *~1000 C*
Columnar structure

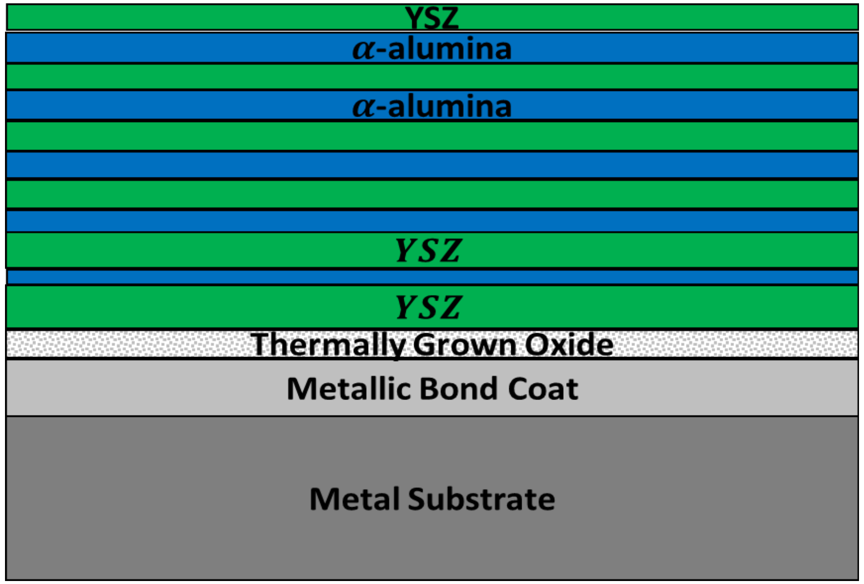
Challenge

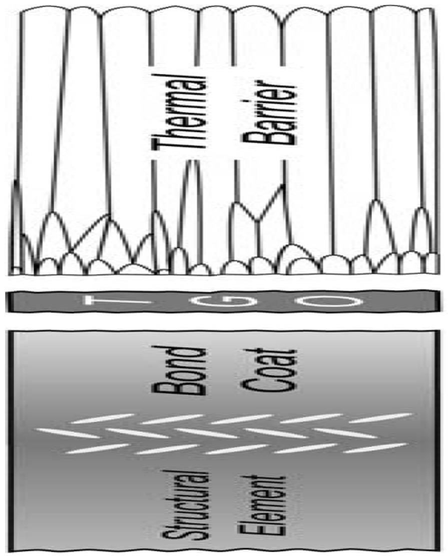


Scanning electron microscope (SEM) images comparing the topcoat delamination during 1-h thermal cycles at 1100 C in 10 vol.% water vapor. (a) TBC on X4 bond coat after 340 cycles, (b) TBC on 1483 bond coat after 280 cycles. White arrows indicate non-protective alumina undercutting the yttria-stabilized-zirconia (YSZ).

Ref: M. J. Lance, K. A. Unocic, J. A. Haynes, and B. A. Pint, "Effect of water vapor on thermally-grown alumina scales on Pt-modified and simple aluminide bond coatings," Surface & Coatings Technology, vol. 237, pp. 2-7, 2013.

Approach





- Schematic of the proposed thermal barrier coating composed of alternating YSZ layers and α-alumina layers (left) and the state of the art YSZ coating (right).
- Reduce the perpendicular thermal conductivity of the thermal barrier coating by interfacial thermal resistance between dissimilar layers.
- Improve the resistance to oxygen and water vapor diffusion by introducing ionic-insulator α-phase alumina layers.

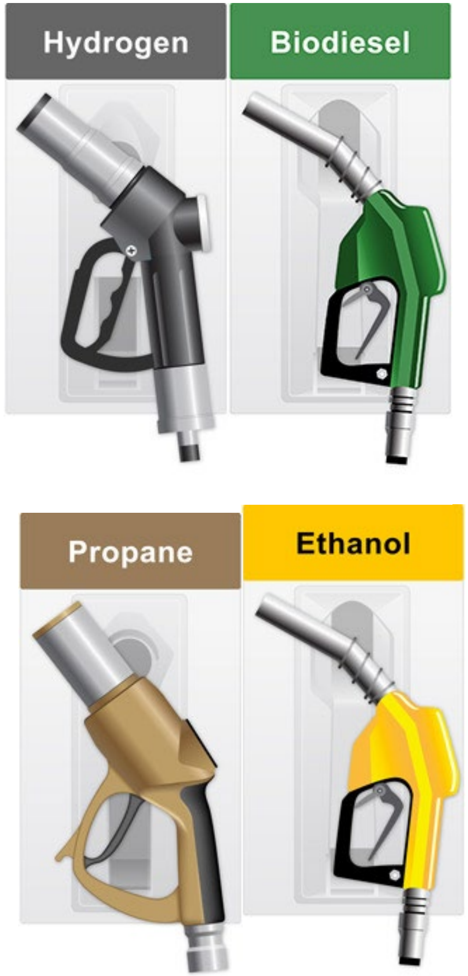
Approach

	Thermal conductivity (W/mK)	Ionic Conductivity $(\Omega^{-1}cm^{-1})$	Thermal Expansion Coefficient (10^{-6} K^{-1})	Phase Stability (°C)
YSZ	~2	~10^{-3} @500°C	7-12	1800
Alumina	~10	~10^{-10} @500°C	6.8-8	1700

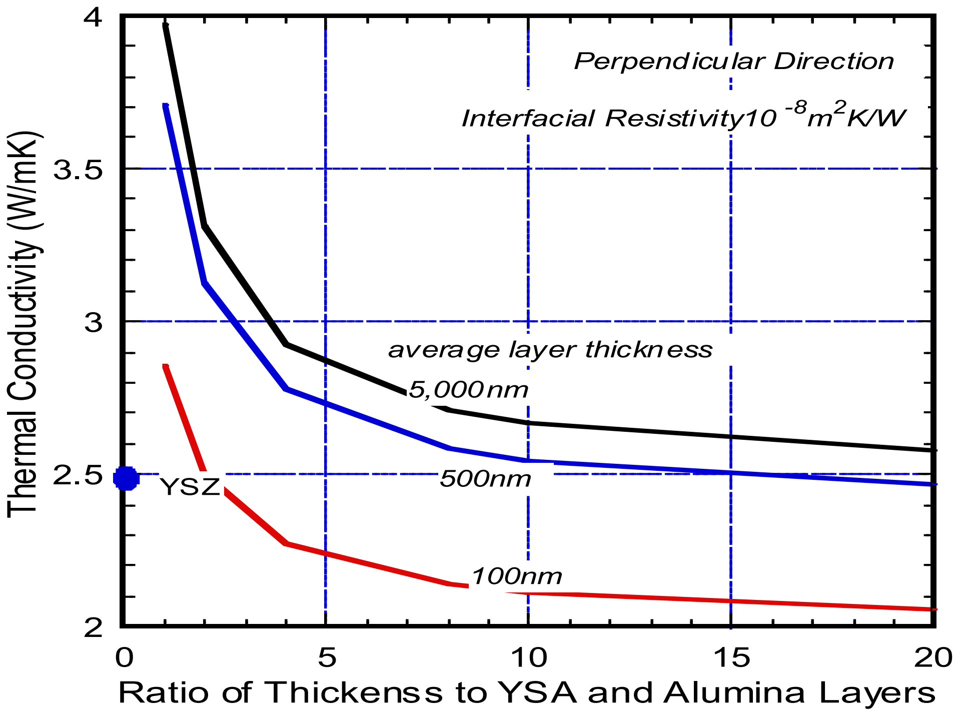
Properties of yttria stabilized zirconia (YSZ) and α-alumina. (Data from various literature)

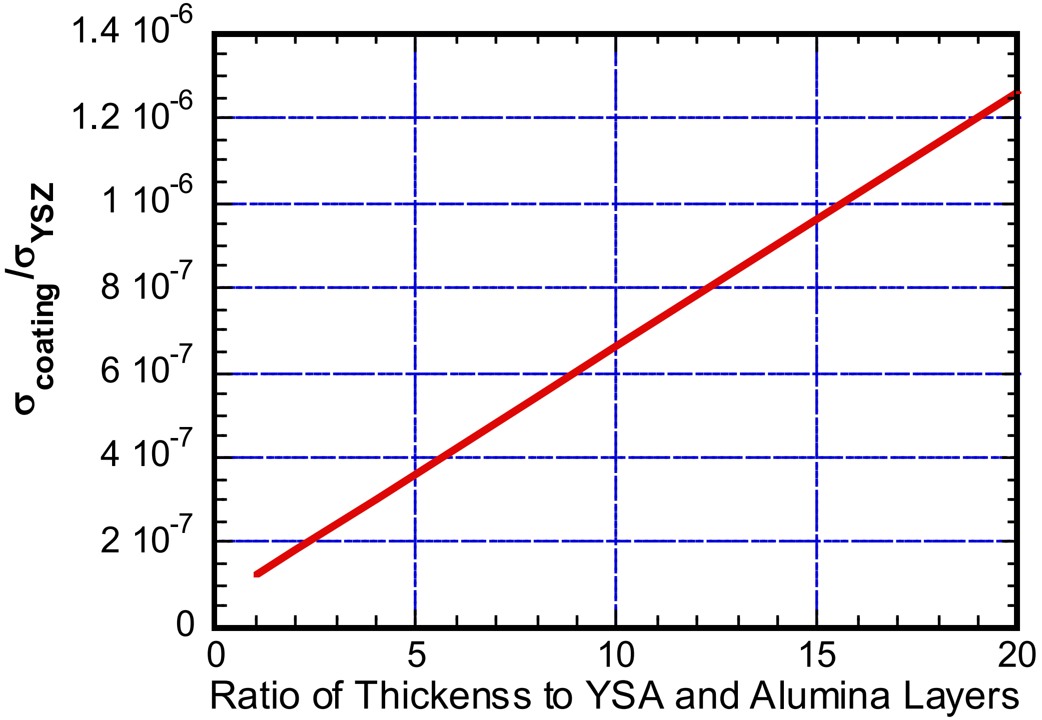
Impact

- Alternative fuels are currently experiencing increased interest as a way to address climate change and national energy security.
- The traditional thermal barrier coatings used in hot section component of combustor are limited to combustion with small moisture content, due to their oxygen transparence at elevated temperatures.
- The proposed multilayered thermal barrier coating is expected to provide a potential 150-200 ^{o}C increase in temperature capability compared to the state-of-the-art technology, if the project achieves its technical goals.
- The proposed technology offers applications in many different kinds of power and propulsion technologies, which range from stationary power generators to advanced rocket engines that can operate at higher temperatures and high moisture content using hydrogen enriched alternative fuels



Progress

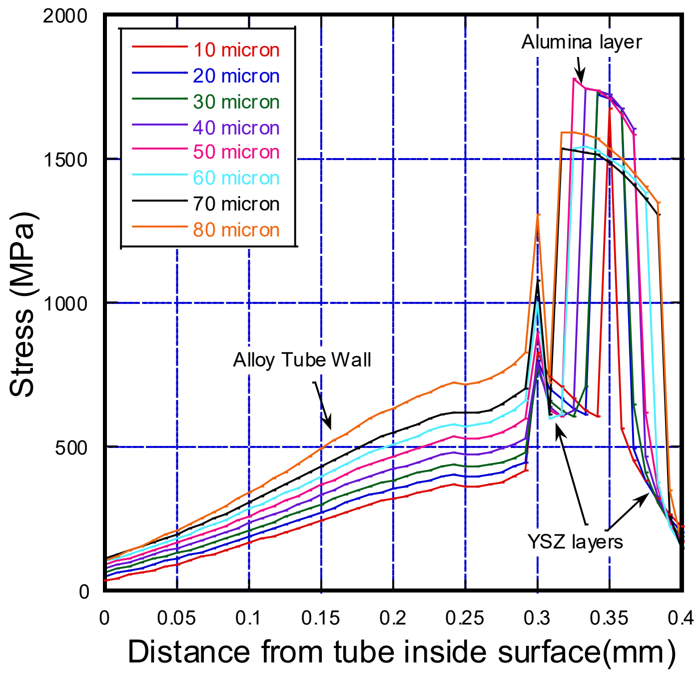


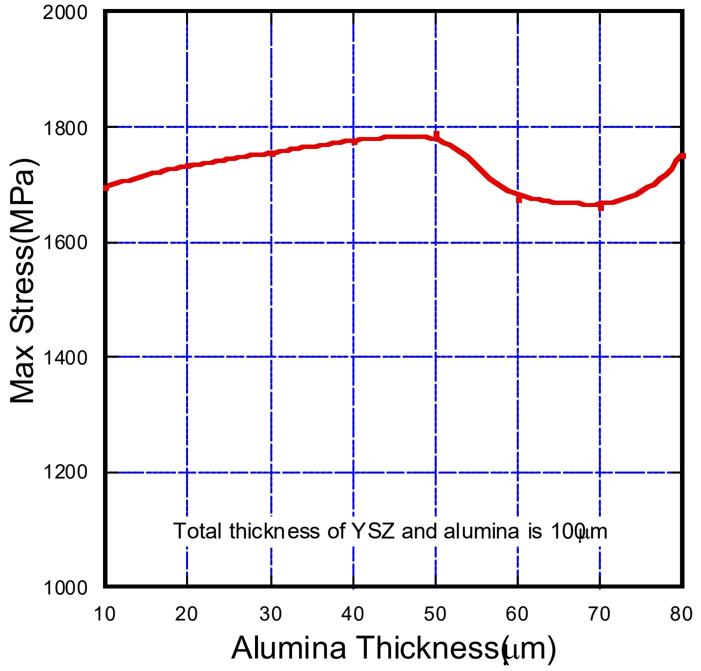


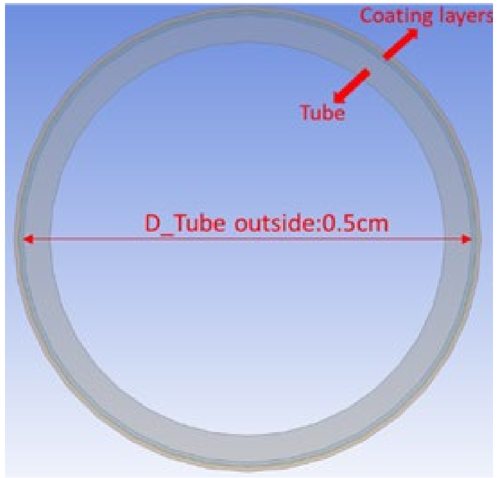
Numeric simulation showing the perpendicular thermal conductivity (left) and ionic conductivity (right) of the multilayer thermal barrier coatings as a function of the ratio of YSZ layer thickness to alumina layer

In Task 2 of this project, theoretical models and analysis were performed to investigate the design parameters of the thermal barrier coatings and their thermal conductivity, thermal stress, and ionic conductivity.

Progress



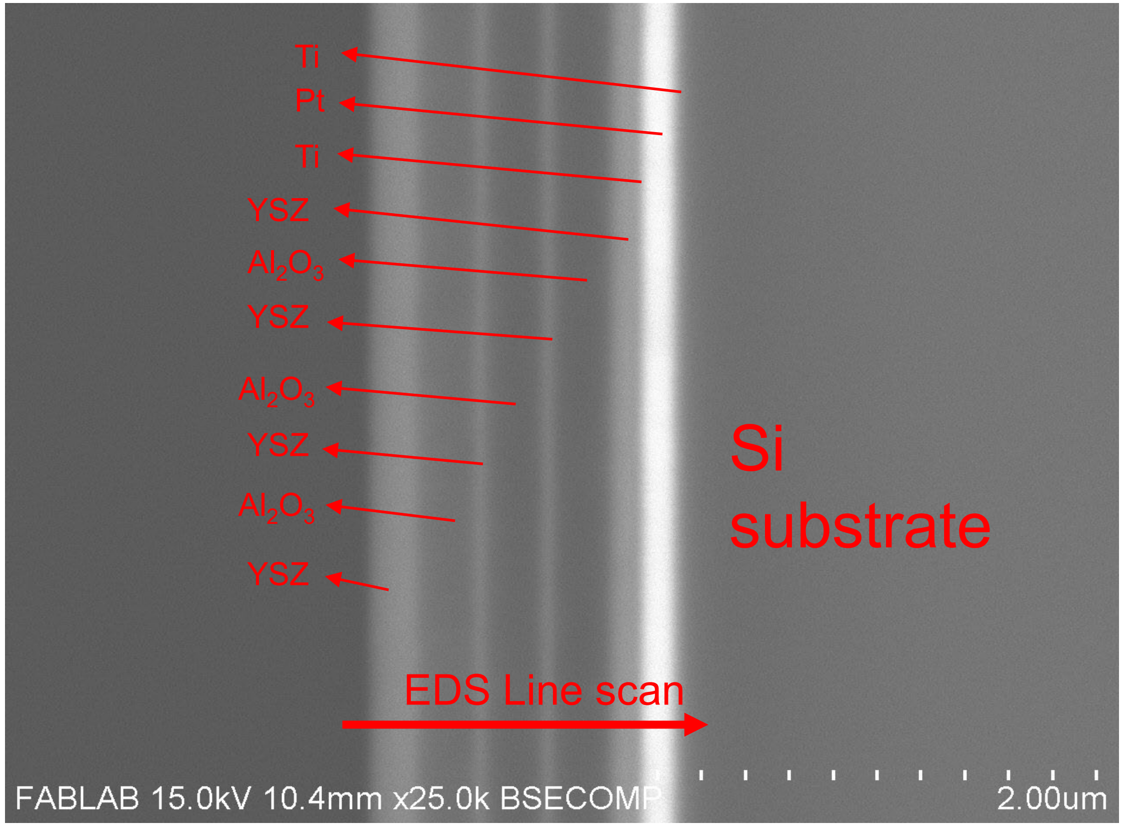




Numeric simulation showing(Left) Thermal stress distribution along the radial direction for different alumina layer thickness. (Center) The maximum thermal stress found in the thermal barrier coating as a function of thickness of the alumina layers. (Right) The geometry built in the Design Modeler was a Nickel alloy tube coated with three layers, YSZ, alumina, and YSZ.

Progress

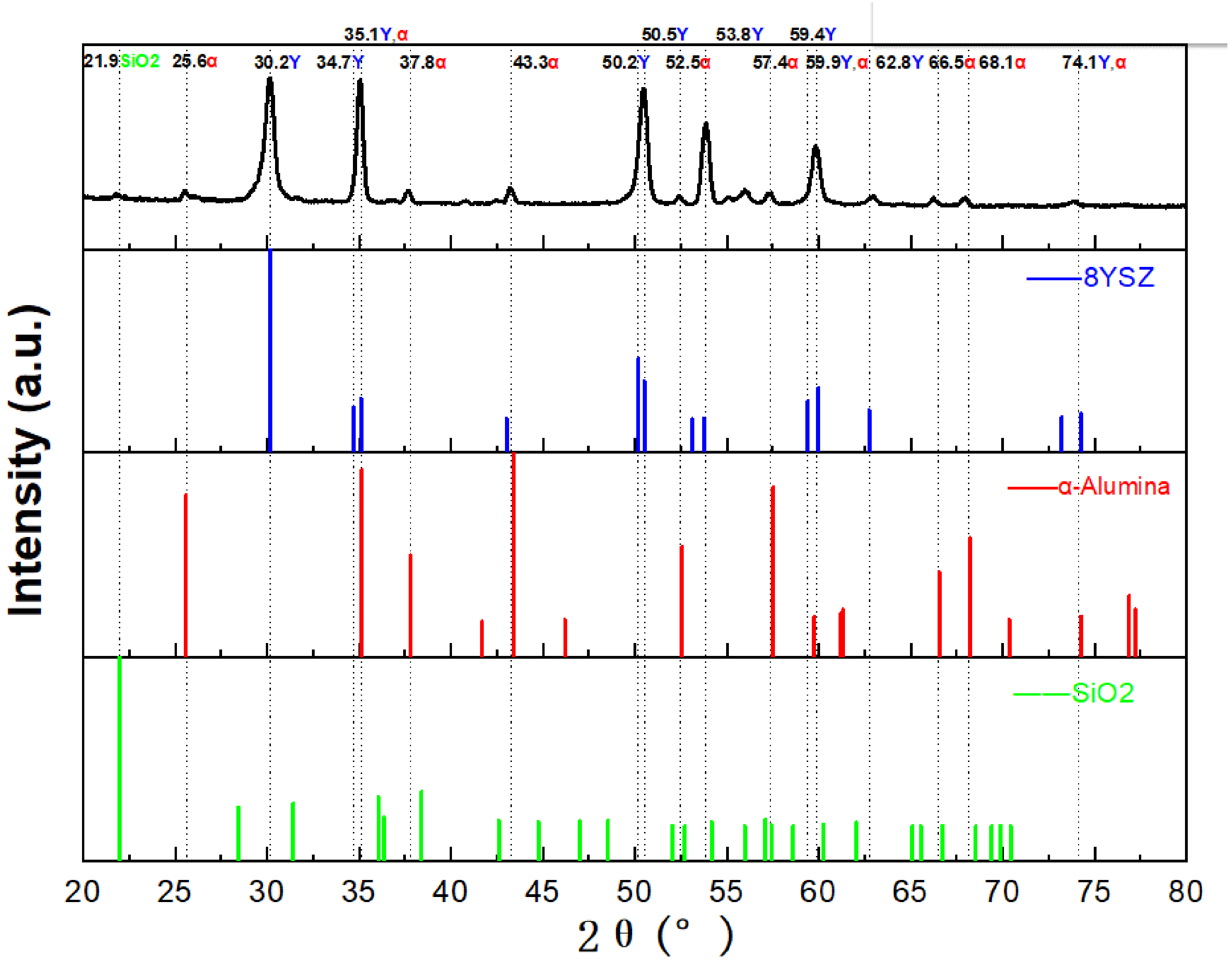
Orion 8 Sputtering system



SEM image of cross-section of multilayer YSZ/alumina coating

In Task 3.1 of this project, the multilayered coatings were manufactured by alternating deposition of YSZ and alumina using radio frequency (r.f.) sputtering deposition technique. The effects of process parameters, such as sputtering power and target-substrate distance, on the film crystalline phase were investigated.

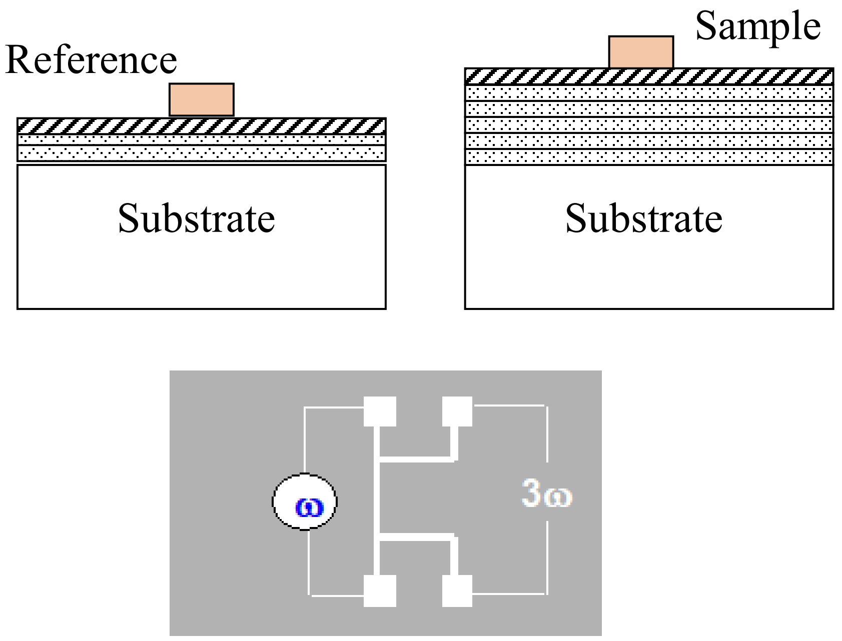
Progress



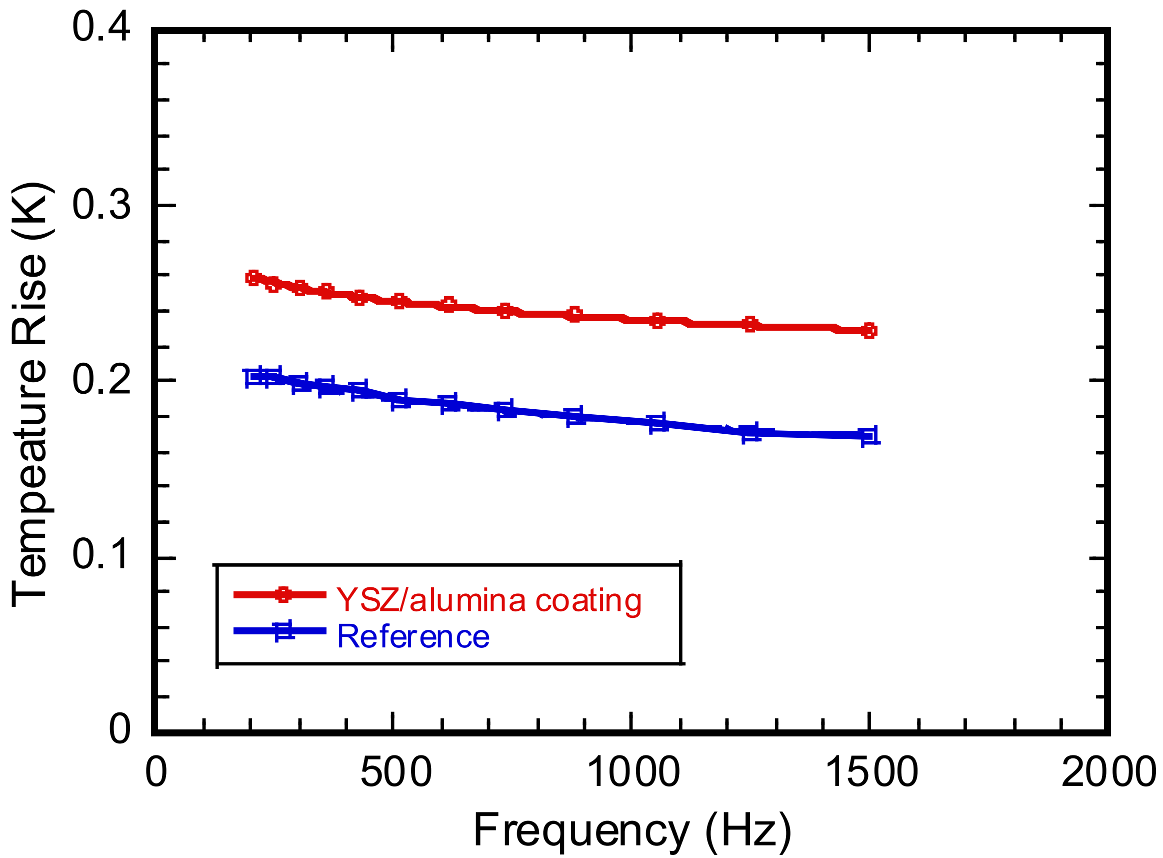
The crystalline phase of the YSZ/alumina coating was determined using the Grazing Incidence X-ray Diffraction (GIXRD) (PANalytical X'pert Pro Diffractometer).

The XRD peaks align with 8YSZ at tetragonal(t) phase, and α alumina at hexagonal phase.

Progress



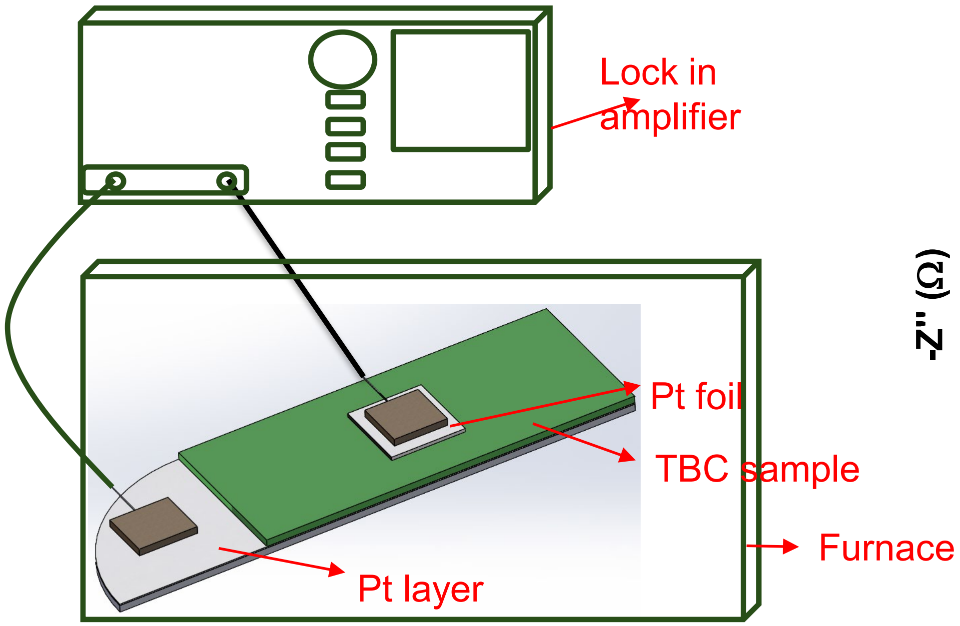
Differential 3ω method



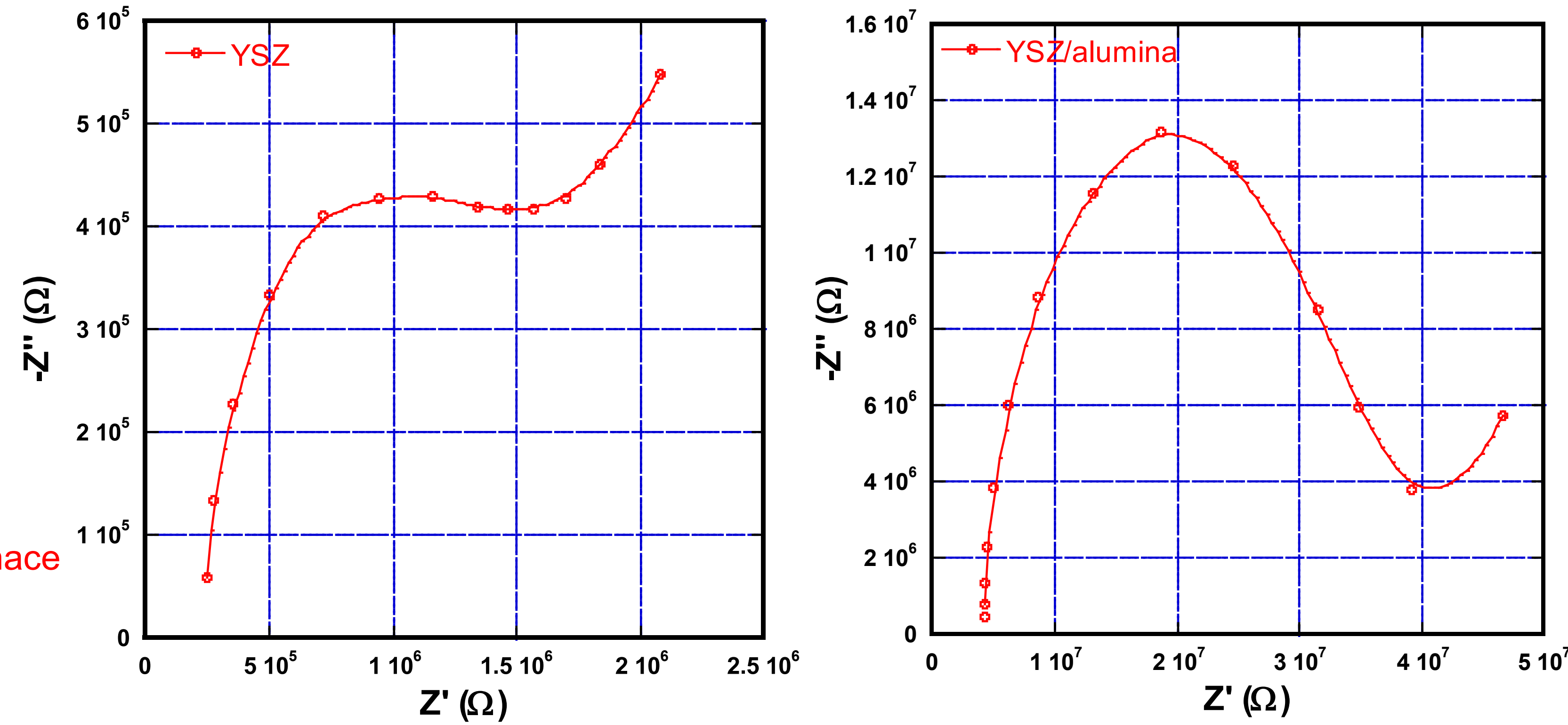
In Task 3.2 of this project, thermal conductivity, ionic conductivity, microstructure and composition of the multilayer YSZ/alumina coatings were measured.

The thermal conductivity of the YSZ/alumina coating was determined using the 3ω method and was found to be 47% lower than the state of the art YSZ.

Progress



Schematic of Electrochemical Impedance Spectroscopy (EIS)system



Complex impedance spectra (Nyquist plot) of the YSZ (left) and YSZ/alumina coatings.

In Task 3.2 of this project, thermal conductivity, ionic conductivity, microstructure and composition of the multilayer YSZ/alumina coatings were measured.

The thermal conductivity of the YSZ/alumina coating was determined using the electrochemical impedance spectroscopy method and was found to be 35 times lower than the state of the art YSZ.

Stakeholder Engagement

- **Stakeholder Engagement will be preformed in Task 5 in Year 2 of this project. It is in early stage of the project.**
- **The UMD team has started to contact the potential stakeholders.**
- **Types of Stakeholders**
  - Business Associations
    - American Institute of Aeronautics and Astronautics (AIAA), American Society of Mechanical Engineers (ASME),, etc.
    - Engagement: conferences, publications and tech briefs.
  - TBC technology developers and system integrators
    - Aerojet Rocketdyne Inc., Orbital ATK. etc.
    - Engagement: collaboration, tech briefs.

Remaining Project Work (Year 2)

- **Task 3.0: Manufacturing and Characterization of Thermal Barrier Coatings - Continued**
- **Task 4.0: Performance Evaluation of Thermal Barrier Coatings in Combustors with H2 enriched Fuels**
- **Task 5.0: Techno-Economic Feasibility Assessment**

Thank You

Performing Organization(s): University of Maryland, College Park

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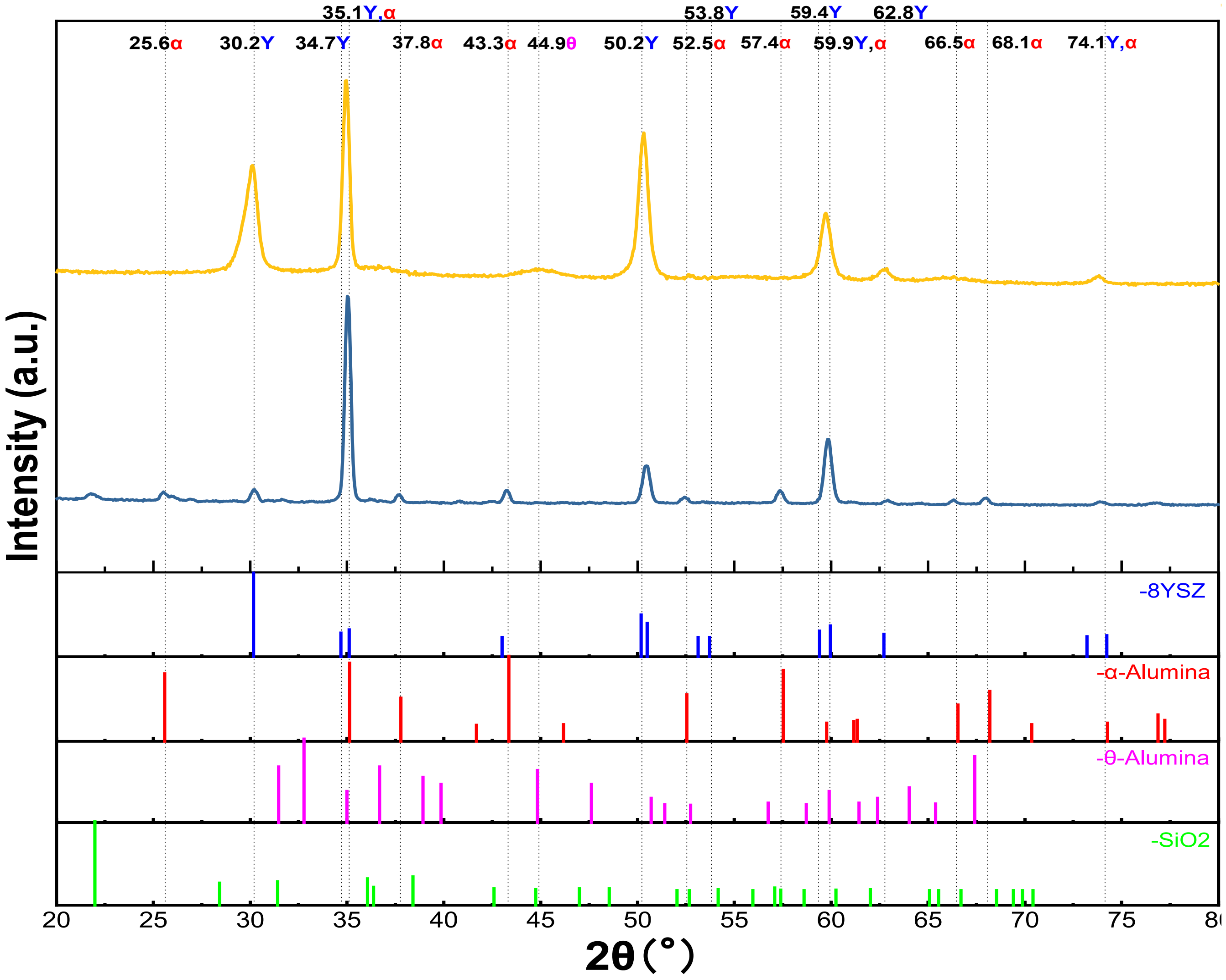
REFERENCE SLIDES

Backup Slides


35.1Y,α
53.8Y
59.4Y
62.8Y
25.6α
30.2Y
34.7Y
37.8α
43.3α
44.9θ
50.2Y
52.5α
57.4α
59.9Y,α
66.5α
68.1α
74.1Y,α
Intensity (a.u.)
-8YSZ
-α-Alumina
-θ-Alumina
-SiO2
20
25
30
35
40
45
50
55
60
65
70
75
80
2θ (°)