Hafnia-Based Nanostructured Thermal Barrier Coatings for Advanced Hydrogen Turbine Technology

C.V. Ramana (PI)
Ahsan R. Choudhuri (Co-PI)
NASA Center for Space Exploration Technology Research (cSETR), University of Texas at El Paso

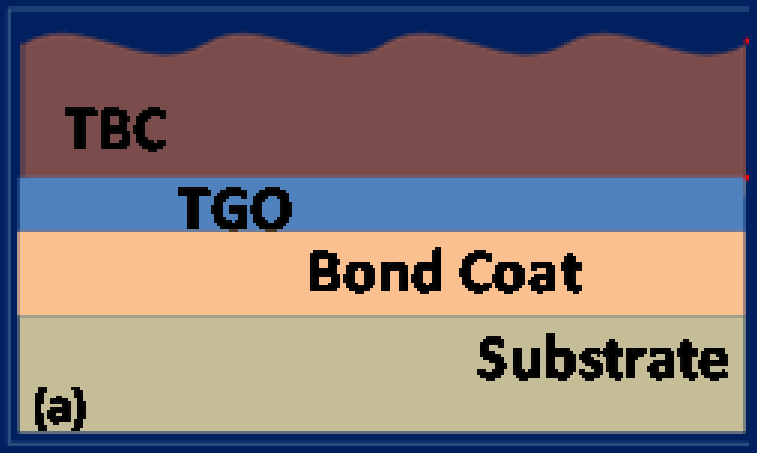
Program Manager:
Briggs White, NETL, DOE

Overview

- Introduction
- Experiments
- Results and Discussion
- Conclusions & Future Work

TBCs

- Multifunctional thick coatings of low thermal conductivity ceramic material
- Protect the metal component from extreme temperature
- Allow to increase the turbine operating temperature
- Increase the efficiency



Nitin et al., *Science* **296**, 280 (2002);
Evans et al., *Prog. Mater. Sci.* **46**, 505 (2001);
D.R. Clarke, S.R. Phillpot, *Mater. Today* **8**, 22 (2005)

TBCs

Current Standard: YSZ (Yttria Stabilized Zirconia)
Mainly due to ZrO_2: refractory oxide, 'coatings' using well-known PVD technology, and mechanical stability and low thermal conductivity
Y_2O_3: stabilizer

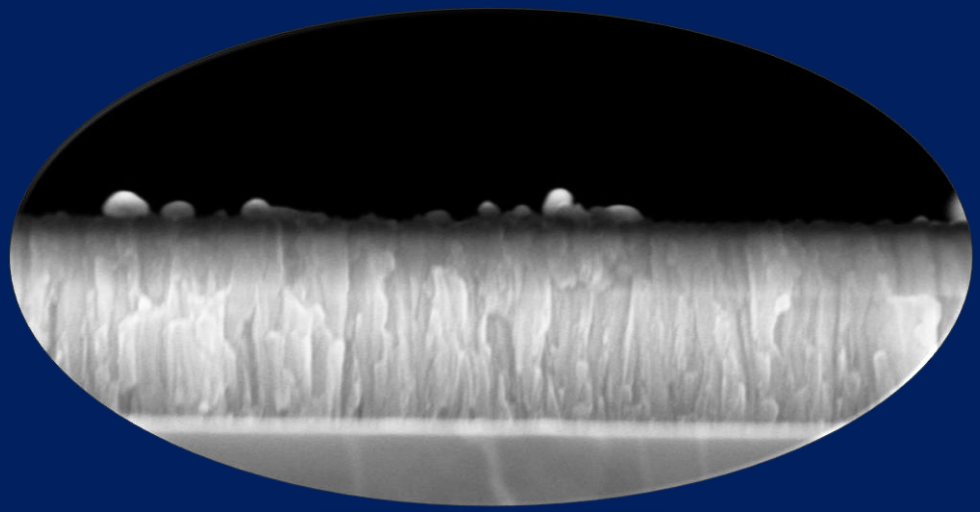
YSZ Problems: Temperature Tolerance (1200 ^oC) and Durability (cracking and spallation due to phase and, hence, volume change)

Goal (Ref: DE-FOA-0000031):
Temperature Tolerance $\geq$ 1300 ^oC &
Minimum Operating Time ~ 8000 hours

Hafnia-Based TBCs

HfO_2 exhibits:

- Higher melting point (2900 ^oC)
- Lower thermal conductivity (1.5 W/m.K)
- Crystal structure and phase transformation behavior



m-HfO_2

↓ **1700 ^oC**

t-HfO_2

↓ **2900 ^oC**

HfO_2

(2700 ^oC)

Objectives

- Design and fabrication of hafnia-based coatings
- Characterization and evaluation of the coatings
- Look for:
  - Higher temperature tolerance
  - Lower thermal conductivity
  - Higher materials' strength
  - Enhanced durability

EXPERIMENTS

Materials

Substrate(s):

- Ni super alloy(IN-738)
- SS-403
- Alumina

TBC :

Y_2O_3 stabilized HfO_2 (YSH)

Y_2O_3 stabilized ZrO_2 – HfO_2 (YSZH)

Target/ingot preparation

Tineous Olsen/Die Press

<u>Targets/Ingots</u>:

(1) YSH

(2) YSHZ (variable composition)

Y-stabilized Hafnia

YSH: 7.5 % Y_2O_3: HfO_2

Y-Stabilized Hafnia-Zirconia

YSHZ-1 : (HfO_2 : ZrO_2 = 4:1)

YSHZ-2 : (HfO_2 : ZrO_2 = 2:1)

YSHZ-3 : (HfO_2 : ZrO_2 = 1:2)

YSHZ-4 : (HfO_2 : ZrO_2 = 1:4)

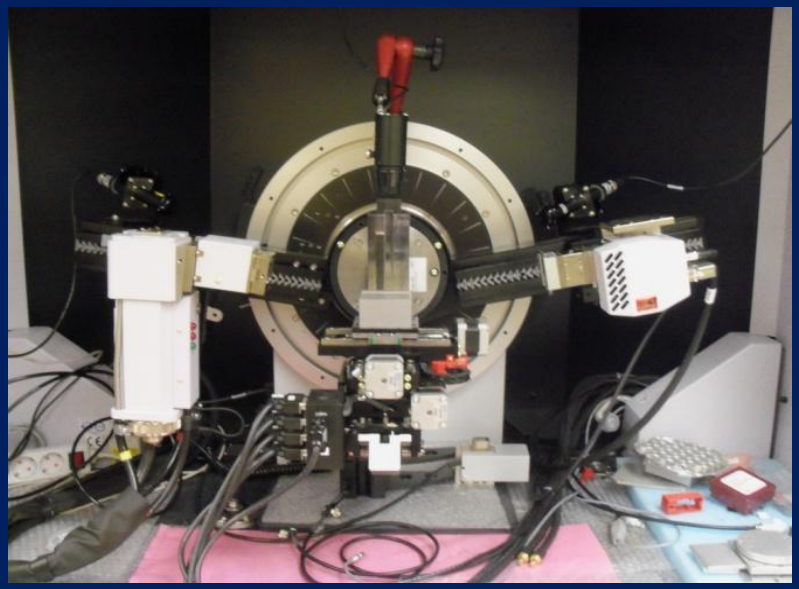
YSHZ-5 : (HfO_2 : ZrO_2 = 1:1)

Fabrication of TBCs

PVD: Sputtering

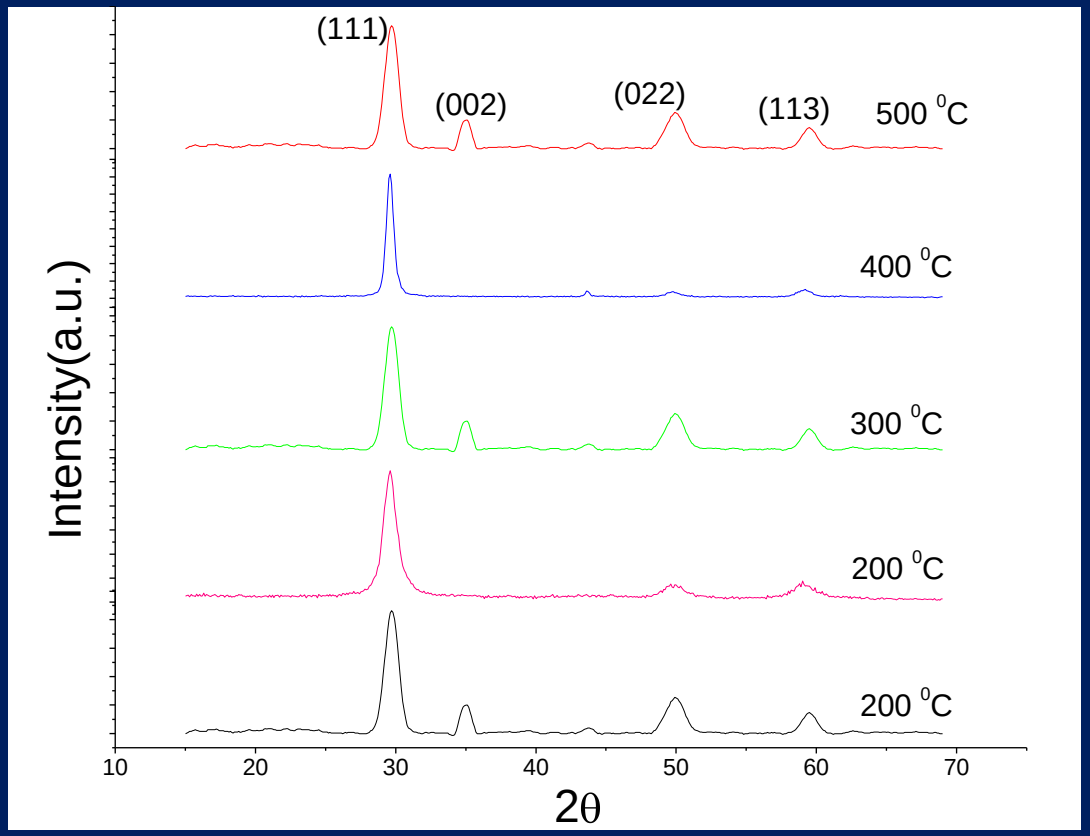
Characterization

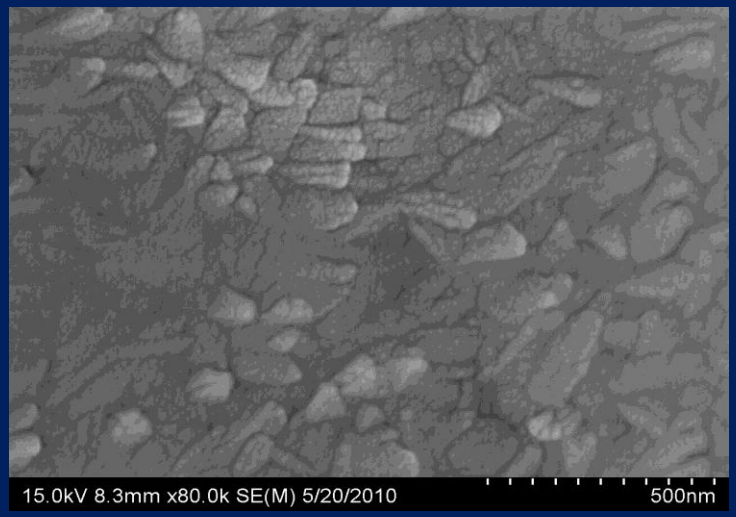
- XRD
- SEM
- EDS
- Micro-hardness
- Laser 3D Microscope

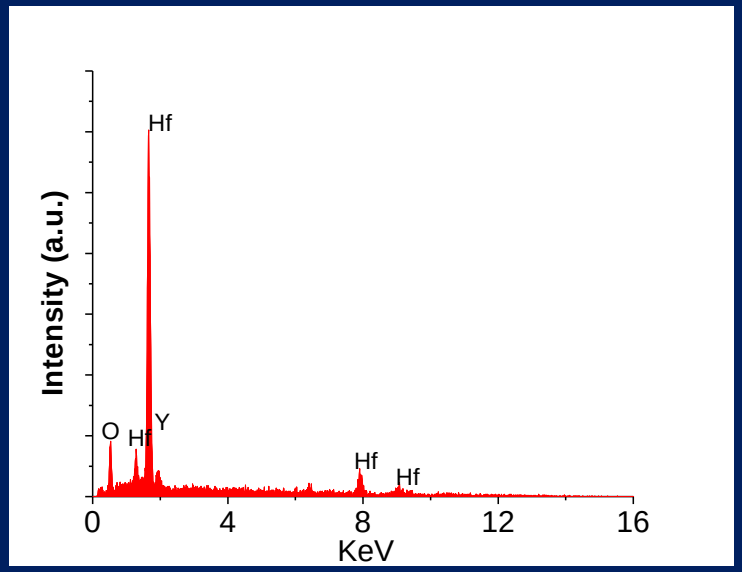


Structure, Phase & Morphology

XRD patterns of YSH coatings on Ni super alloy

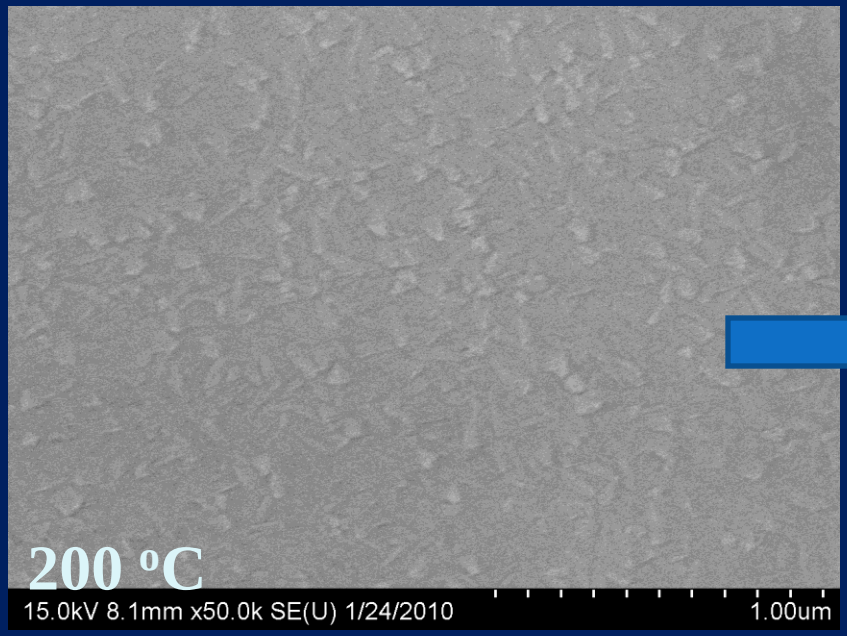


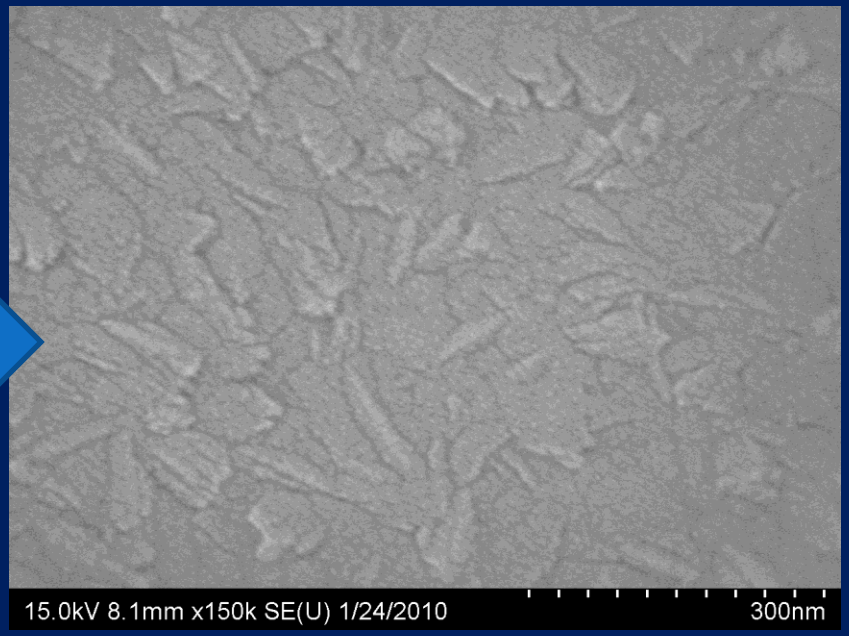


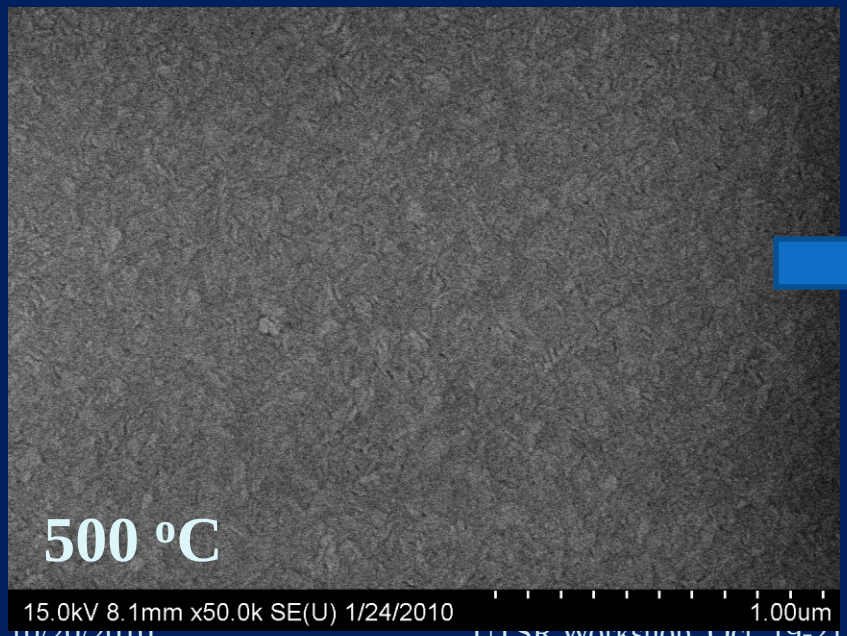


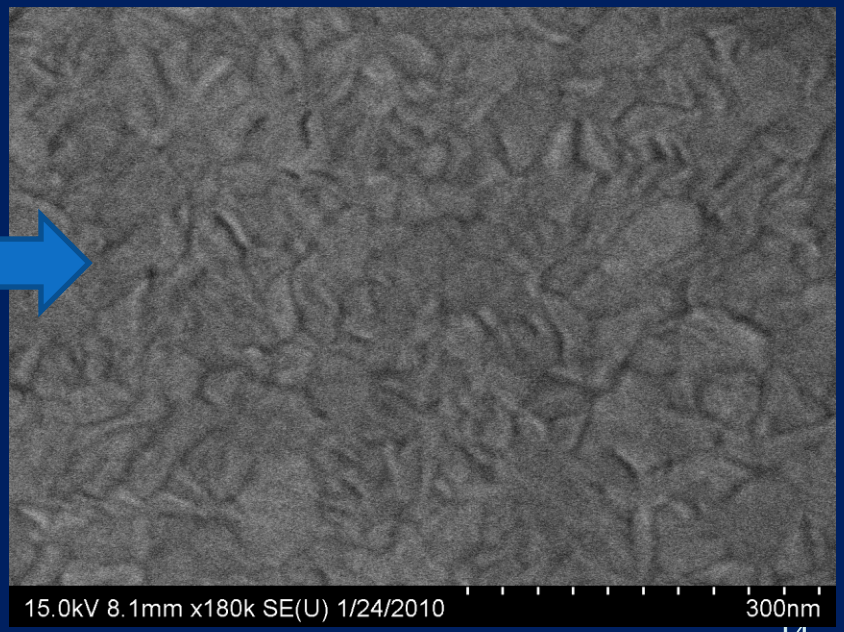
Cubic hafnia phase

The target composition is transferred to the coatings

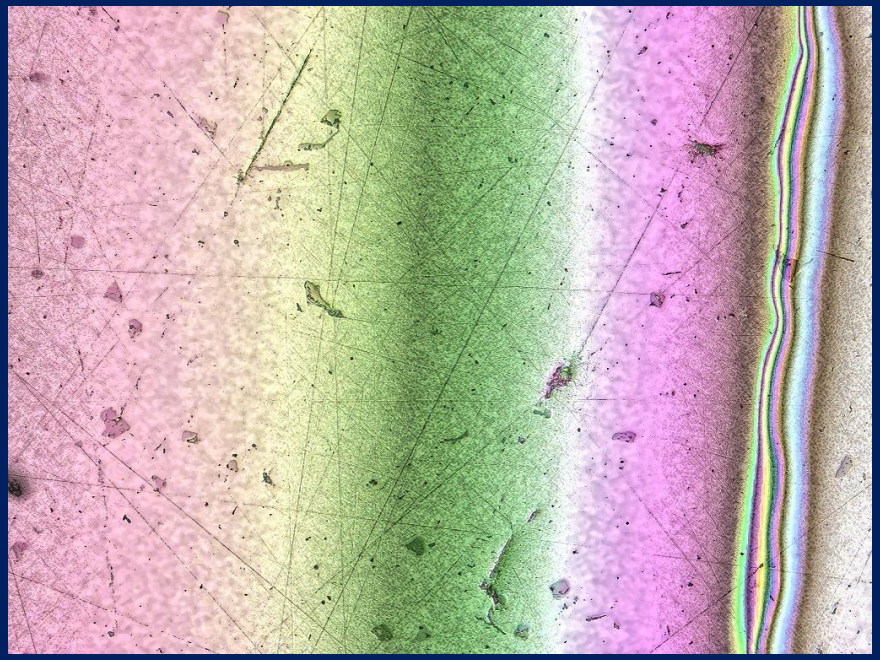

200 ºC
15.0kV 8.1mm x50.0k SE(U) 1/24/2010
1.00um

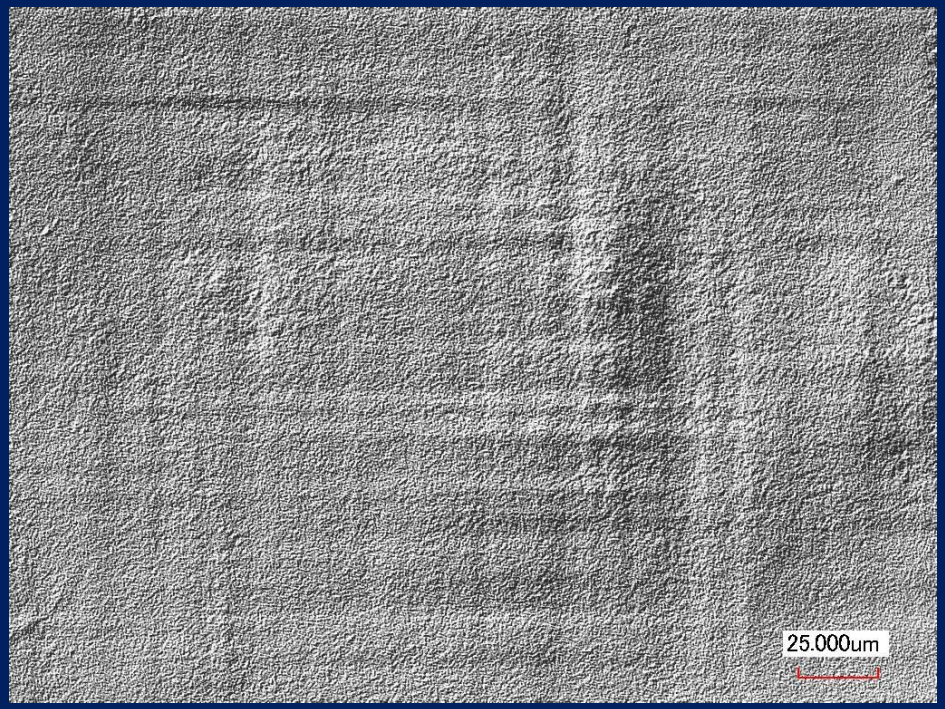

15.0kV 8.1mm x150k SE(U) 1/24/2010
300nm


500 ºC
15.0kV 8.1mm x50.0k SE(U) 1/24/2010
1.00um


15.0kV 8.1mm x180k SE(U) 1/24/2010
300nm

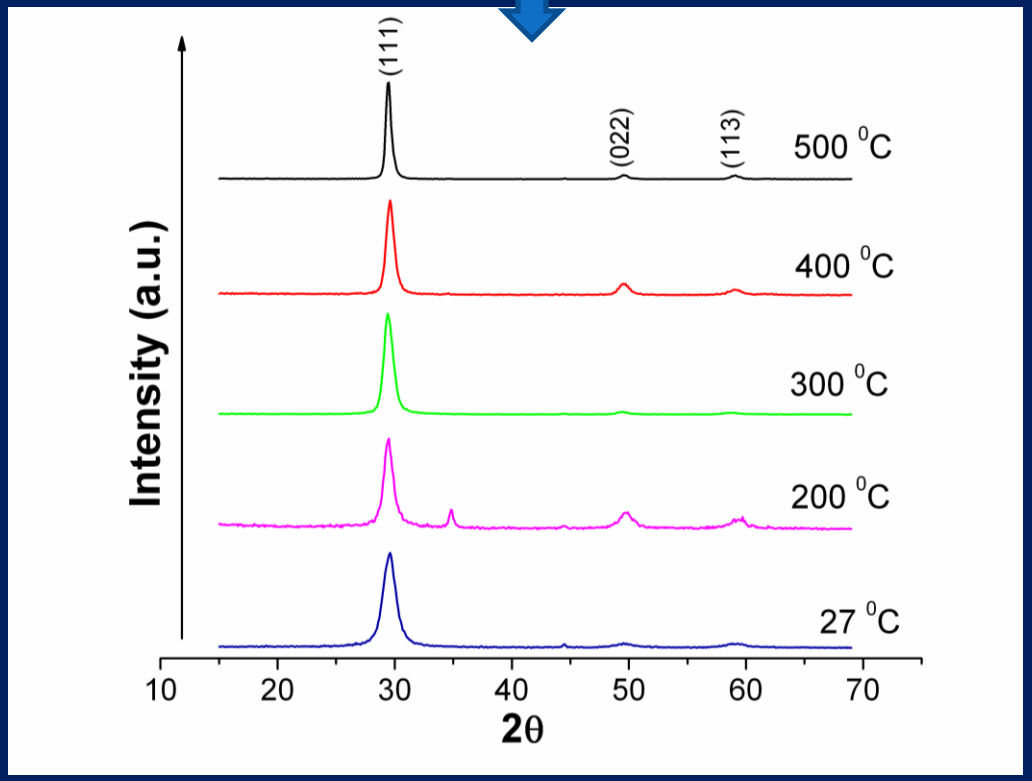
Morphology – Broad View

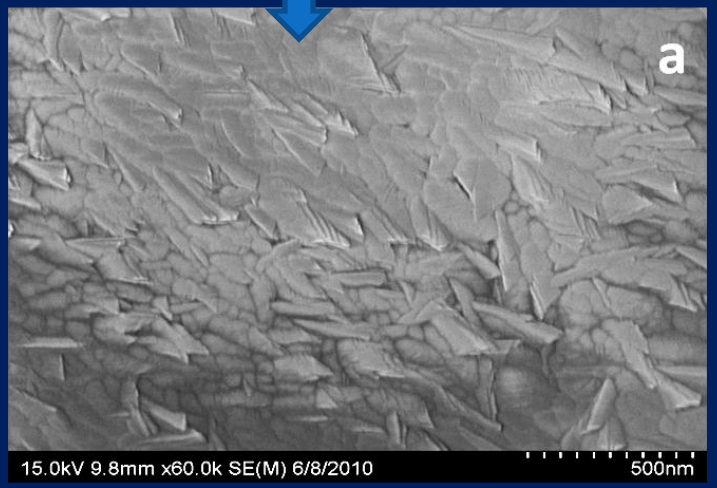


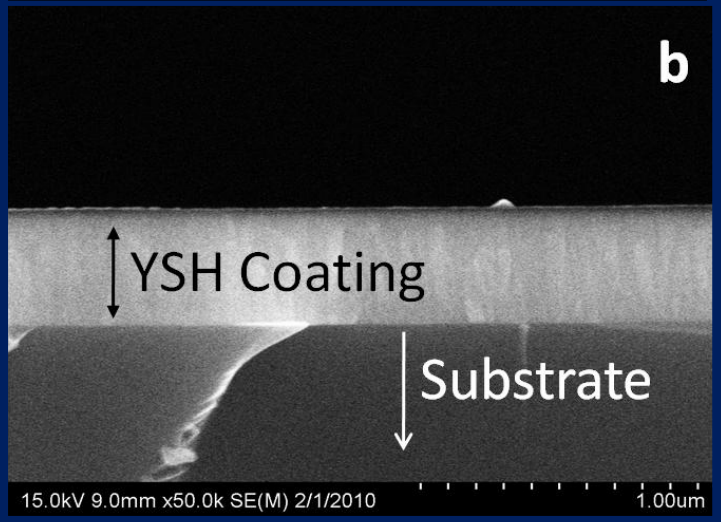


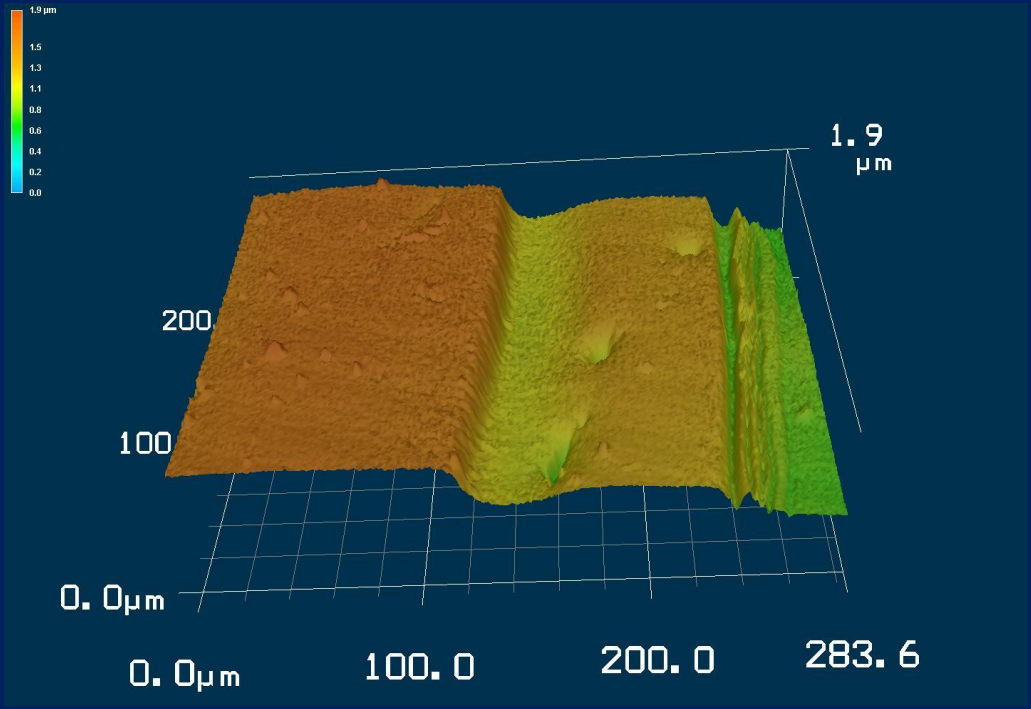
Crystal Structure, Morphology & Phase

XRD & SEM /SS-4-3



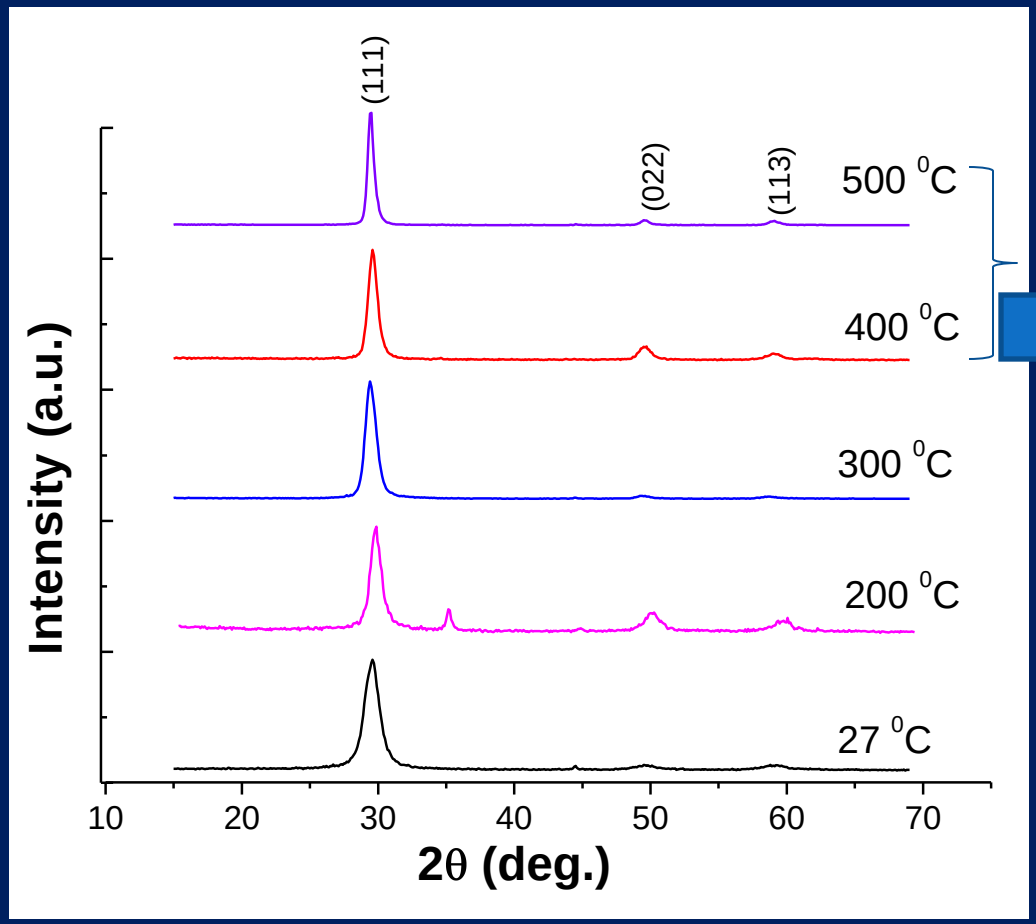


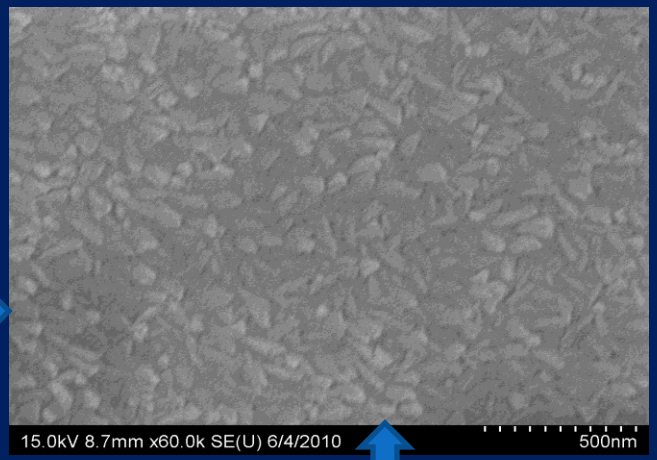


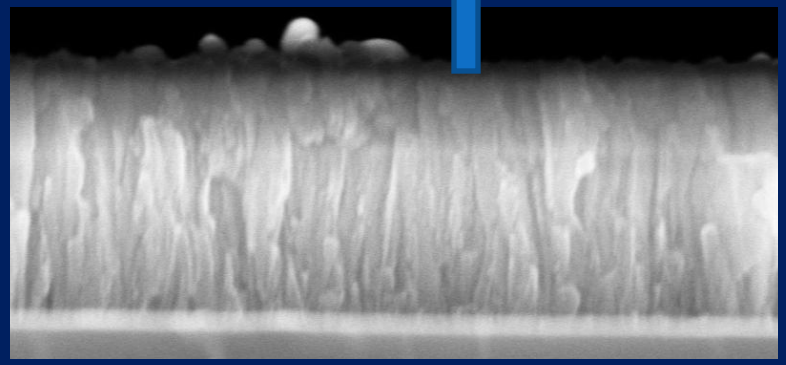

1.9 µm
1.5
1.3
1.1
0.8
0.6
0.4
0.2
0.0
1.9
µm
200
100
0.0µm
0.0µm
100.0
200.0
283.6

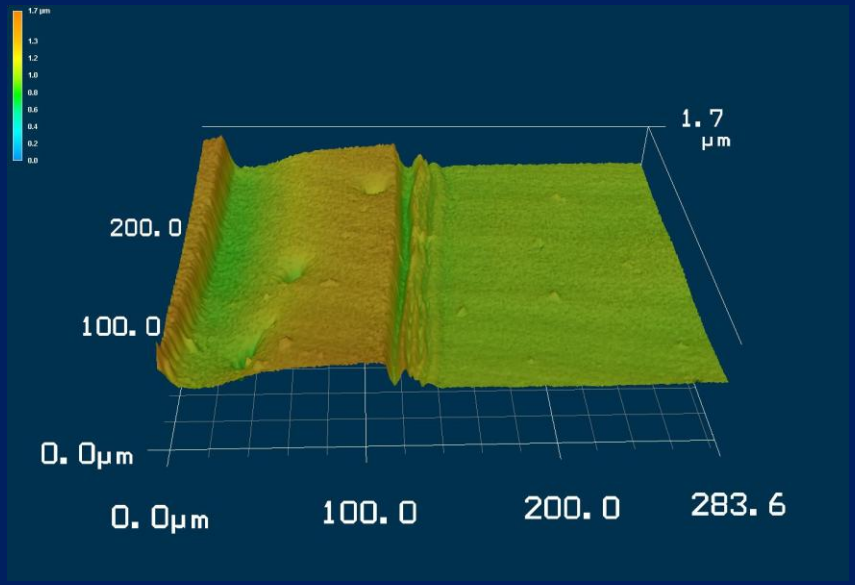
Structure, Phase & Morphology

XRD and SEM /Alumina

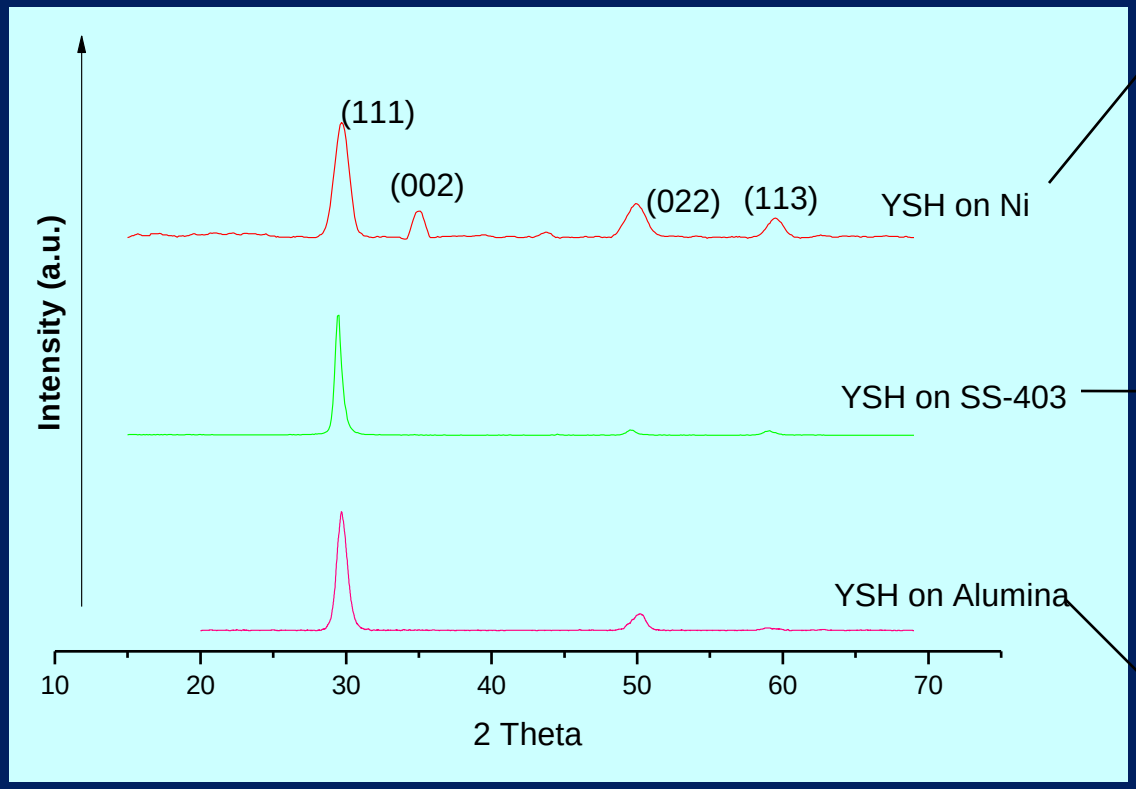


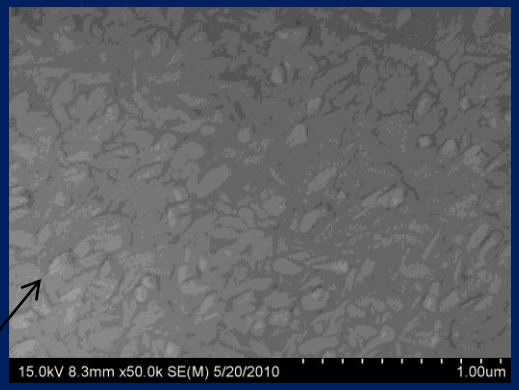


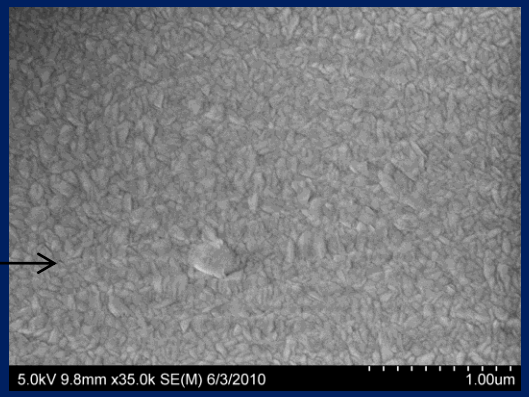


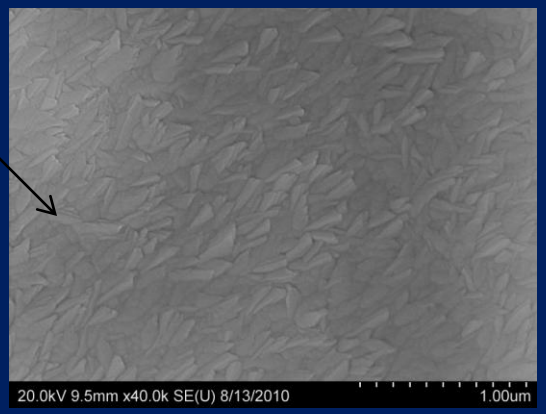

1.7 µm
1.3
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.7 µm
200.0
100.0
0.0µm
0.0µm
100.0
200.0
283.6

Crystal Structure: Effect of Substrate Materials

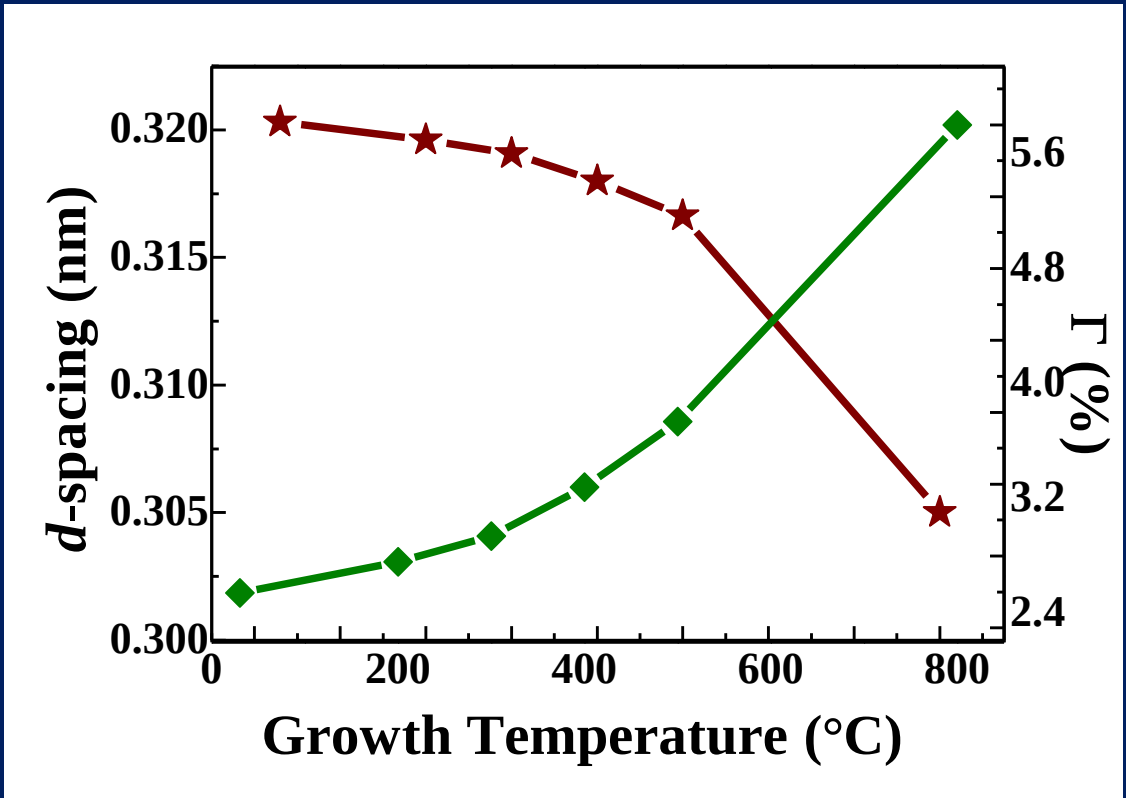




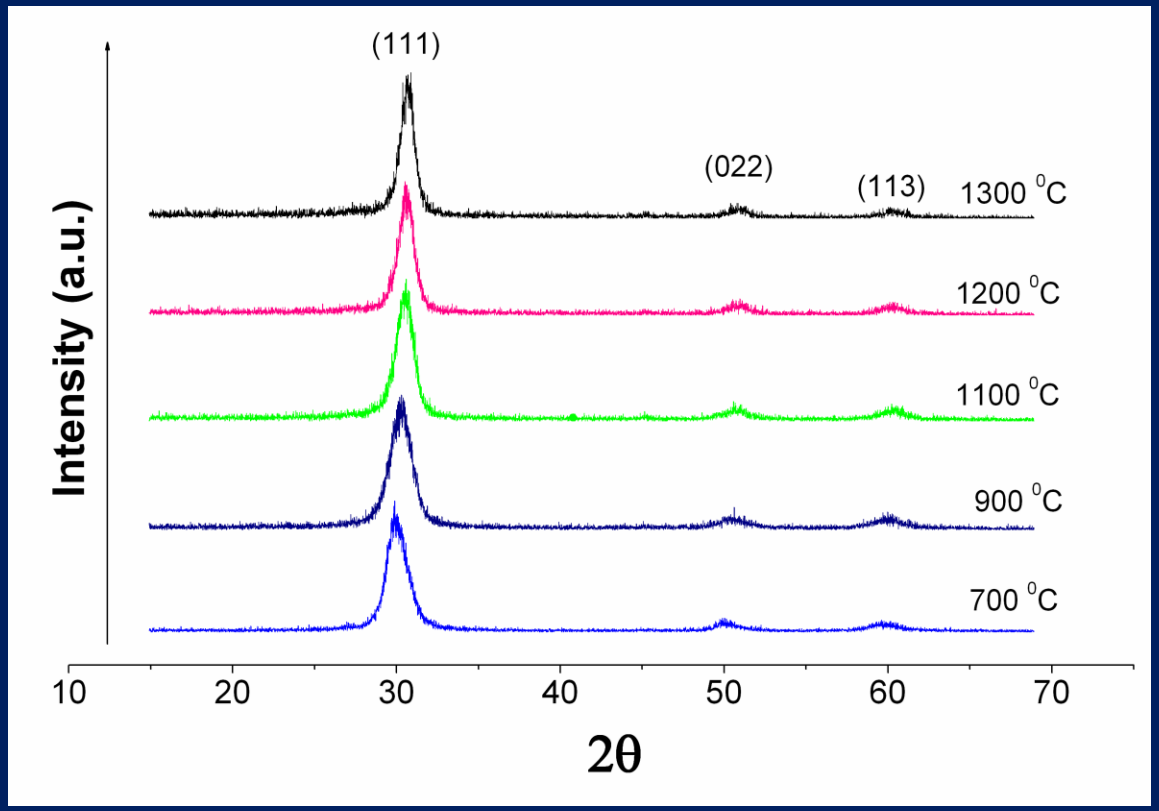




Monoclinic Hafnia

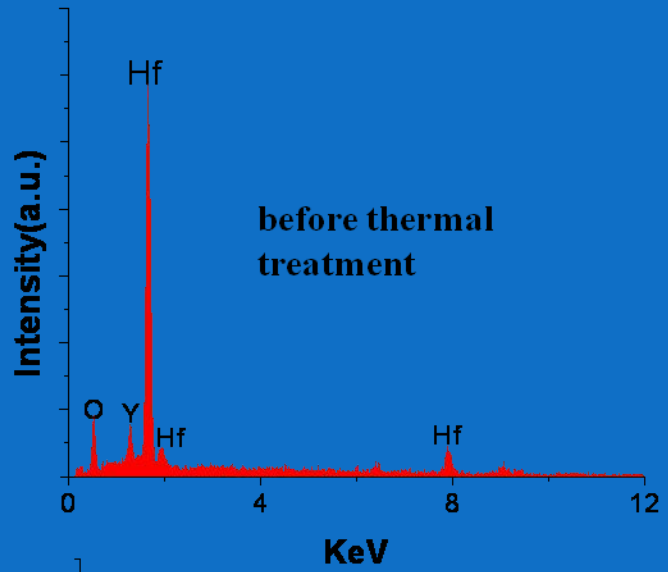


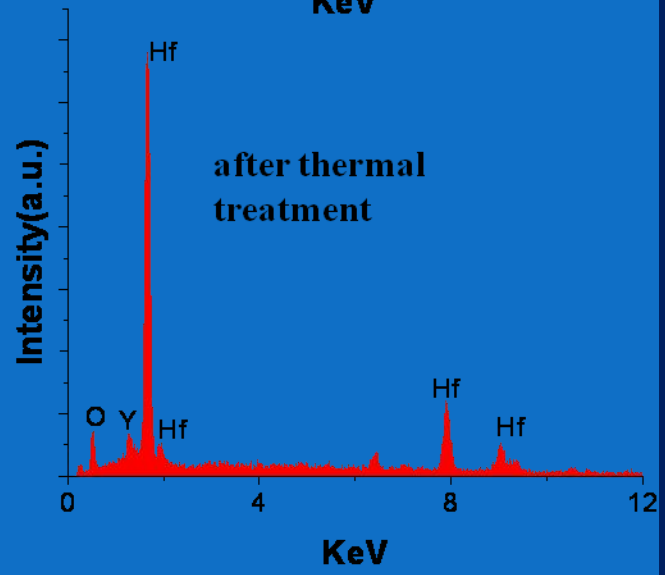
Structural and Phase Stability



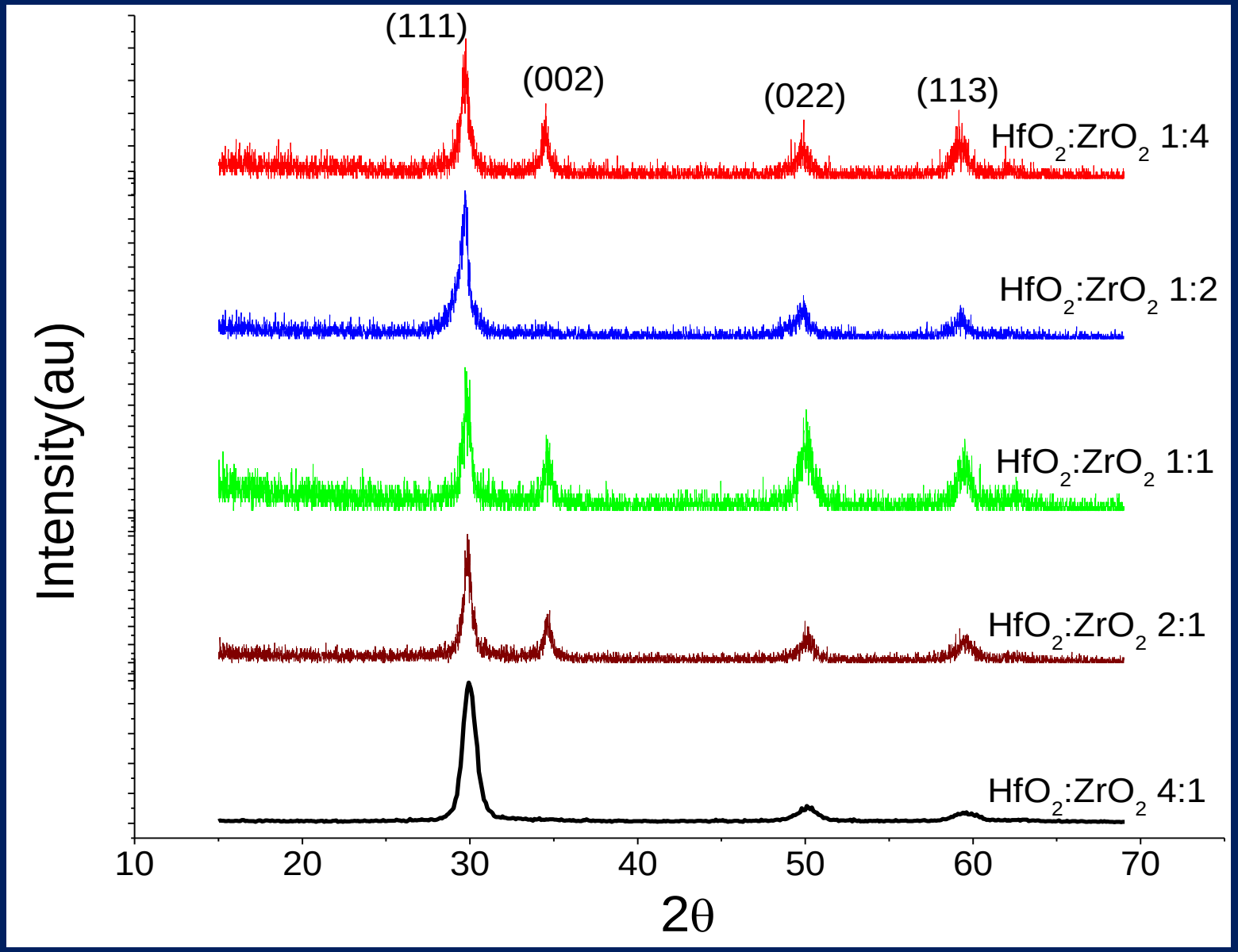
No change
*Phase and chemical stability to 1300 °C

Structural and Phase Stability

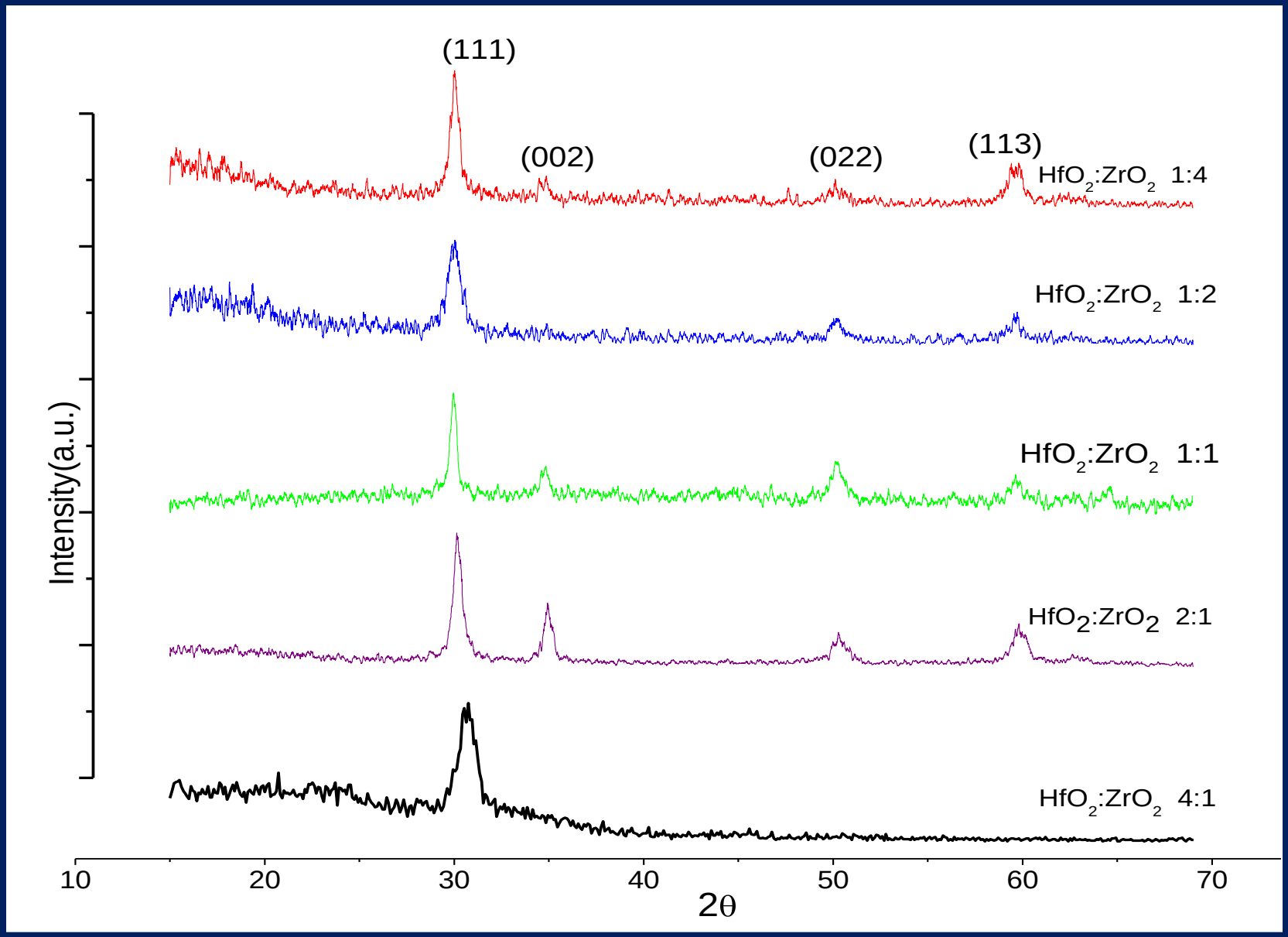




YSZH Coatings on Alumina

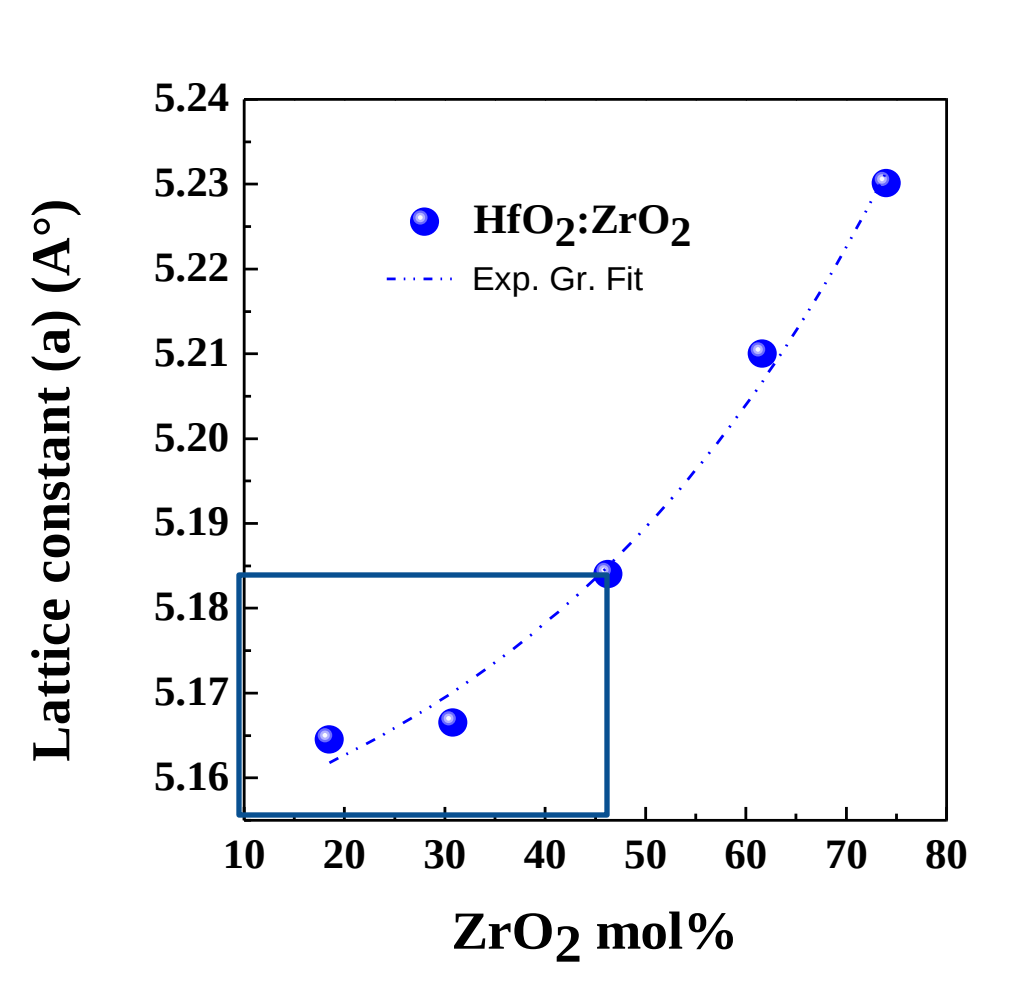


YSZH Coatings on Ni-alloy

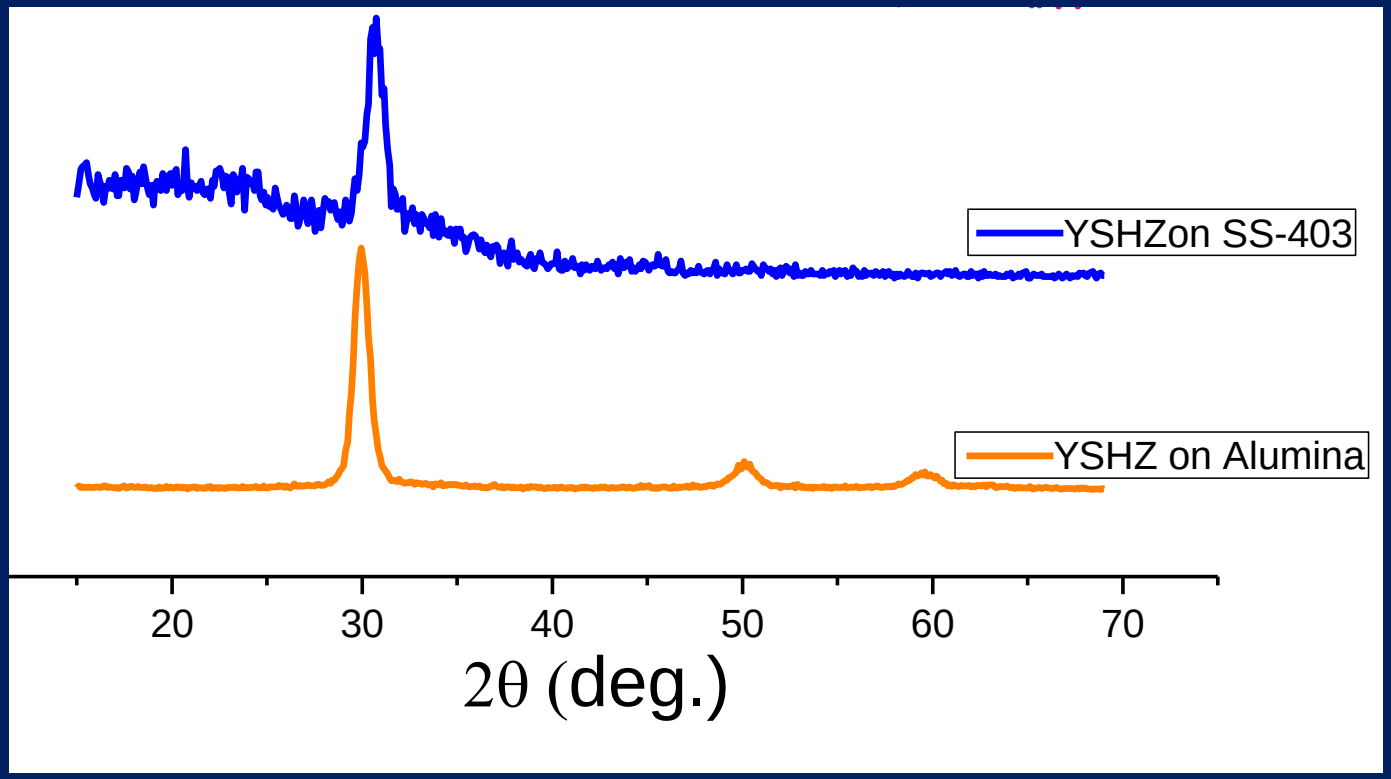


Effect of Composition

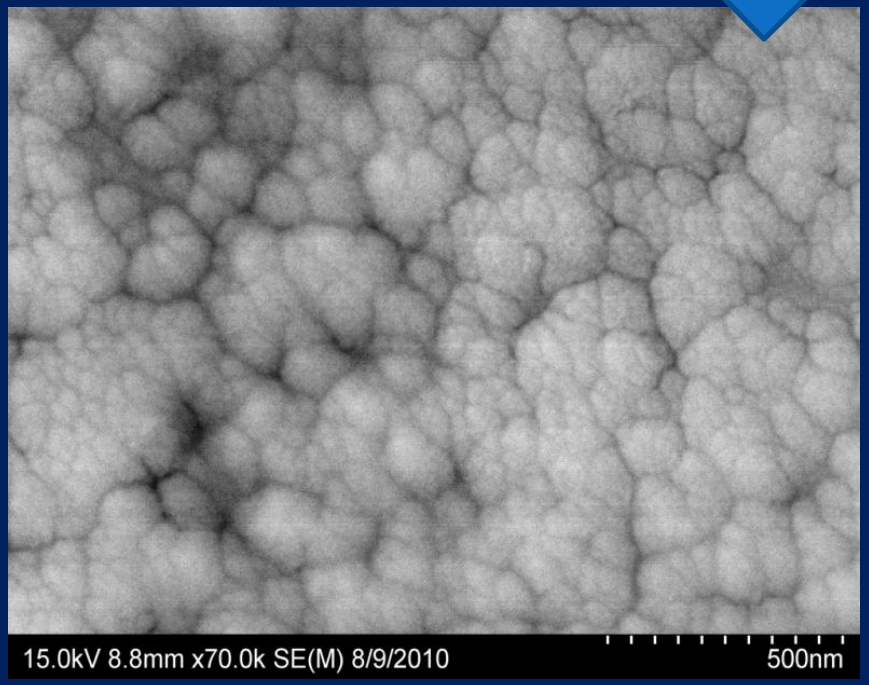
Lattice Expansion
Strain
Exponential

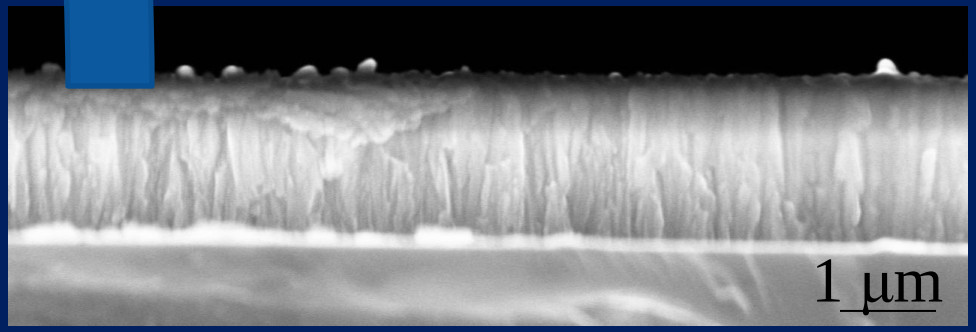


Structure and Phase: YSHZ (4:1)



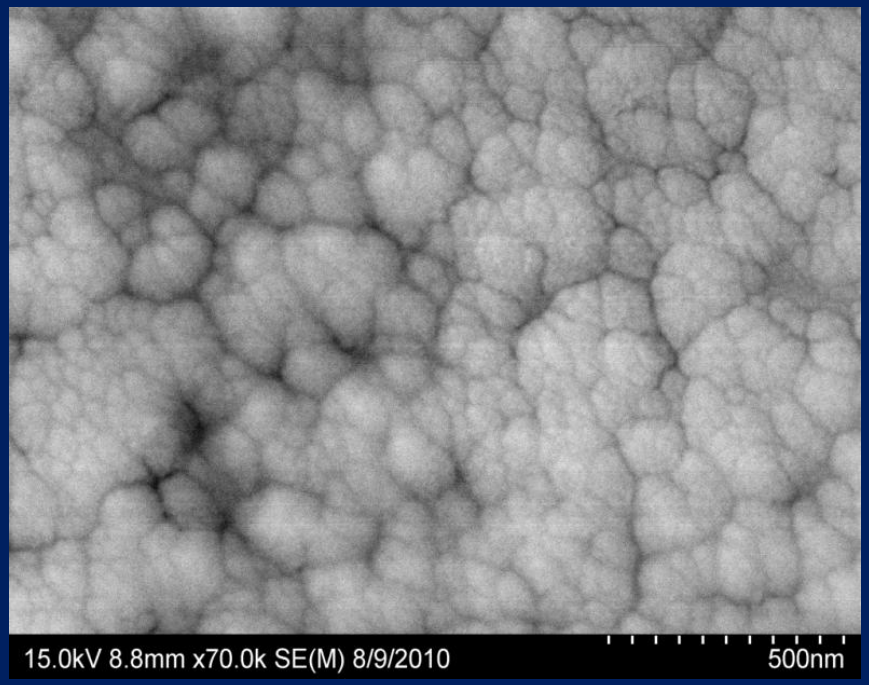
Morphology: YSHZ (4:1)



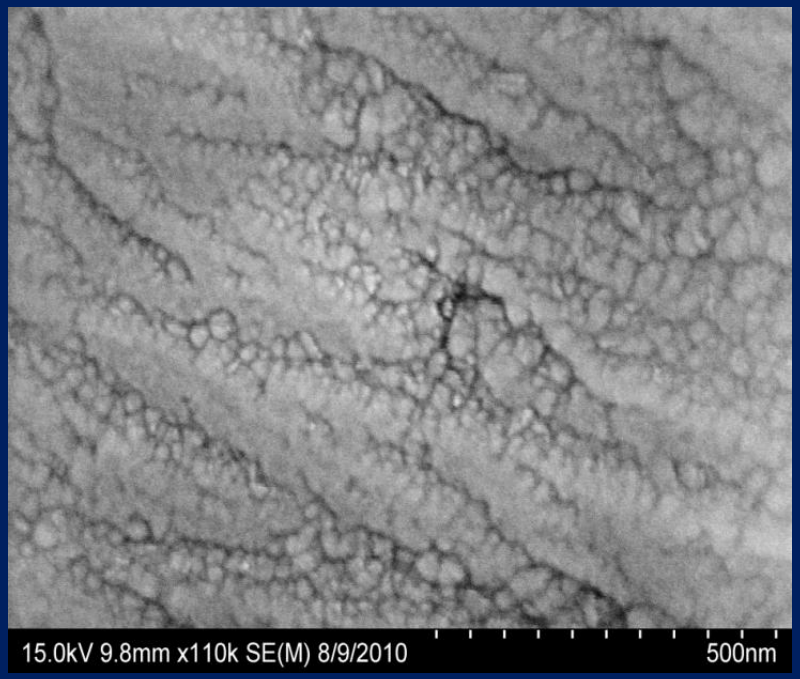


Microstructure

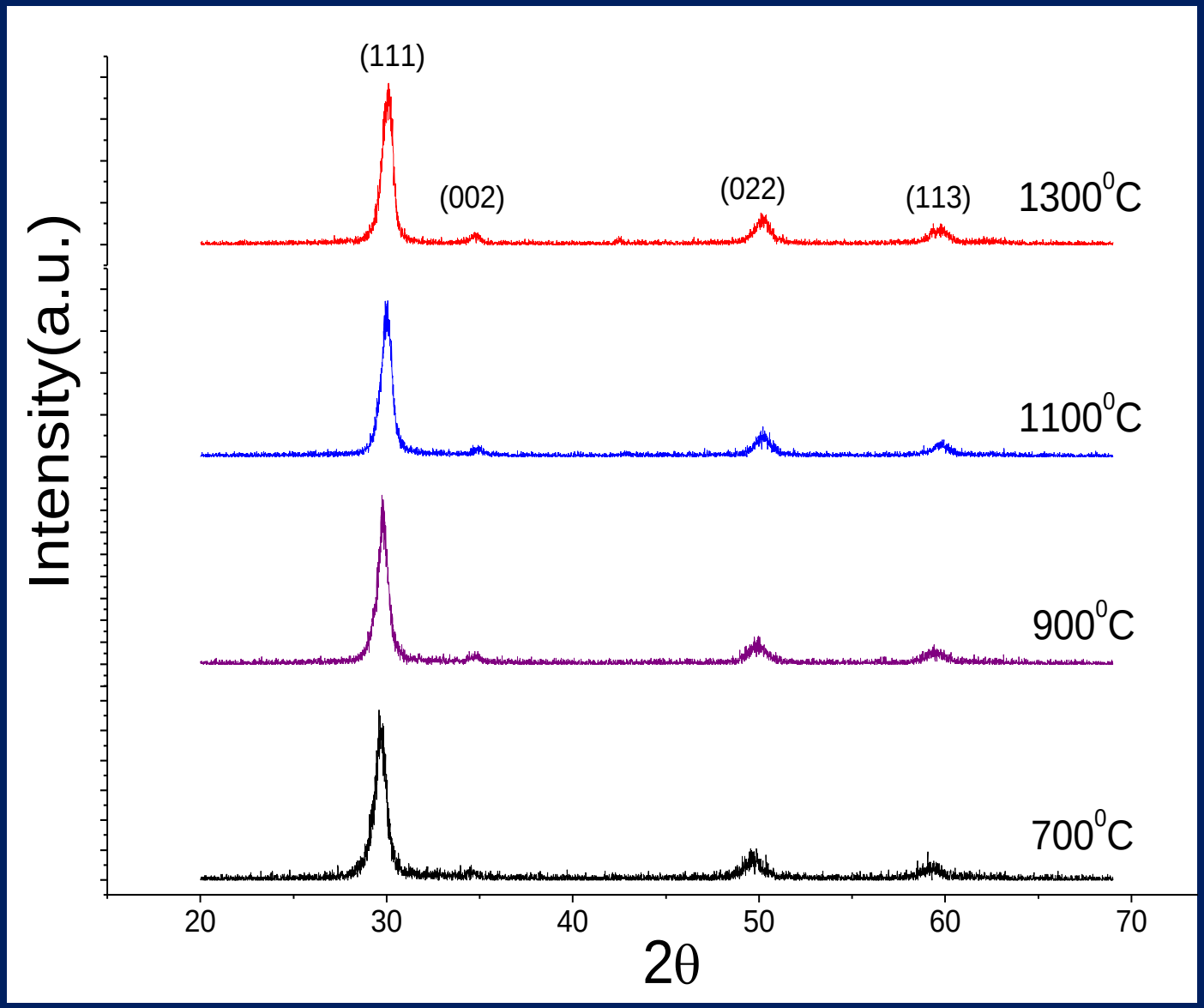
YSHZ 1 Ni



YSHZ 1 SS



Phase and Chemical Stability - YSHZ (4:1)



Summary and Conclusions

- Hafnia-based coatings were grown and their microstructure and phase/compositional stability is studied
- Hafnia based TBC show columnar structure
- The stabilized cubic phase is stable to higher temperatures
- Lattice expansion indicates there is a limit to play with the Hf-Zr-O composition
- More experiments need to be performed

Acknowledgements

- DOE
- Briggs White
- cSETR
- Noor-A-Alam & Chris Bradley

THANK YOU!

QUESTIONS/
COMMENTS?