# Synchrotron X-Ray Diffraction Measurements of Thermal Barrier Coating Configurations with Rare Earth Elements for Phosphor Thermometry

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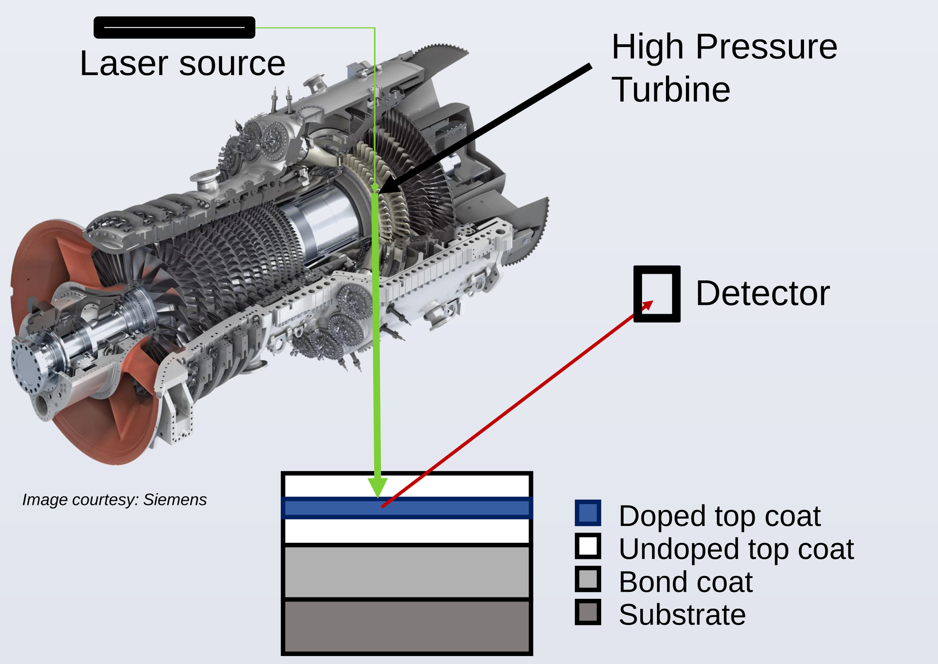
## Background and Introduction

- Introducing Rare Earth (RE) dopants into Thermal Barrier Coating (TBCs) can enable temperature sensing coatings.
- The temperature measurement is achieved by the photoluminescence property of RE elements
- However, maintaining mechanical integrity in service environments is of utmost importance while achieving temperature sensing TBCs
- Introducing the new layer with RE elements may alter the mechanics of the topcoat depending on TBC configurations
- In this work, TBC configurations are probed using synchrotron X-ray Diffraction (XRD) to determine spatial strain distribution.




## Motivation and Objectives

### Motivation:

- High energy Synchrotron X-ray Diffraction (XRD) provides high-resolution biaxial strain data in the coating that allows for accurate evaluation of residual strain in the coatings

### Objectives:

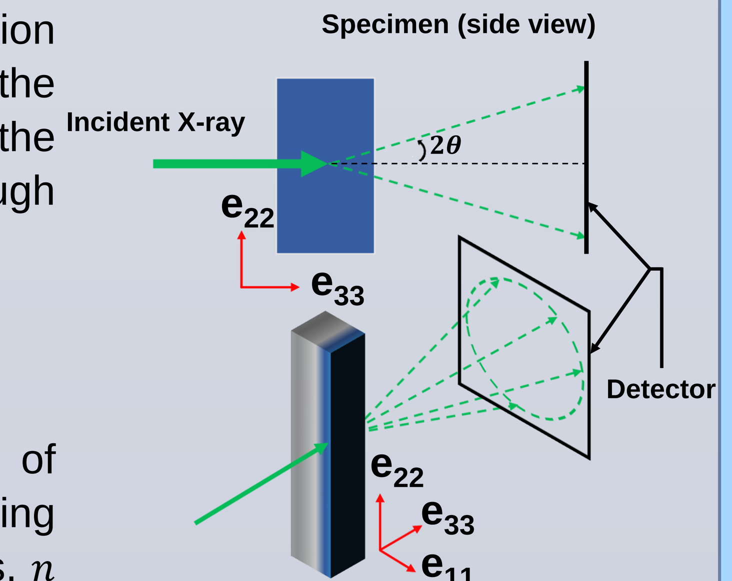
- Obtain strain state in TBC configurations with and without doped layer
- Investigate the effects of doped layer on spatial residual strain distribution in the TBC top coat at room temperature and 1100 ºC

## Theory

- XRD can provide information about crystal structure, distribution of phases, and microstrains when the X-ray beam interacts with the material of interest
- The angle of diffraction ($\theta$) relates to the spacing ($d$) of the atomic planes through Bragg's Law:

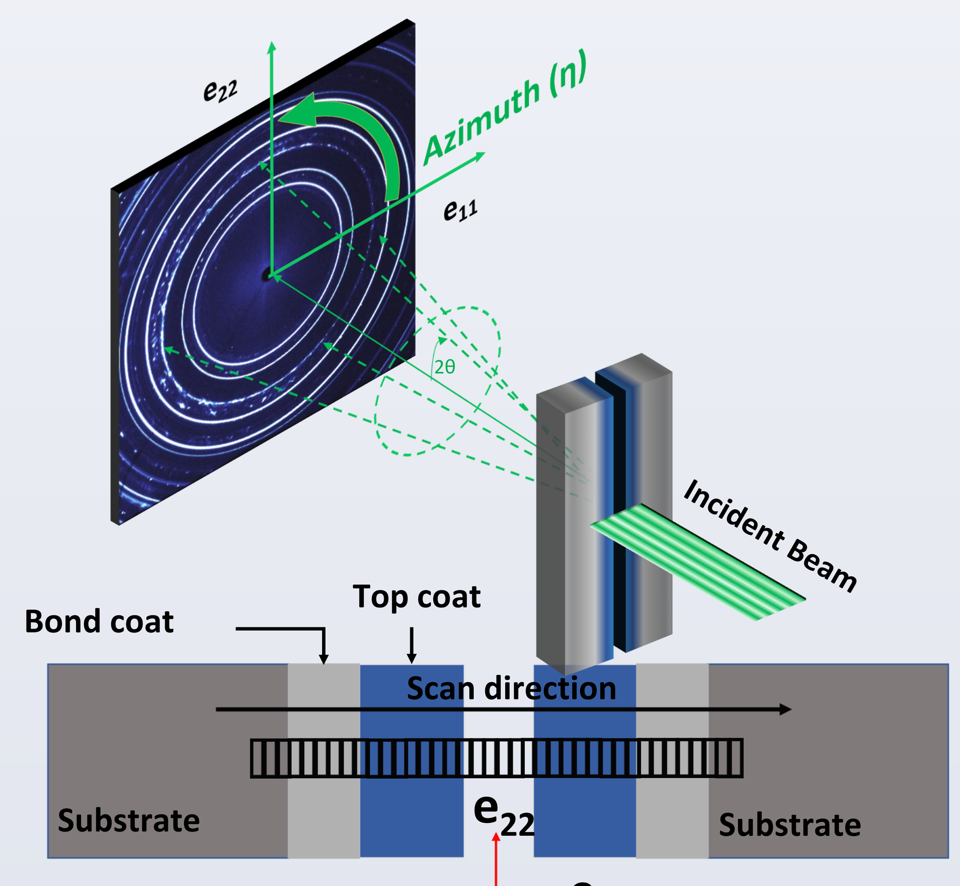
$$n\lambda = 2d\sin\theta$$

where $\lambda$ is wavelength of X-ray and $d$ is spacing between layers of atoms, $n$ an integer.

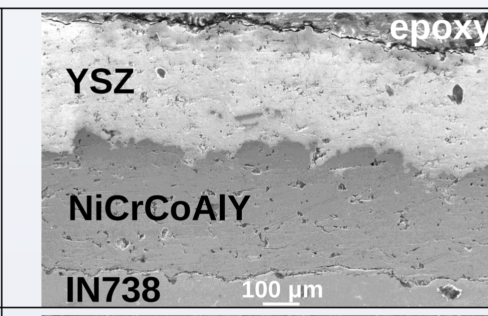
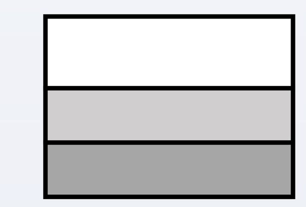
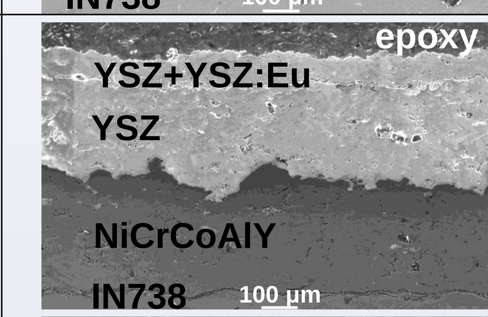
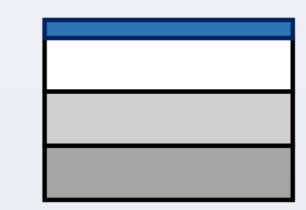
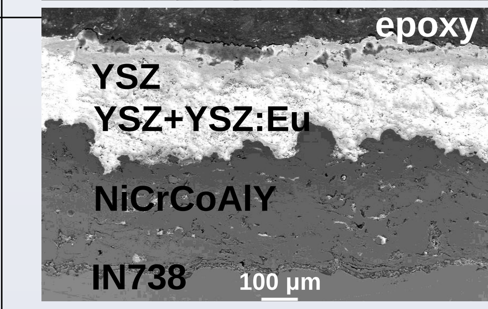



## Methods and Materials

- A high-energy (71 keV) X-ray beam of size of 30 x 300 μm$^2$ impinged on samples with a resolution of 30 μm
- Transmission XRD method was used
- The data was analyzed to quantify strain in the coatings

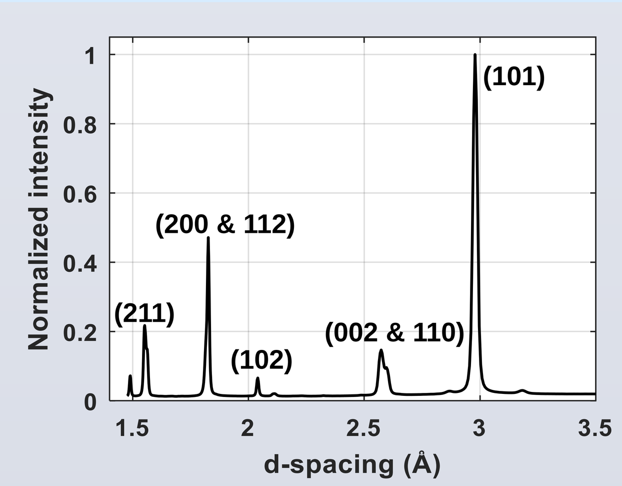



Schematic view of XRD data collection in transmission mode

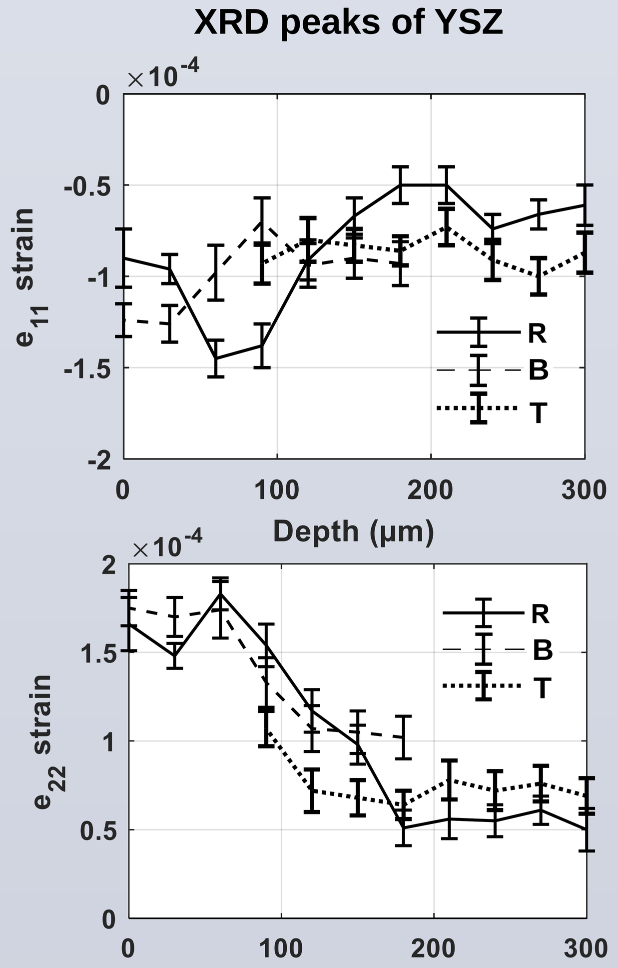
| | | |
|---|---|---|
| Reference sample (R) |   |  |
| Doped layer placed at top (T) |   |  |
| Doped layer placed at bottom (B) |   |  |

- TBC coupons have been fabricated using Air Plasma Spray (APS) coating technique at the Florida Institute of Technology
- The regular TBC coupon consists of NiCoCrAlY bond coat, and YSZ top coat
- Doped layer consists of a YSZ+YSZ:Eu mixture (2:1 by wt%) in the top coat

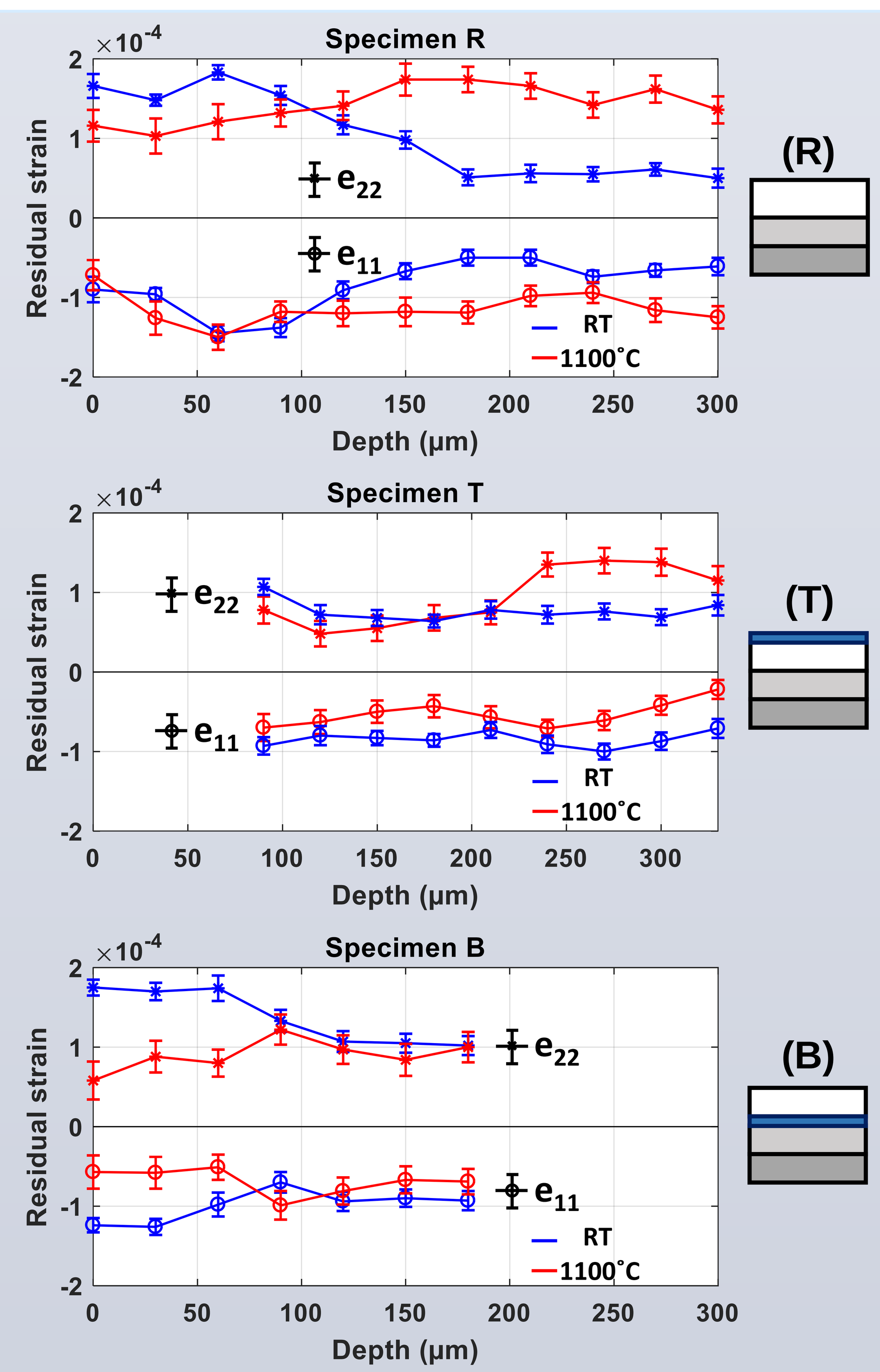
## XRD results



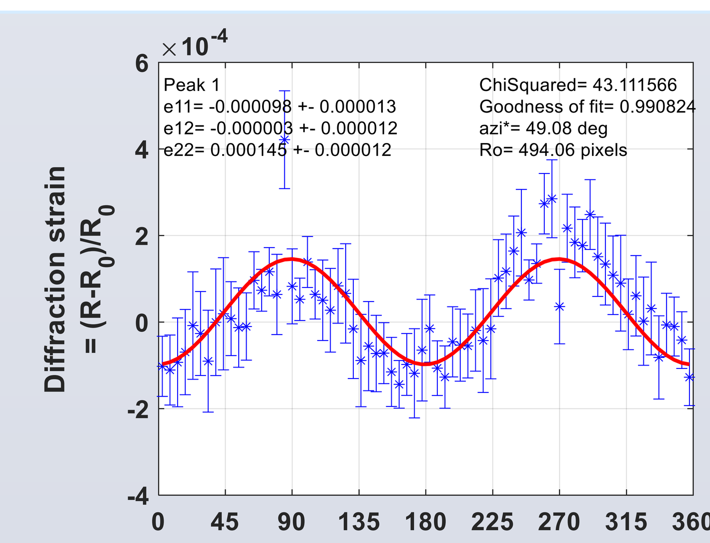

XRD peaks of YSZ




Spatial distribution of strain across depth of coating




Residual strain distribution across the thickness of coatings ($e_{11}$: out of plane strain, $e_{22}$: in-plane strain) for room temperature (RT) and high-temperature (1100˚C)




Fit to determine biaxial strain state

- The coating is found to be under tensile in-plane strain ($e_{22}$) and compressive out-of-plane strain
- Introducing the dopant layer at top increases the strains in YSZ layer closer to bond coat compared to regular configuration
- At high temperature, more thermal expansion is observed away from the doped layer, and less thermal expansion close to doped layer, in both cases

## Summary

- High-resolution Synchrotron XRD experiments were performed using three TBC configurations at Argonne National Laboratory
- Introduction of doped layer at top increases the residual strain in YSZ layer
- At high temperature, larger thermal expansion is observed away from the doped layers

## Future Work

### Determination of coefficient of thermal expansion (CTE) and inter-layer mismatch at high temperature

- Coefficient of thermal expansion can be determined from high temperature XRD data
- Mismatch in thermal strain in different layers will provide insight into the interfacial mechanics of the TBC at service conditions

### Phosphor Thermometry by time decay method

- The intensity of photoluminescent light from RE elements decays over time with a characteristic time constant, called decay time
- The decay time is temperature sensitive. Therefore, measurement of decay time traces the temperature of the doped layer
- Measurement of photoluminescence will elucidate the viability of the above configurations to develop temperature sensing TBCs

## References/Acknowledgements

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