Combustion CVD Coatings for TBC Improvement

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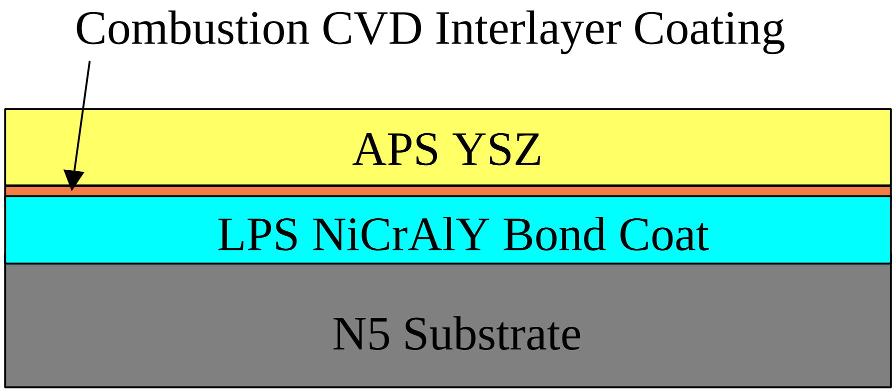
Motivation

- Toughen the interface between air plasma sprayed YSZ and the nickel-chromium-aluminum-yttrium bond coat of thermal barrier coatings (TBC's) used on hot section components of gas turbines.



Combustion CVD Interlayer Coating

APS YSZ

LPS NiCrAlY Bond Coat

N5 Substrate

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Procedure

- Bond coated substrates supplied by GEPS (Schenectady, NY)
- Combustion CVD interlayer coatings applied by Georgia Tech
- APS YSZ applied by GEPS
- Furnace Cycle Testing to be performed at Georgia Tech

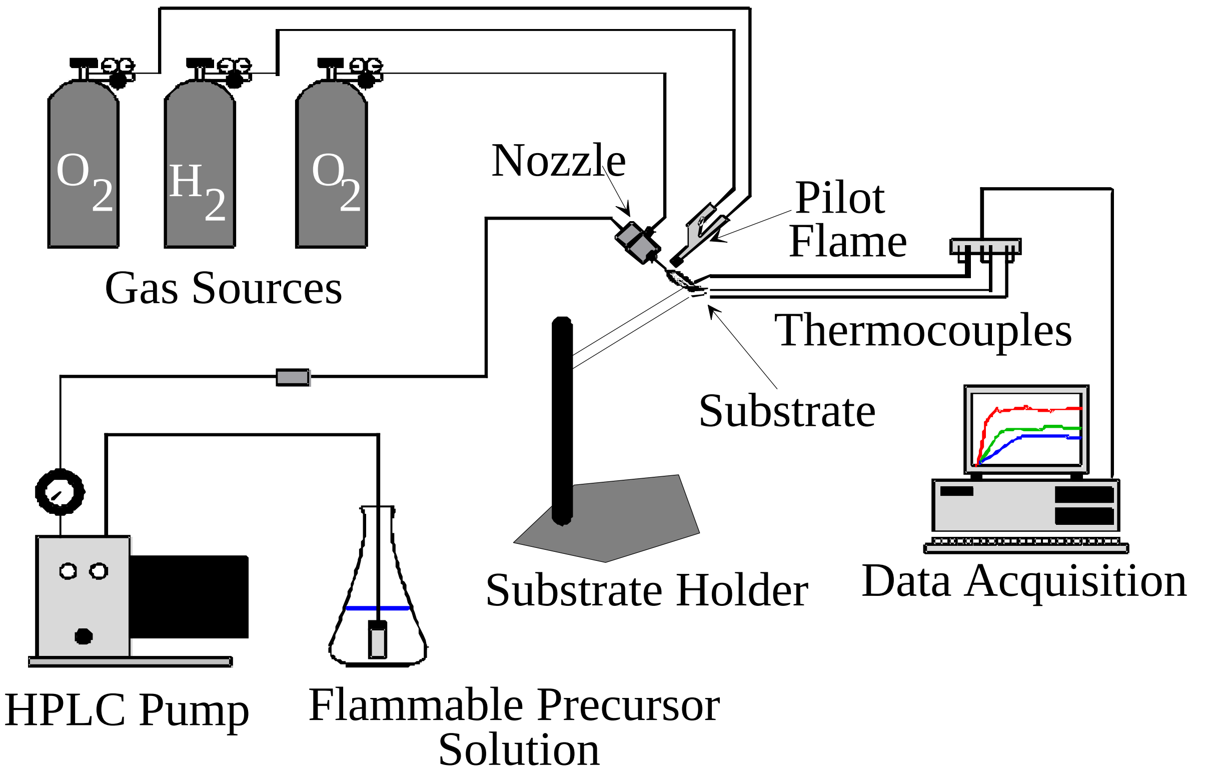
Interlayer Coatings Under Investigation

- YSZ/Alumina Composite
- YSZ/Alumina Graded Coatings
- Alpha Alumina Coatings

Combustion Chemical Vapor Deposition

- A Novel Approach for Depositing Ceramic Thin Films
- A Reaction Chamber Is Not Necessary
- Combustion Provides Most of the Heat for:
  - Chemical Reactions
  - Diffusion
  - Nucleation
  - Film Growth
- The Substrate Is Located in or near a Flame

Combustion CVD System



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Process Parameters for YSZ/Alumina Composite Coatings

Solvent	Toluene
Precursors:	Yttrium 2-EH* Zirconium 2-EH Aluminum acac**
Solution Flow Rate	4 ml/min
Precursor Concentration	0.002 M
Oxidizer	Oxygen
Oxidizer Flow Rate	6 - 12 lpm
Deposition Rate	1.8 - 2.5 µm/hr
Flame Temperature	1350 - 1550°C
Substrate	a-plane sapphire

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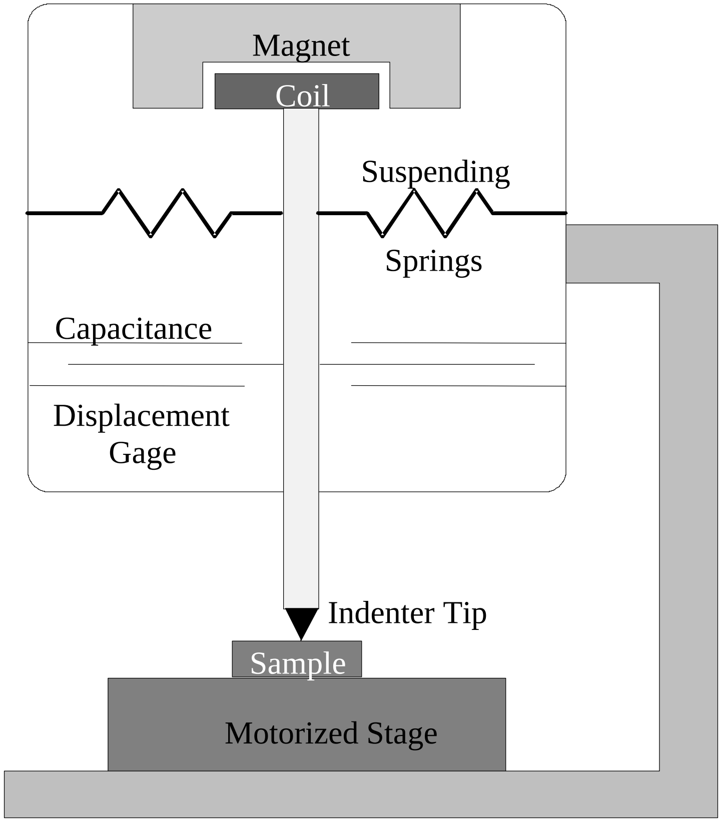
*2-ethylhexanoate

**acetylacetonate

YSZ/Alumina Composite Coatings

- Alumina is a Desirable Additive
  - Higher Elastic Modulus and Hardness than Zirconia
  - Lower Cost than Zirconia
- Alumina Additions to YSZ (in Bulk Sintered Powders) Shown to Improve Mechanical Properties
  - Reduced Amount of Monoclinic Phase
  - Increased Elastic Modulus
  - Increased Hardness
  - Increased Fracture Toughness

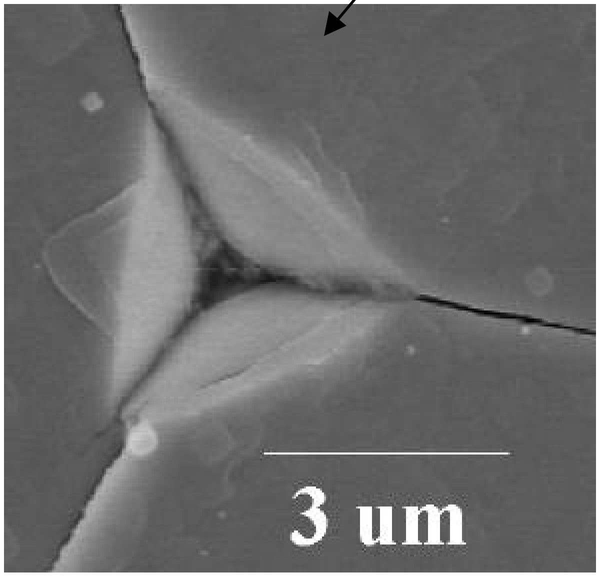
Nanoindenter**7**



- Schematic of the Nanoindenter**7**
  - – Load Resolution ± 75.0 nN
  - – Depth Resolution ± 0.04 nm

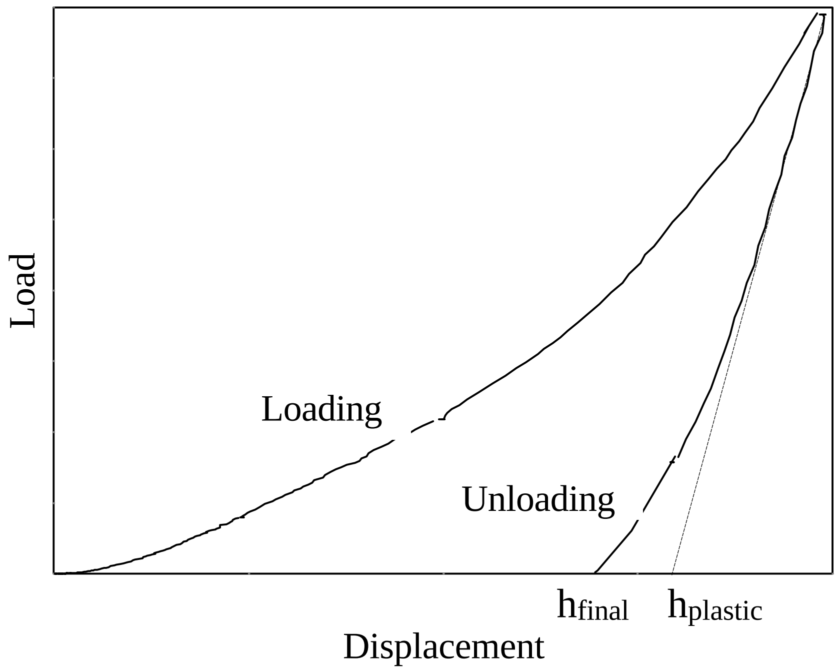
Nanoindenter7

Typical Indentation Left in a Film after Loading by the Nanoindenter**7**



- Berkovich Indenter Tip
  - Triangular Pyramid
  - Area-to-Depth Function Equal to Vickers Indenter
  - Hardness and Elastic Modulus Measurements
- Cube-corner Indenter Tip
  - Much Sharper than Berkovich
  - Displaces More Material with same Load
  - Fracture Toughness Measurements

Nanoindenter**7**

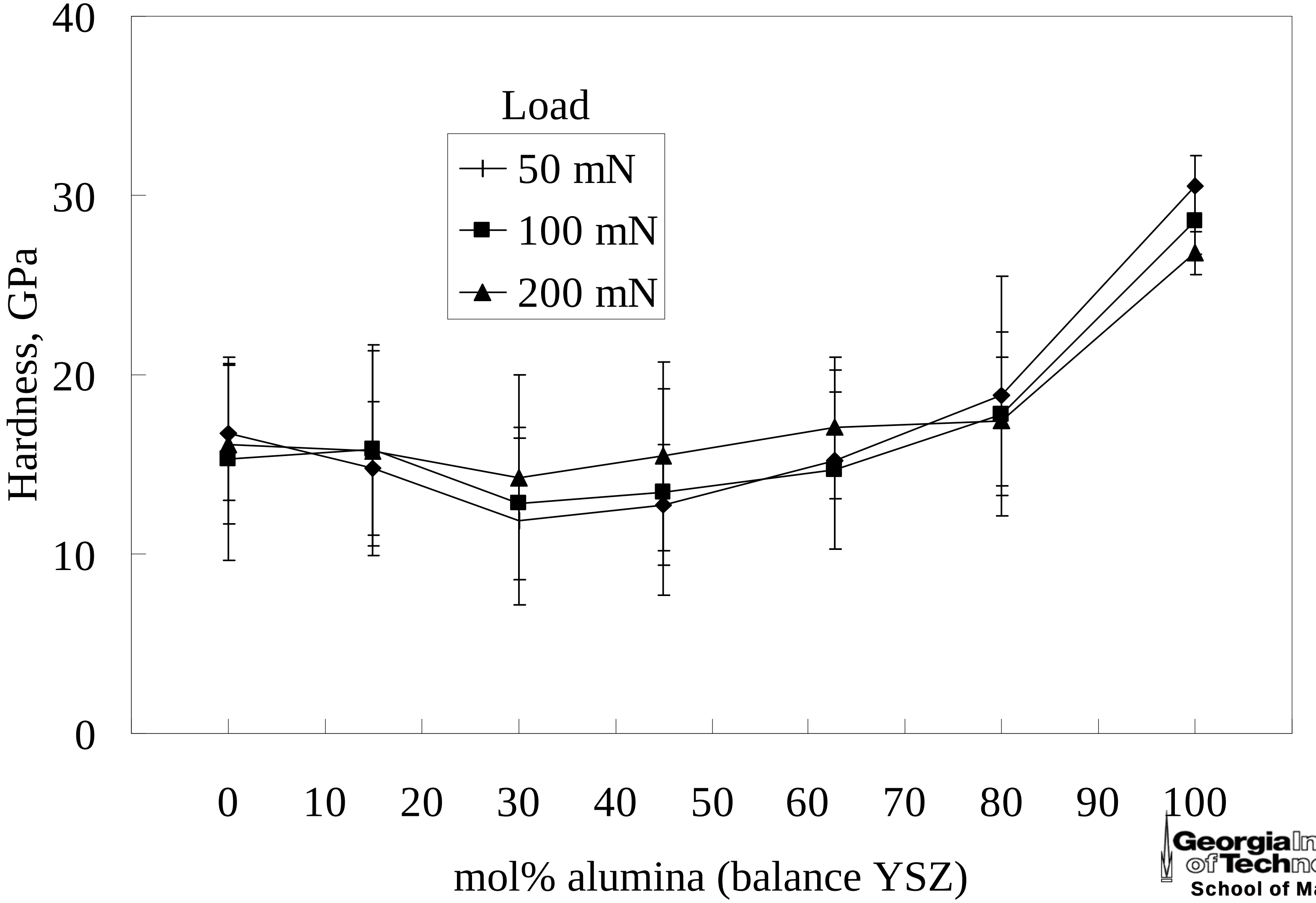


- Typical Load vs. Displacement Curve for a Nanoindenter**7** Indentation

Microhardness

- $H = P/A$
  - P: Applied Load
  - A: Projected Area of the Indentation after Removal of the Load ($A=24.5h_p^2$ for Berkovich Indenter Tip)
  - Same for Bulk Materials and Thin Films
- Hardness of Thin Films (Microhardness)
  - Small Indenters (Radius of Curvature <100nm)
  - Shallow Indentation Depths (5-10 times less than the Film Thickness)
  - Light Loads (~mN down to μN)

Hardness as a Function of Alumina Amount



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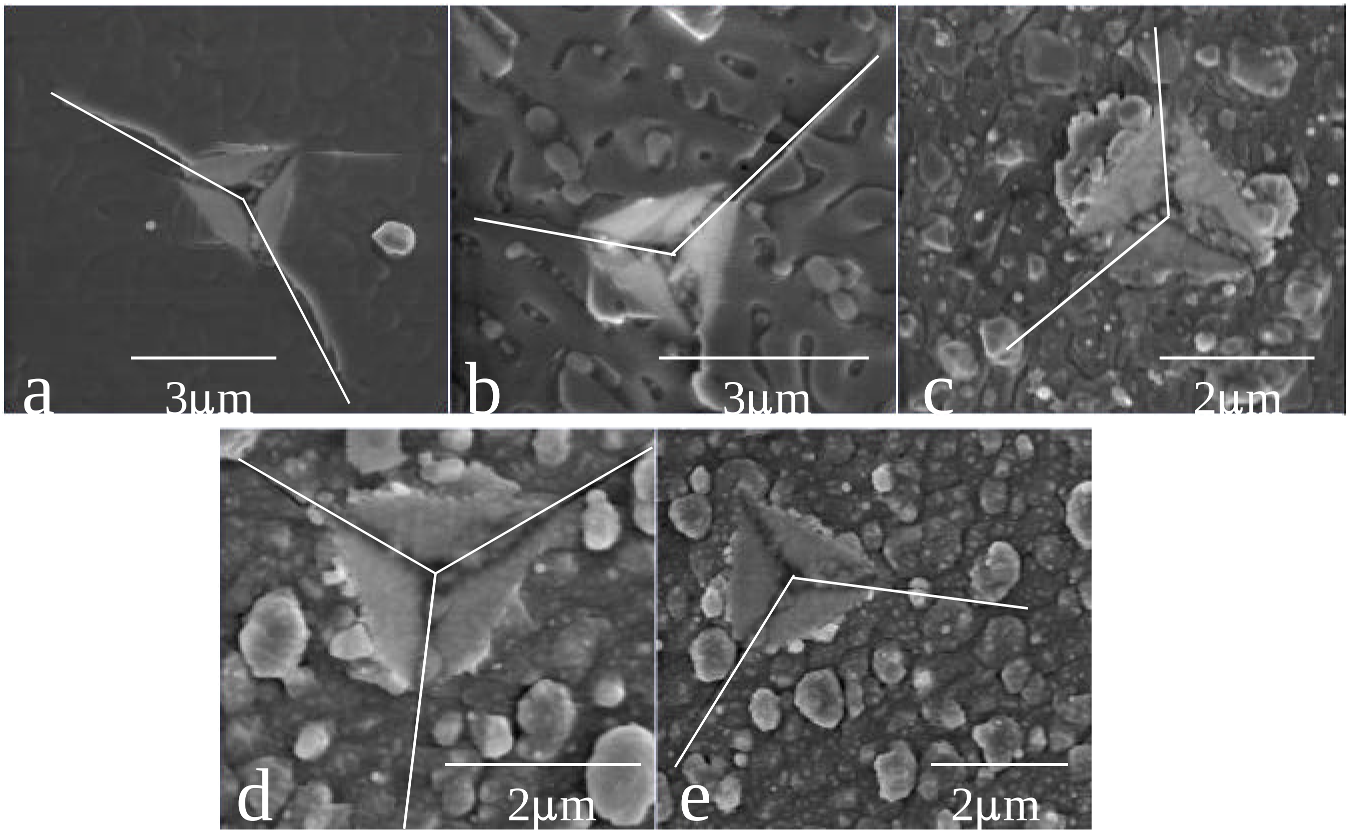
Crack Measurement

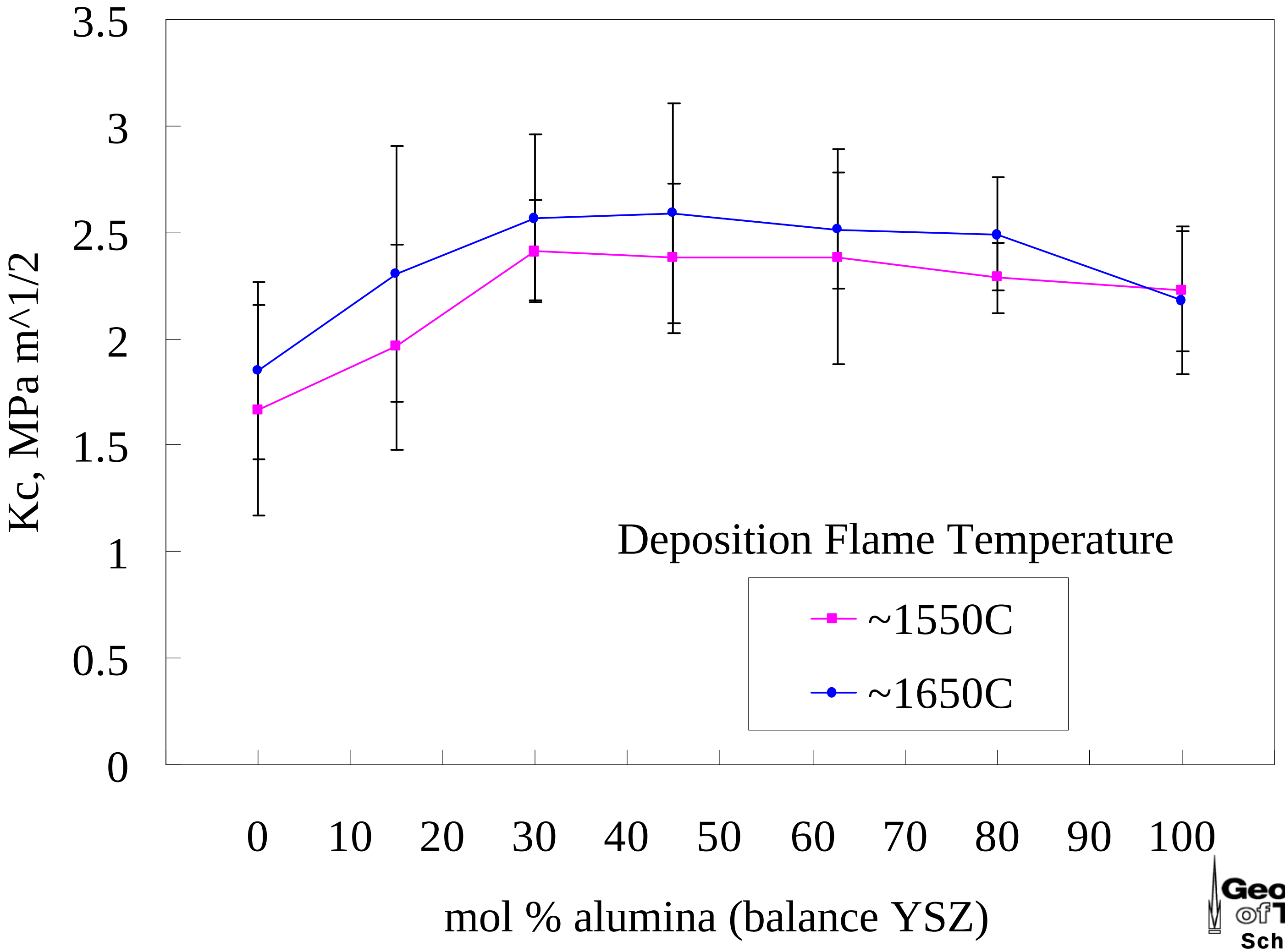


- Cube-corner indentations via Nanoindenter**7** for each of the YSZ-alumina films; a) 100% YSZ, b) 15 mol% Al_2O_3, c) 30 mol% Al_2O_3, d) 45 mol% Al_2O_3 and e) 62.8 mol% Al_2O_3.

Fracture Toughness

- $$K_C = a\left(\frac{E}{H}\right)^{1/2}\frac{P}{c^{3/2}}$$
  - α = empirical constant, ~0.032 for a cube-corner
  - *E* = elastic modulus
  - *H* = hardness
  - *P* = applied load
  - *c* = crack length
- Crack Length is Determined from Scanning Electron Microscope Image of Indentation

Fracture Toughness as a Function of Alumina Amount



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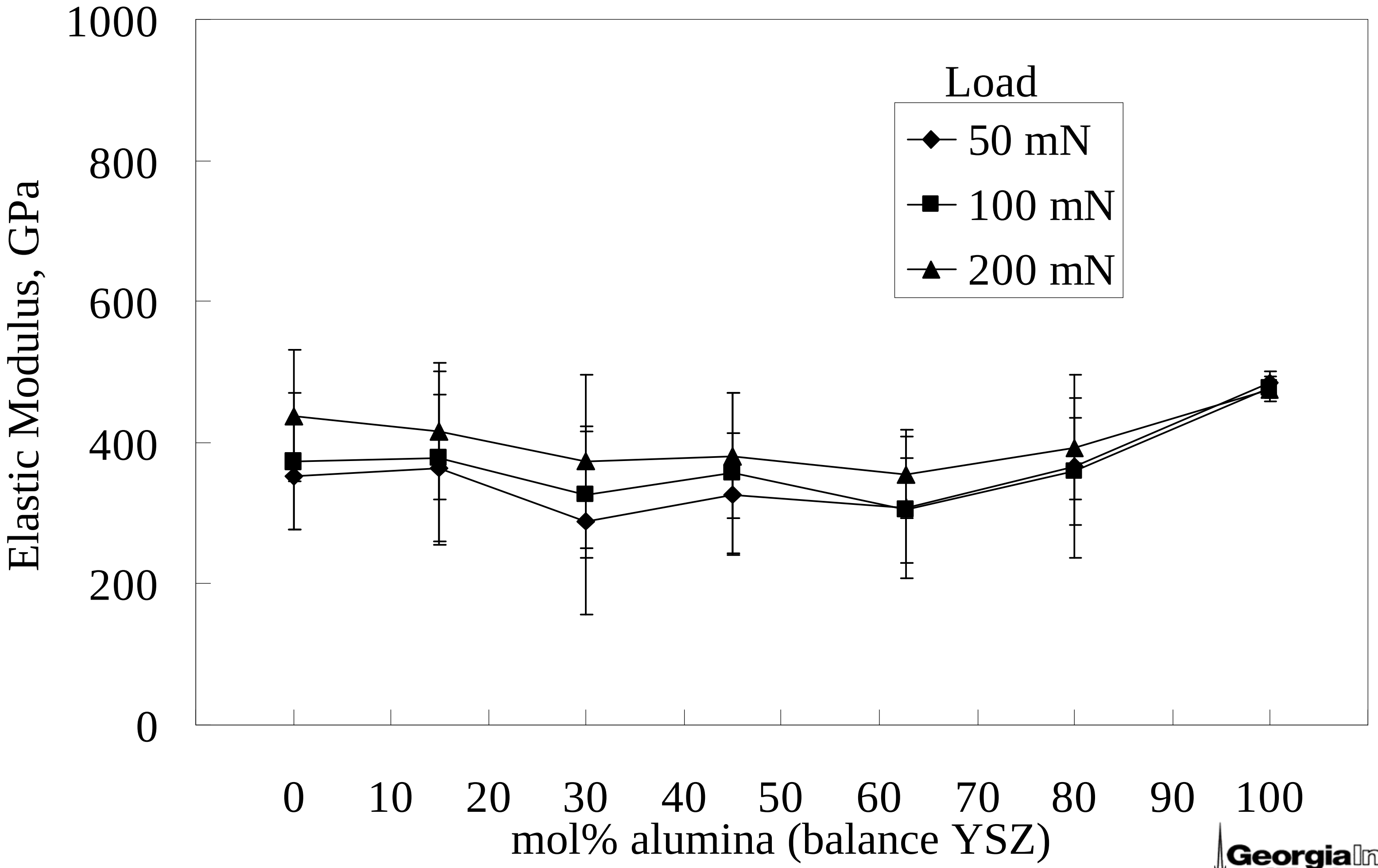
Elastic Modulus

- Determined from Slope of the Unloading Curve
  - $dP/dh = \beta E^* \sqrt{A}$
  - $$\frac{1}{E^*} = \frac{1 - n_0^2}{E_0} + \frac{1 - n^2}{E}$$
  - E^*= effective modulus of the system
  - E_0 = elastic modulus of indenter
  - E = elastic modulus of film
  - ν_0 = Poisson’s ratio of indenter
  - ν = Poisson’s ratio of film
  - β = constant dependent on indenter shape

Elastic Modulus as a Function of Alumina Amount



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Process Parameters for YSZ/Alumina Graded Coatings

Solvent	Isopropanol
Precursors:	Yttrium 2-EH* Zirconium 2-EH Aluminum acac**
Solution Flow Rate	2 ml/min
Precursor Concentration	0.002 M
Oxidizer	Oxygen
Oxidizer Flow Rate	0.6-0.8 liters/min
Deposition Rate	1.8 - 3.0 µm/hr
Flame Temperature	1250 - 1450°C
Substrate	Ni, Cr Superalloy

*2-ethylhexanoate

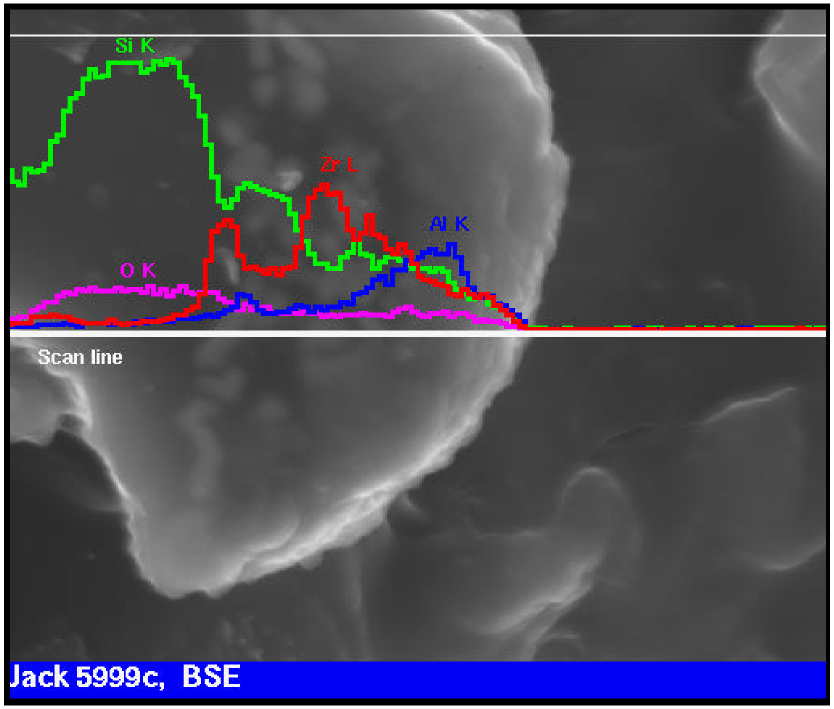
**acetylacetonate

Alumina/YSZ Graded Coating

Deposited on Fused Silica

Line Profiles

- 🟩 Silicon Profile
- 🟥 Zirconium Profile
- 🟦 Aluminum Profile
- 🟪 Oxygen Profile



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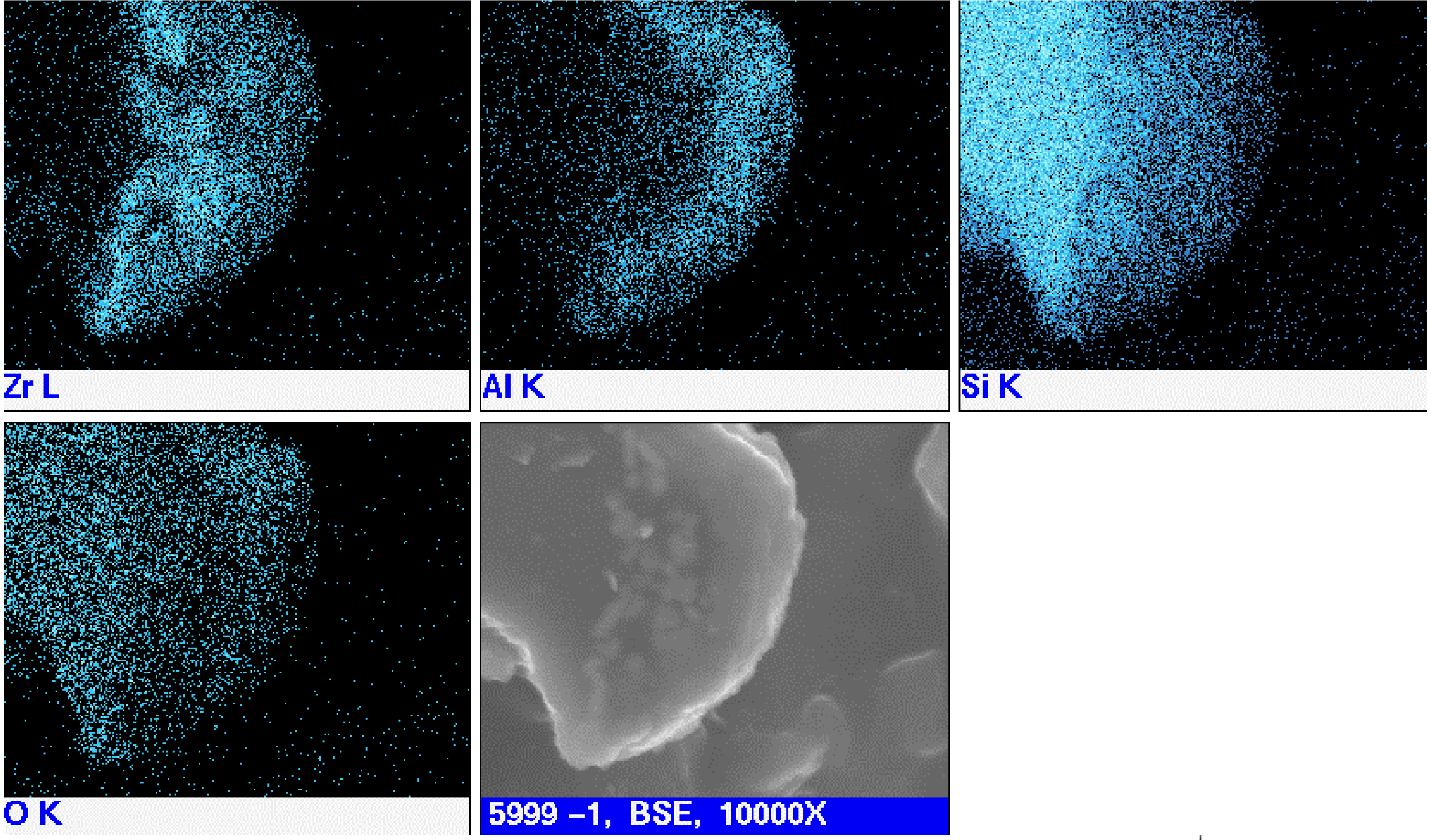
X-Ray Dot Maps of Alumina/YSZ Graded Coating

Deposited on Fused Silica



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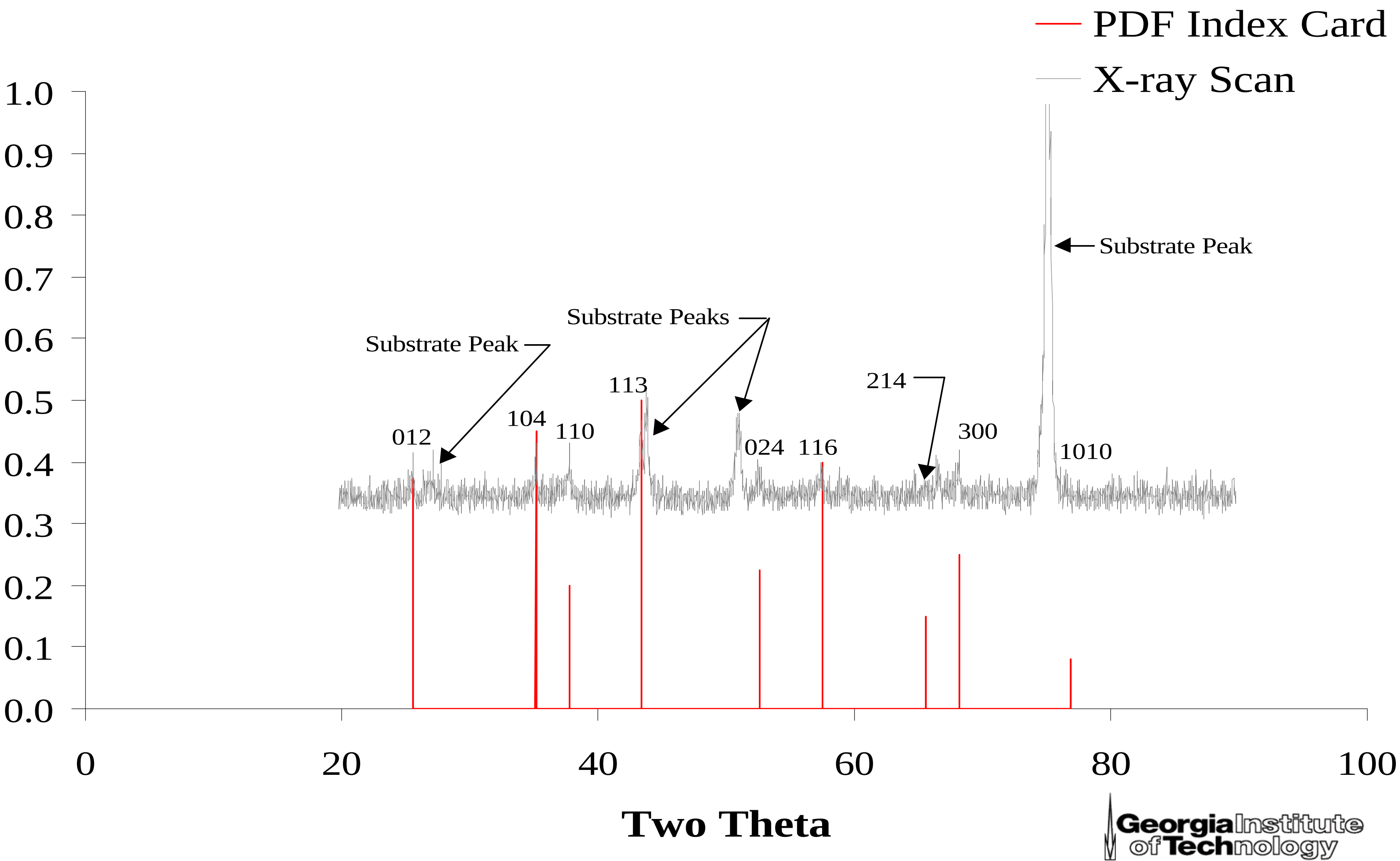
Process Parameters for α–Alumina Coatings

Solvent	Isopropanol
Precursors:	Aluminum acac**
Solution Flow Rate	2 ml/min
Precursor Concentration	0.002 M
Oxidizer	Oxygen
Oxidizer Flow Rate	0.6 - 0.8 liters/min
Deposition Rate	1.8 - 3.0 µm/hr
Flame Temperature	1250 - 1450°C
Substrate	Fused Silica
	Ni, Cr Superalloy

**acetylacetonate

α-Alumina on Super-Alloy

X-Ray Diffraction Data



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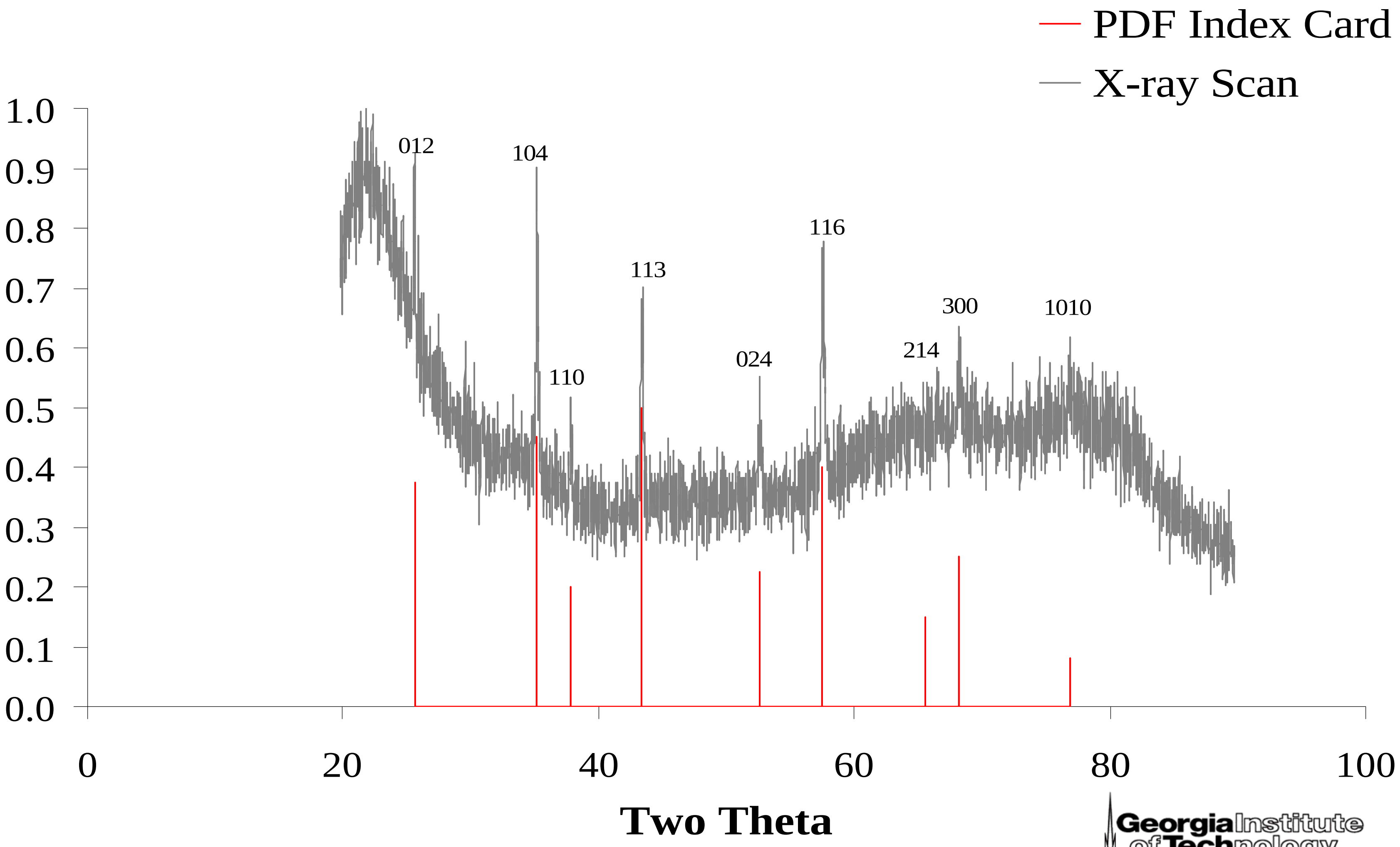
α-Alumina on Fused Silica

X-Ray Diffraction Data



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Conclusions

- Liquid fuel Combustion CVD can be used to deposit YSZ/alumina composite, YSZ/alumina graded, and alpha alumina coatings.
- Fracture toughness of YSZ/alumina composite coatings increases with increasing amounts of alumina (up to 30 mole percent).

Acknowledgments

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