DOE Workshop on EBCs: Microturbines and Industrial Gas Turbines

A POTENTIAL NEW NDE TOOL FOR CHARACTERIZING EBCs

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ENVIRONMENTAL BARRIER COATING WORKSHOP
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OUTLINE OF PRESENTATION

- PURPOSE AND BRIEF NOTES ABOUT PREVIOUS NDE EFFORTS FOR EBCs
- BRIEF DESRIPTION OF LASER BACK SCATTER NDE AND RESULTS FOR TBCS
- OPTICAL COHERENCE TOMOGRAPHY AS AN NDE TOOL
  - WHAT IS OCT
  - ADVANTAGES/DISADVANTAGES OF OCT
- SUMMARY

Purpose

Develop non-contact, nondestructive technologies that can provide “status” (“health”) information for EBCs:

- Components with an EBC(Composites and monolithics)
- Defect types
  - Delaminations: Size and Location
  - Thickness variations
  - Pre-spall conditions
  - Extent of FOD

EBCs UNDER STUDY BY NDE TECHNOLOGIES

- EBCs FOR SIC/SIC COMPOSITES
  - MAINLY FORMS OF BSAS
    - COOPERATIVE EFFORT WITH UTRC, SOLAR TURBINES AND ORNL
- EBCs FOR OXIDE/OXIDE COMPOSITES
  - PROPRIETARY MATERIALS FOR EBC
    - COOPERATIVE EFFORTS WITH SIEMENS-WESTINGHOUSE POWER SYSTEMS AND COMPOSITE OPTICS
- EBCs FOR MONOLOTHICS
  - MAINLY FOR SI3N4
    - COOPERATIVE EFFORT WITH HONEYWELL ENGINES AND SYSTEMS, NORTHWESTERN UNIVERSITY AND ORNL

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NDE TECHNOLOGIES FOR EBCs ON SIC/SIC COMPOSITES

--COOPERATIVE EFFORT WITH SOLAR TURBINES, UTRC AND ORNL

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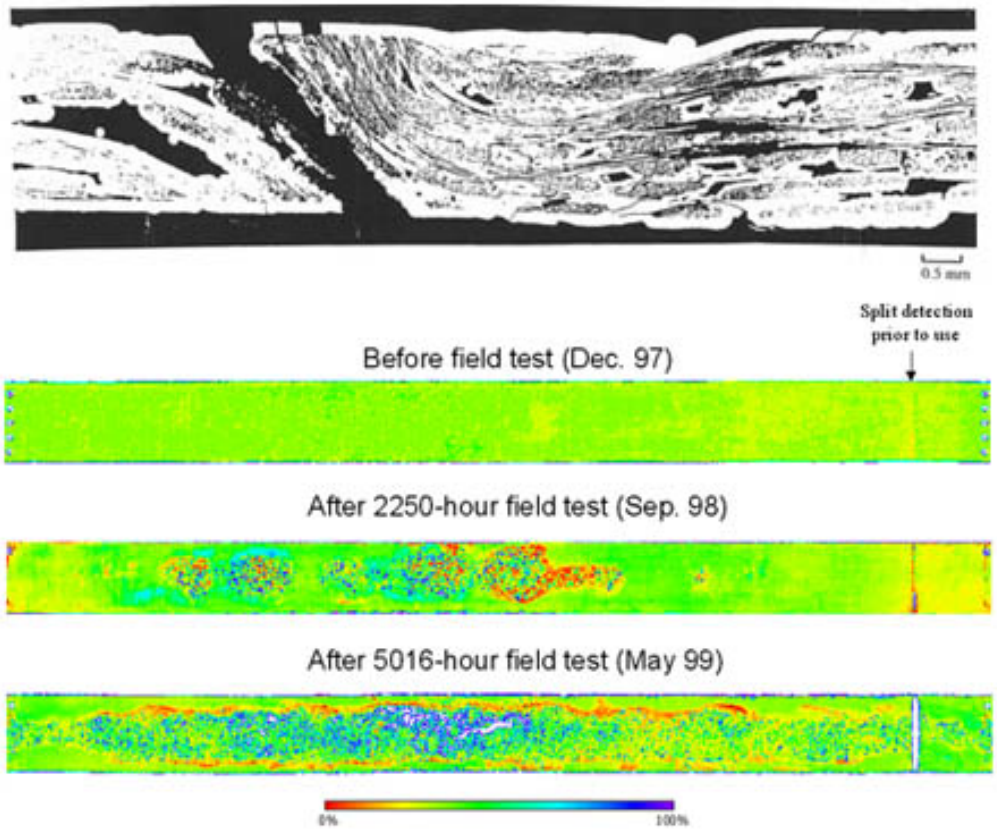
EBC ON SIC/SIC LINER

NDE DATA HAVE BEEN SHOWN TO PROVIDE PRE-CURSOR TO SPLITTING OF THE LINER

THROUGH WALL SPLIT



NDE DATA HAVE DETECTED PRE SPALL LOCATIONS OF EBC

357 hrs.

1573 hrs.

Boroscope Images provided by Solar Turbines, Inc.

SCHEMATIC OF ELASTIC OPTICAL BACKSCATTER NDE EXPERIMENTAL TEST SETUP

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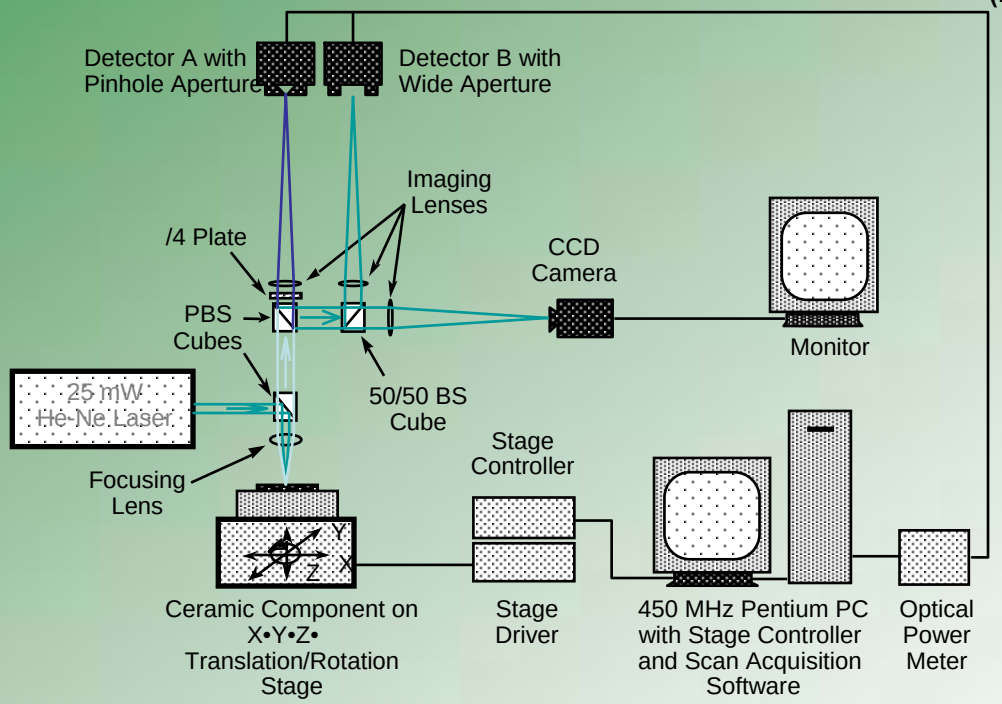

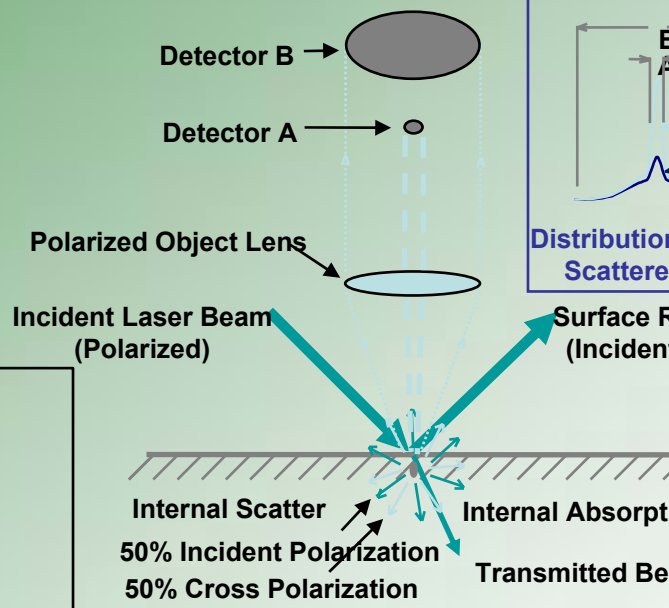

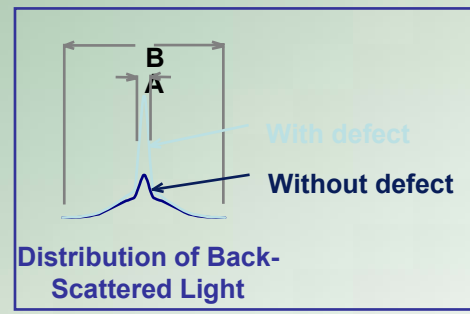

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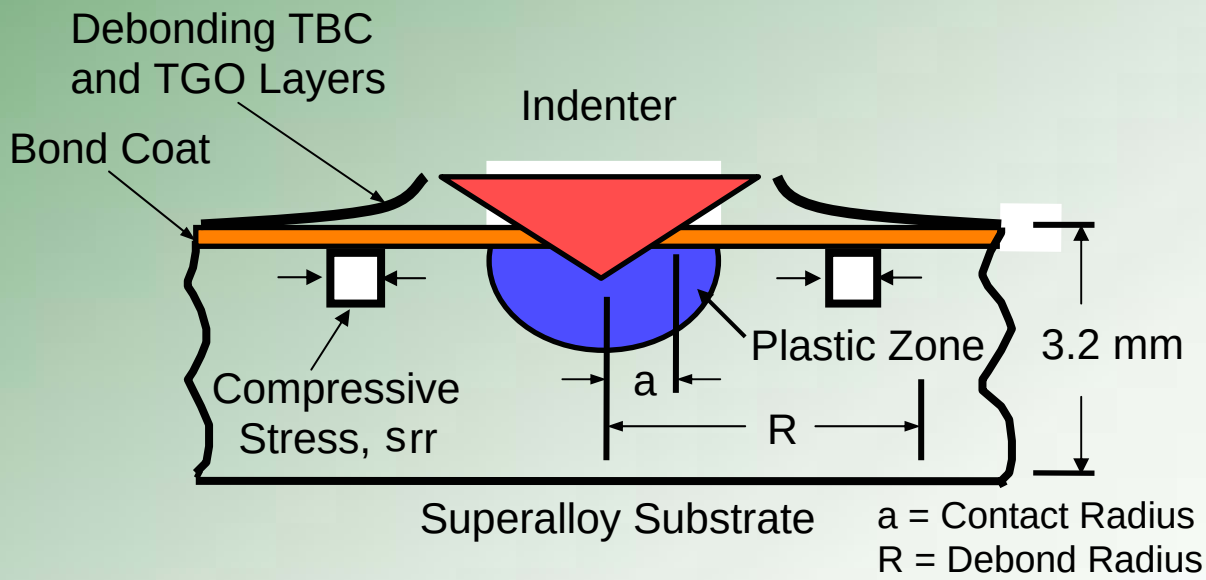
CORRELATING LASER BACK SCATTER TO KNOWN INDENT DAMAGE LEVELS USING TBCs

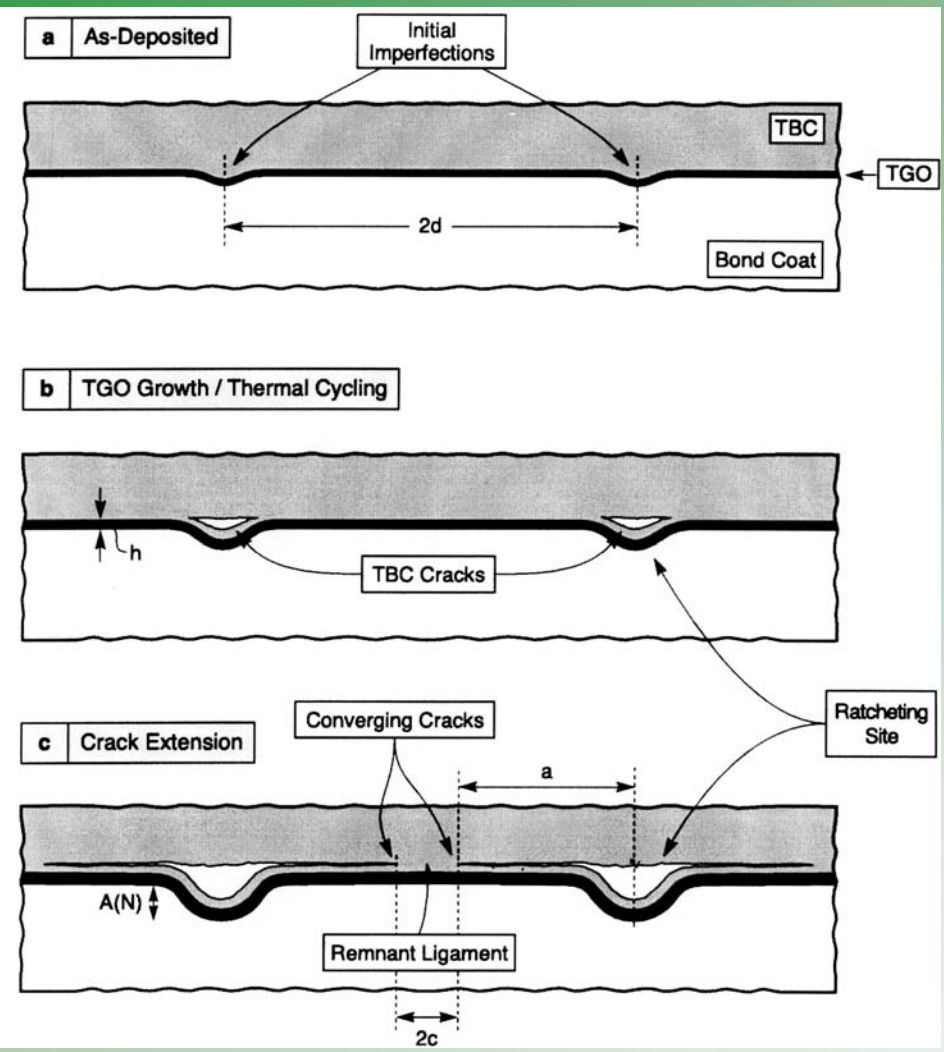
Note: Tests are on YSZ TBC

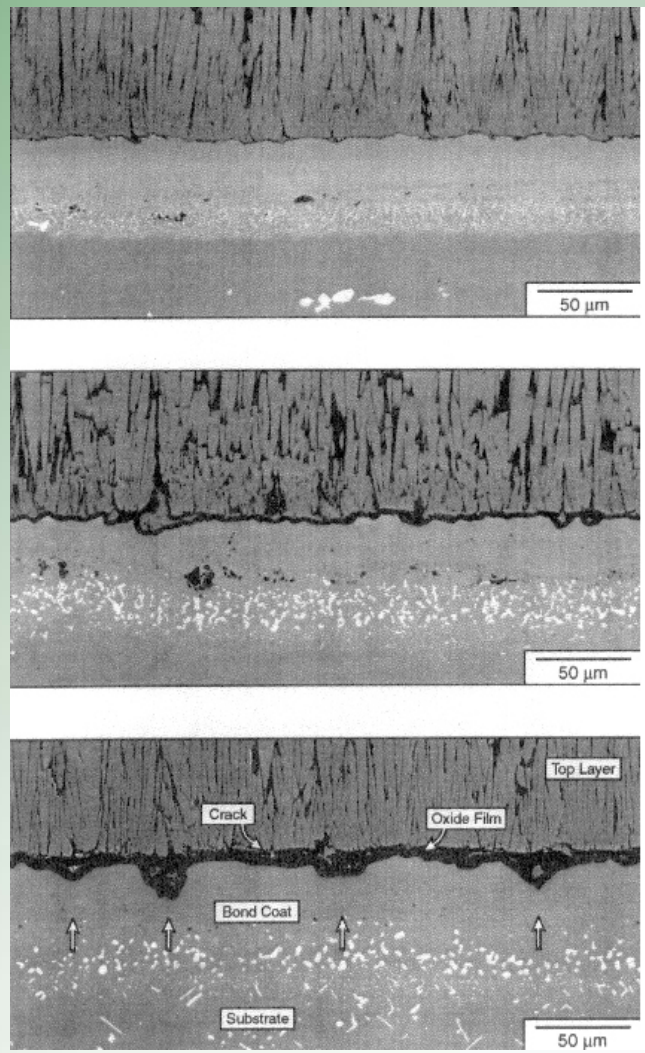
Indentation Test for Interfacial Toughness



From G. Meier, Univ. of Pittsburgh

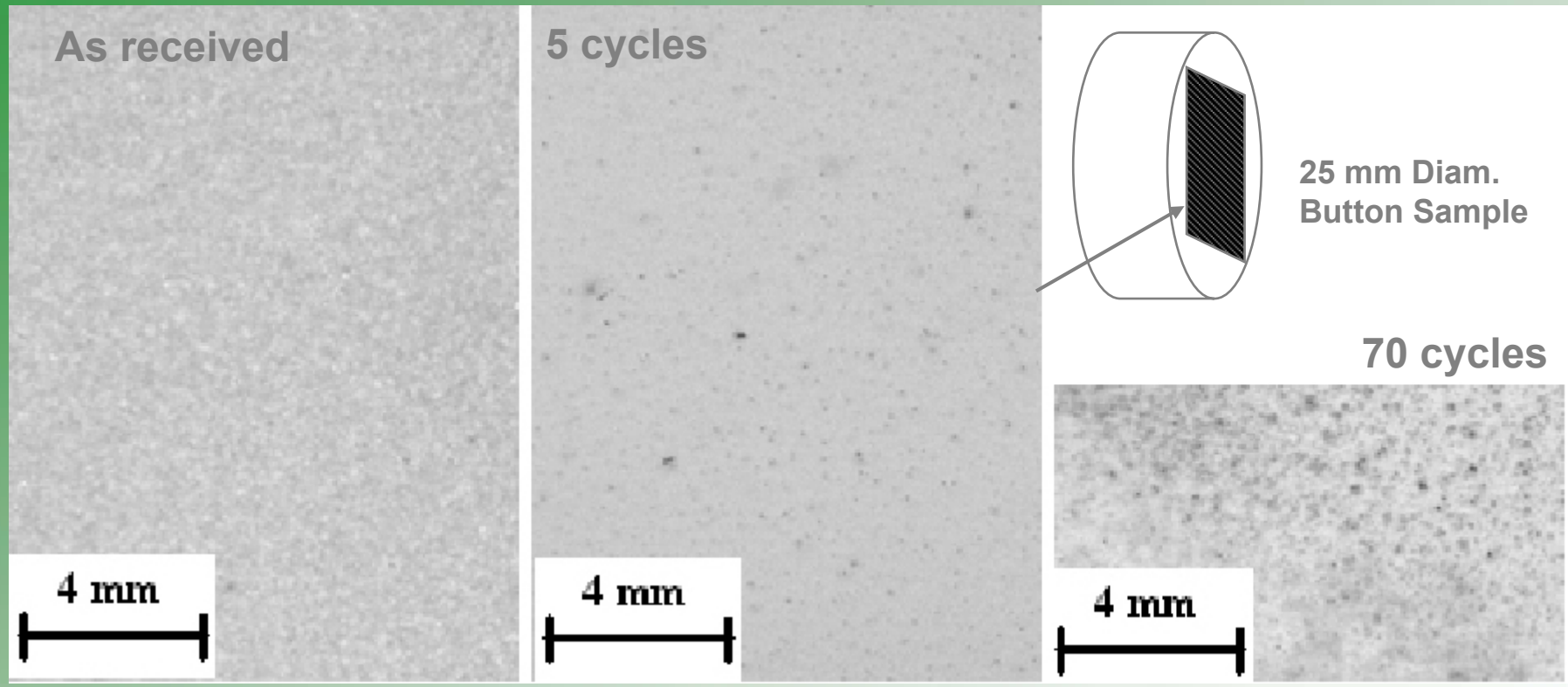
MECHANICS OF SPALLATION OF TBC -ONE THEORY

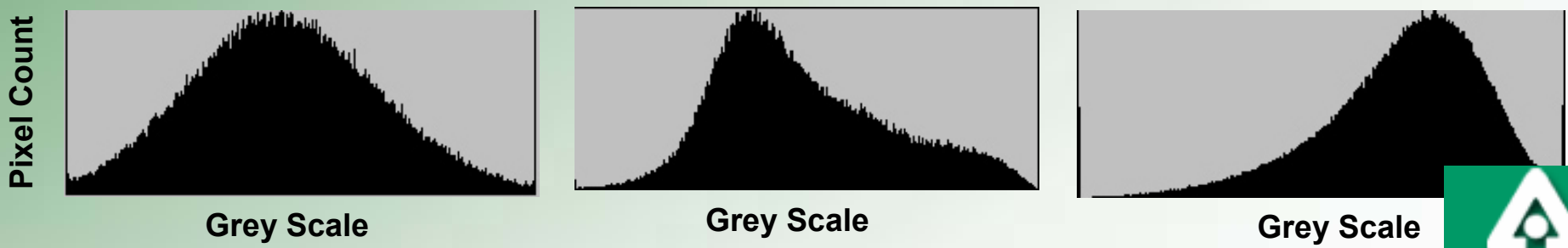




After: Evans et. al, Princeton

LASER SCATTER NDE DATA FROM THERMALLY CYCLED EB-PVD TBC





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Correlation of Laser NDE Data with Other Methods and Optical Data

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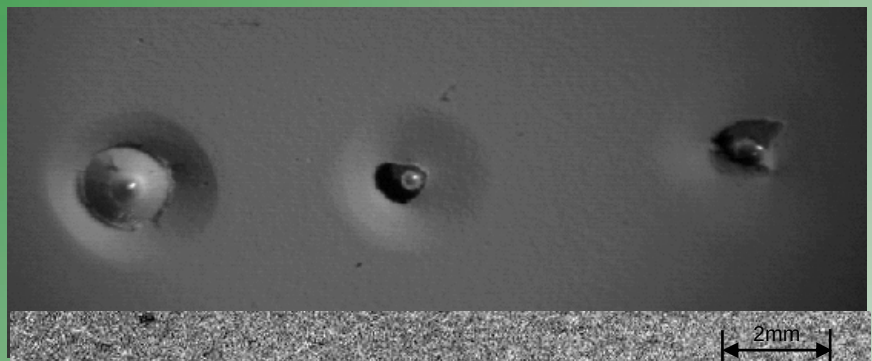
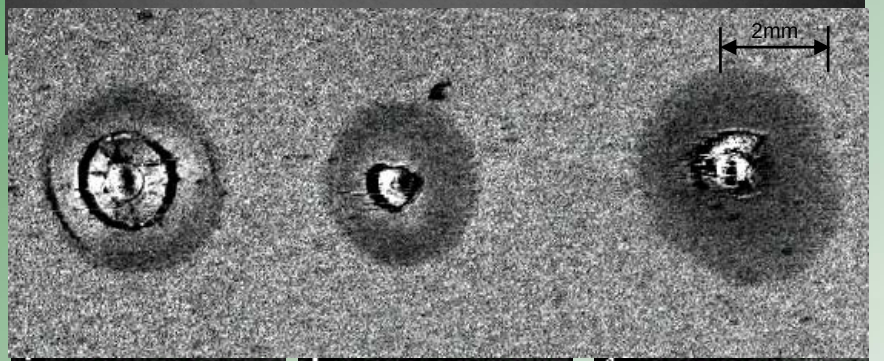
Note: These are for EB PVD, YSZ, TBC

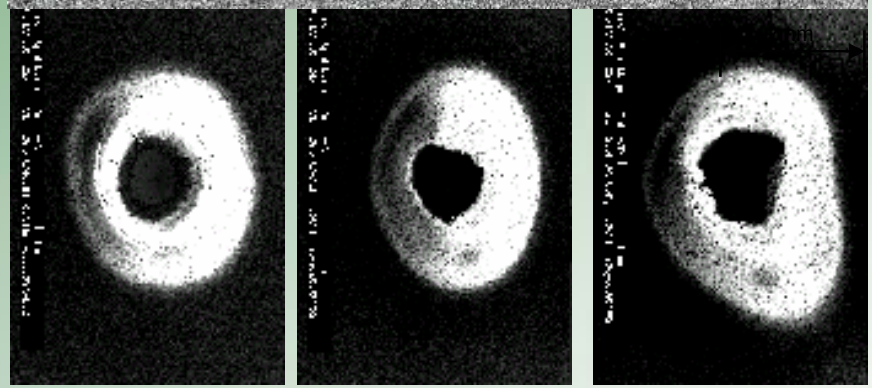
Initially indented after 50 cycles	Initially indented in as-processed condition	Indented after 170cycles



Optical Macrograph



Laser Scatter Image(debonds appear dark)



SEM Charging Image(debonds appear light)

Cycles	R SEM (mm)	R Backscatter (mm)	% Diff
0	1.39	1.40	0.7
50	1.60	1.66	3.8
170	1.74	1.82	4.6

From G. Meier, Univ. of Pittsburgh

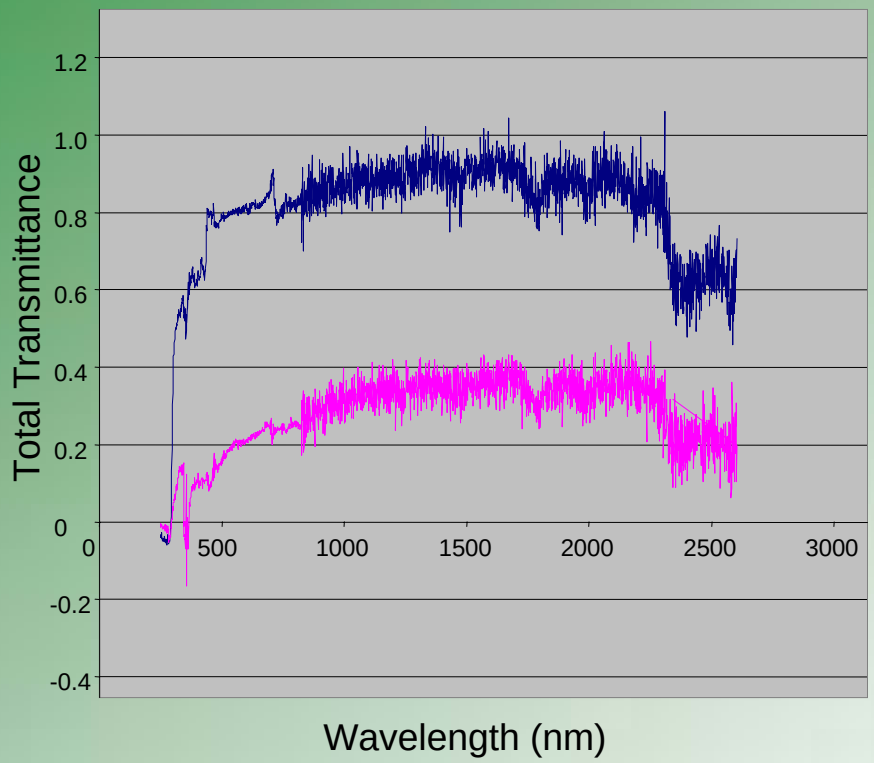
Si_3N_4 Vanes with EBC

All were Honeywell AS800

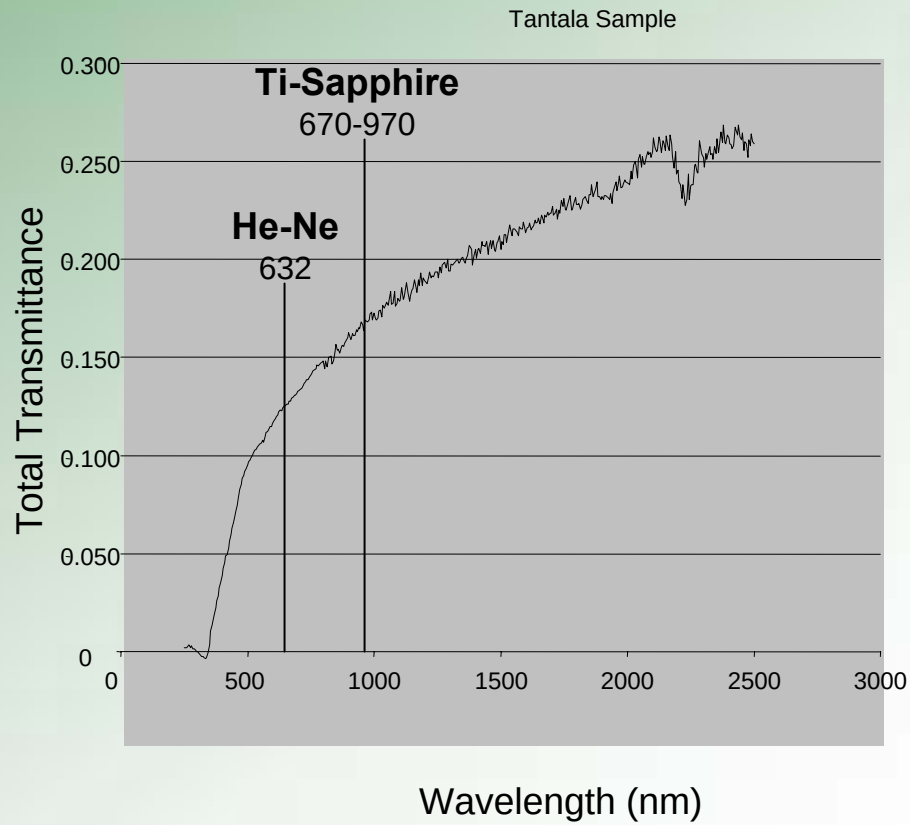
- All coated with tantalum oxide EBC:plasma sprayed
- All either as-received or run in Rolls Royce/Allison 501-KB 4MWe natural gas fired gas turbine
  - 0, 542 and 1621 hours exposure

Optical Transmission Characteristics for Two EBCs for Monolithics

Honeywell EBC



Northwestern EBC



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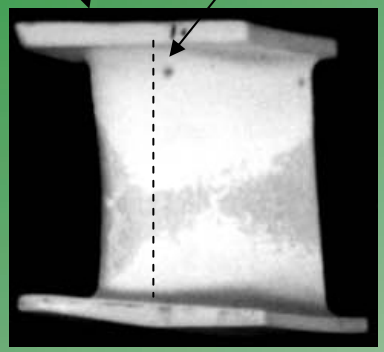
Correlation EBC thickness to elastic optical scatter intensity on AS 800 vane after 1621hrs. [Suction Side]

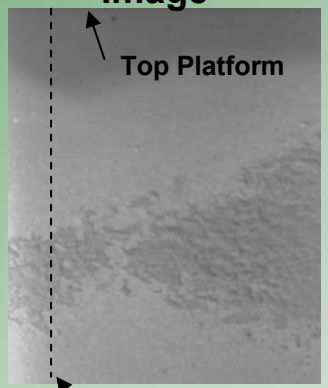
Top Platform

Optical Photo Micrograph



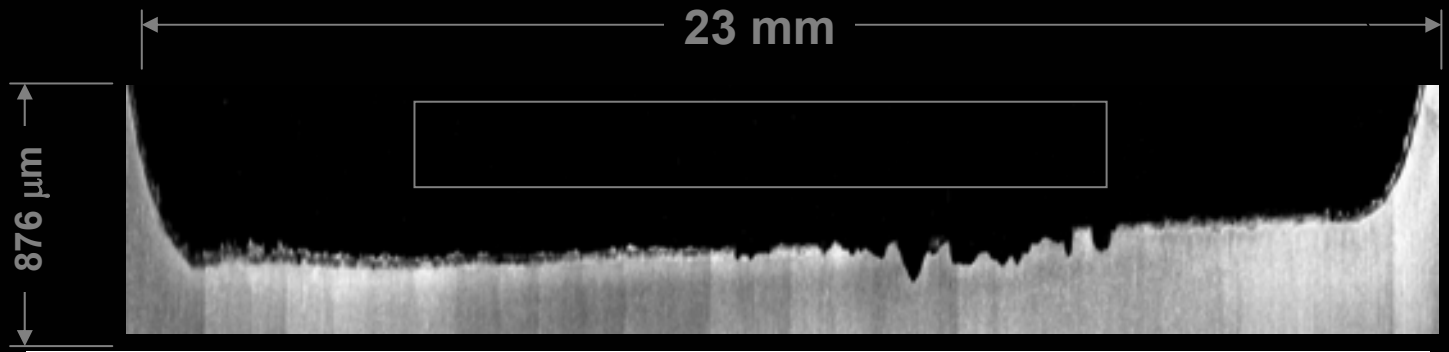
Photograph

Optical Laser Scatter Image



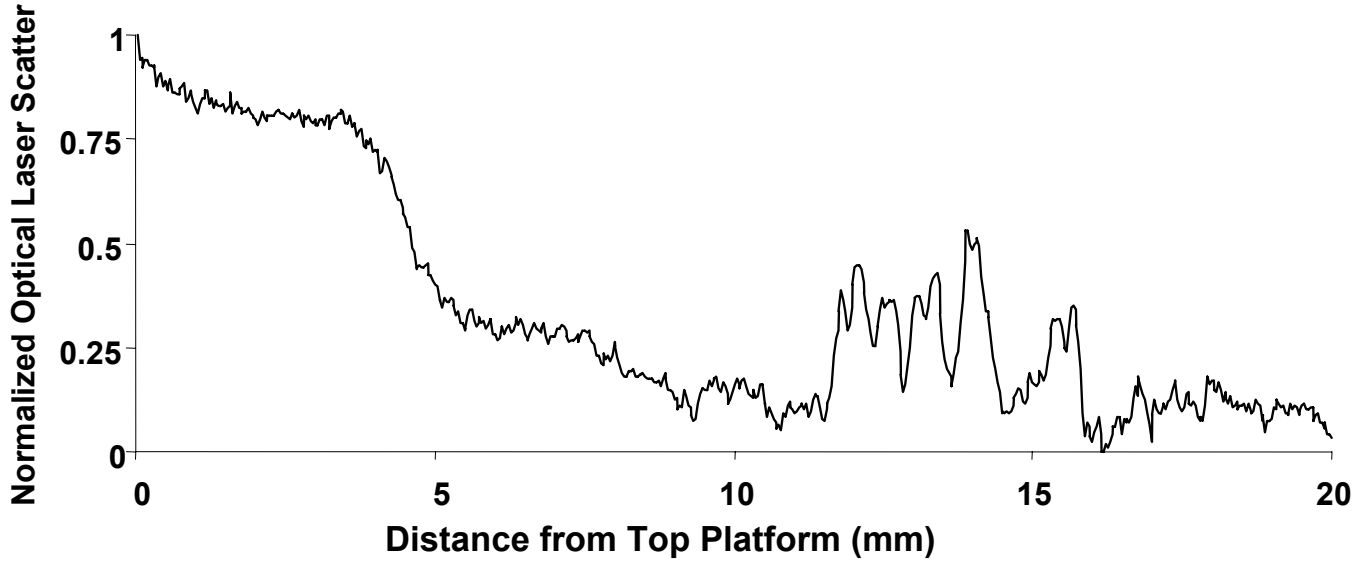
Line Scan

Top Platform



$$1 - \frac{\text{value}(x) - \min}{\max - \min}$$

Elastic Optical Scatter Line Scan



Argonne's Optical Coherence Tomography System

Provided by Saint Gobain Ceramics and Plastics

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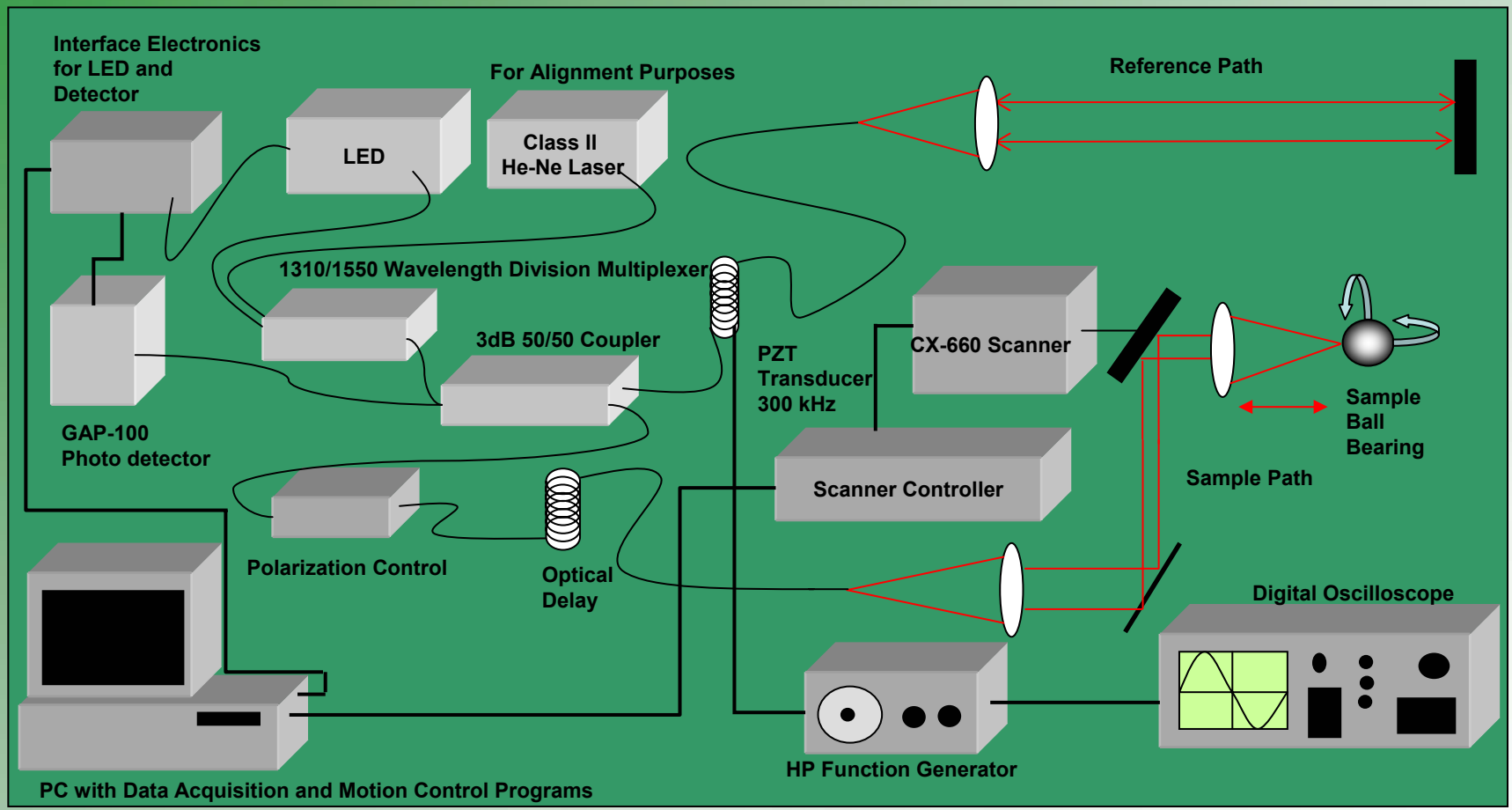

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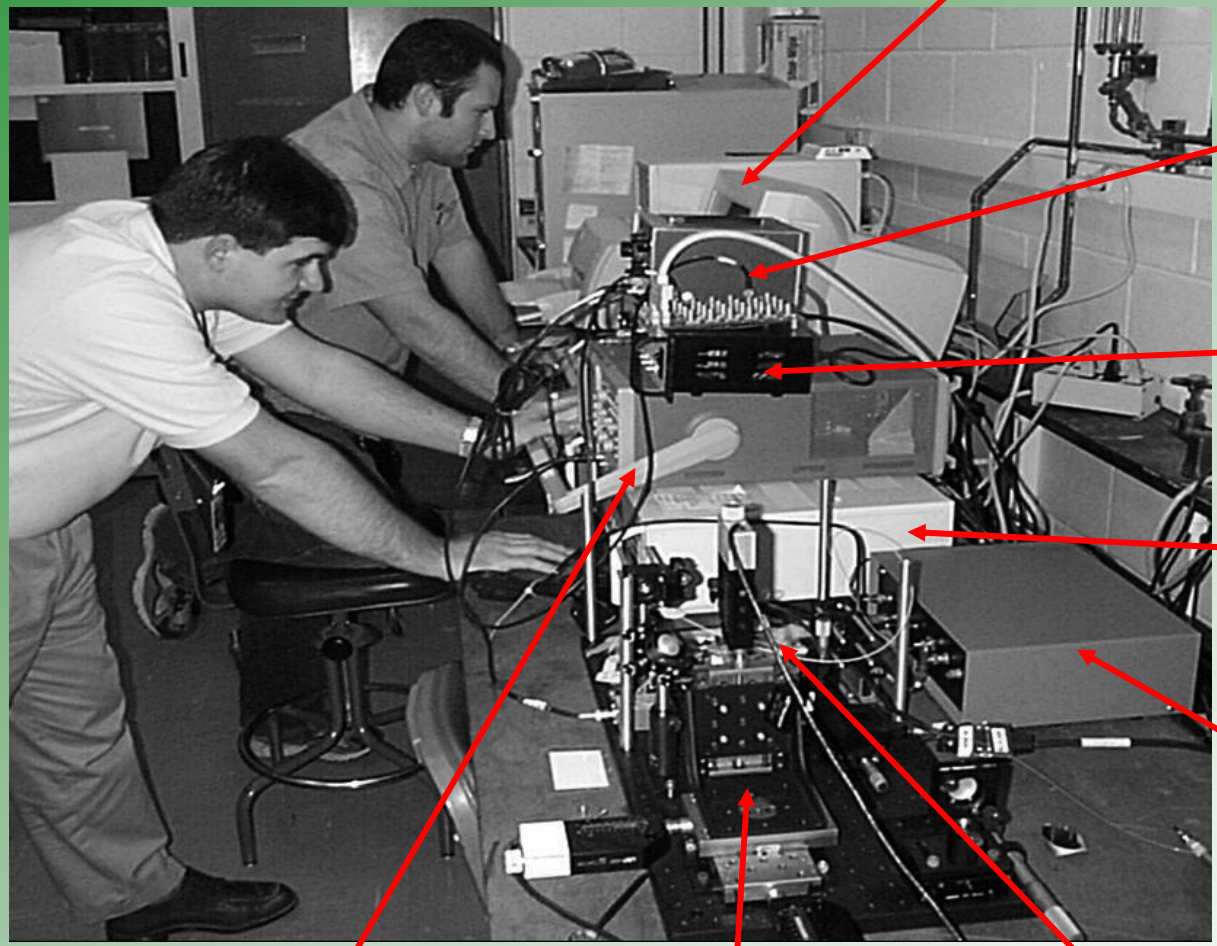

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OCT Cross-Sectional Plane Scans

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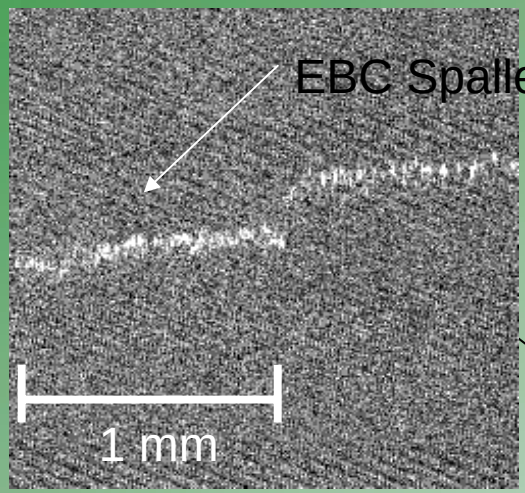
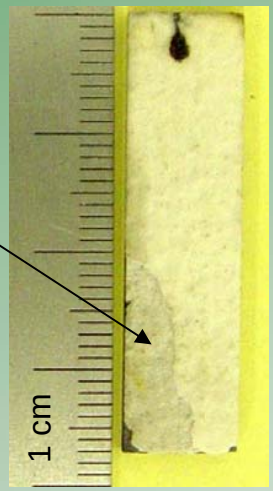
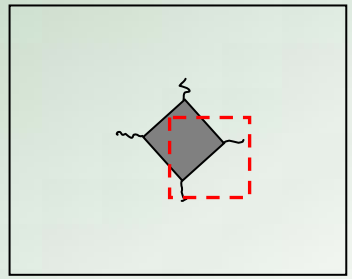
Vertical Cross-Section of EBC Spall BSAS on SiC/SiC

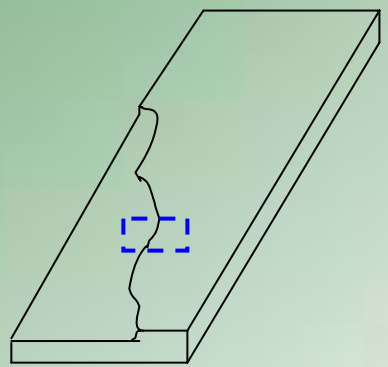


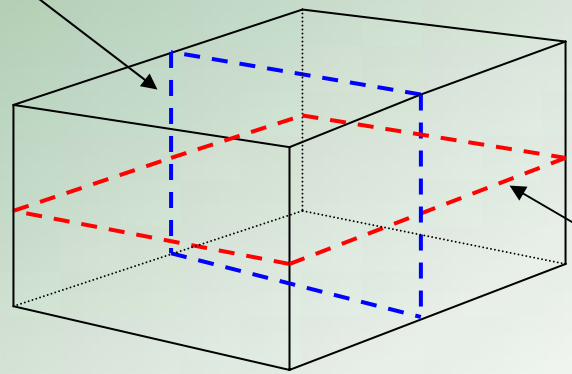


Horizontal Cross-Section of Vickers Indent (20kg) on Saint Gobain NBD-200

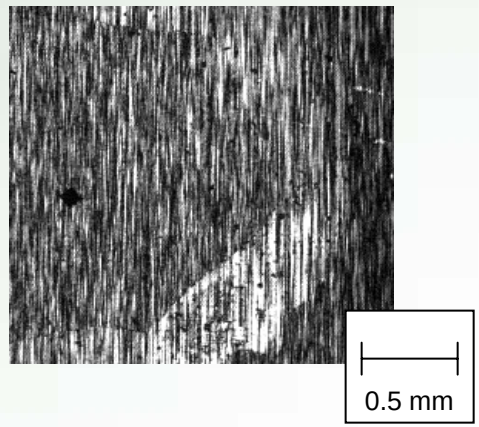
Horizontal View (Red)



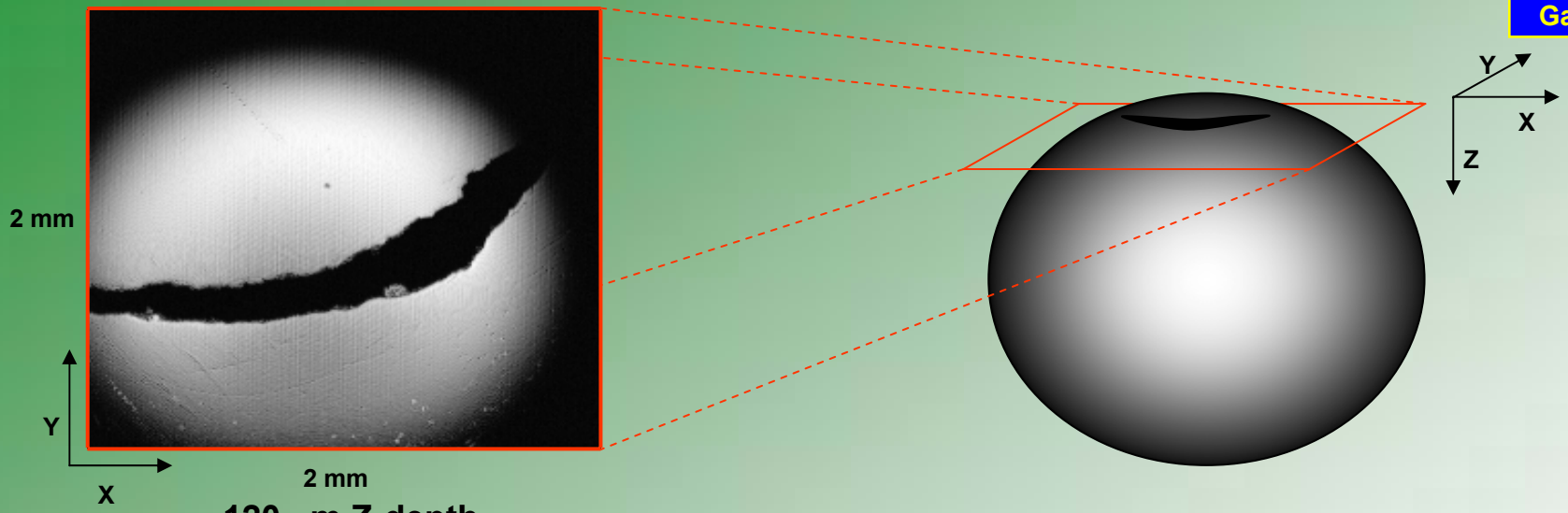




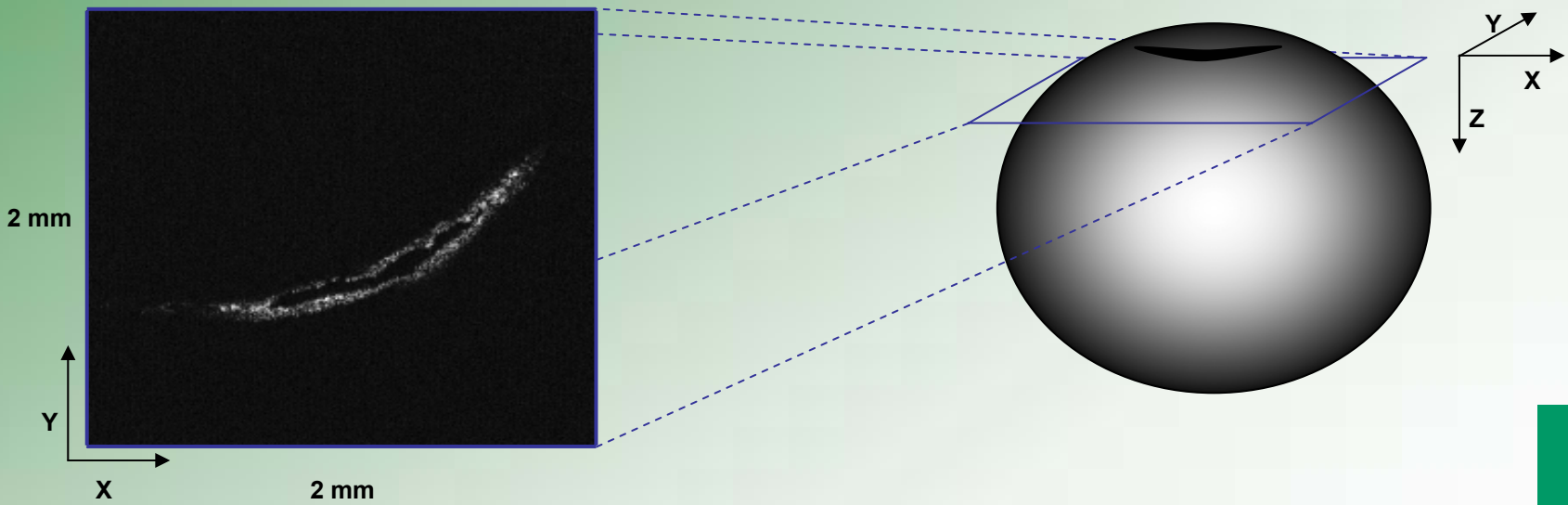
~20 µm below surface



*Norton 3G CB S-01 Si_3N_4 Ball Bearing with 3.3-3.4 g/cm^3 density



120 μm Z-depth



370 μm Z-depth

*Images provided by Saint-Gobain/Norton Industrial Ceramics Corp.

OCT System Comments:

- Low Coherence (High Bandwidth) light is required to generate an interference pattern that can be adequately measured given current electronic hardware constraints.

- Up to 75% of the optical power supplied by the source does not contribute to image formation in the typical OCT system due to power loss in optical components.*

- For a source with Gaussian spectral distribution (e.g. laser diode), depth resolution is directly proportional to the square of wavelength and inversely proportional to coherence length.

$$\Delta z = \frac{2 \ln 2}{\pi} \frac{(\lambda^2)}{\Delta\lambda} *$$

- Transverse resolution is the same as conventional optical microscopy (determined by focusing properties of optical beam)

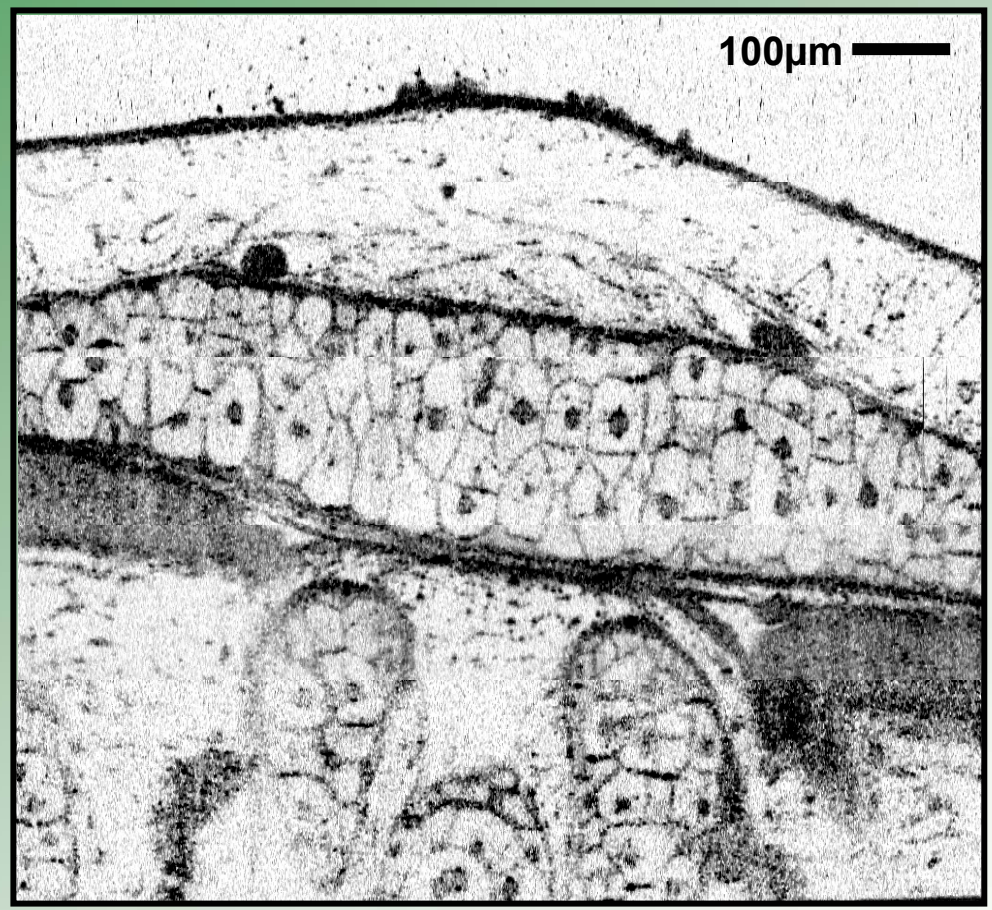
$$\Delta x = \frac{4\lambda}{\pi} \frac{(f)}{d} *$$

where f is focal length of the objective lens and d is the spot size on the sample.

*Bouma, B.E., and Tearney, G.J., ed. *Handbook of Optical Coherence Tomography.* Marcel Dekker, Inc. New York: 2002.

EXAMPLE OF VERTICAL PLANE RESOLUTION IF HIGH LASER PENETRATION

In Vivo Cellular Imaging

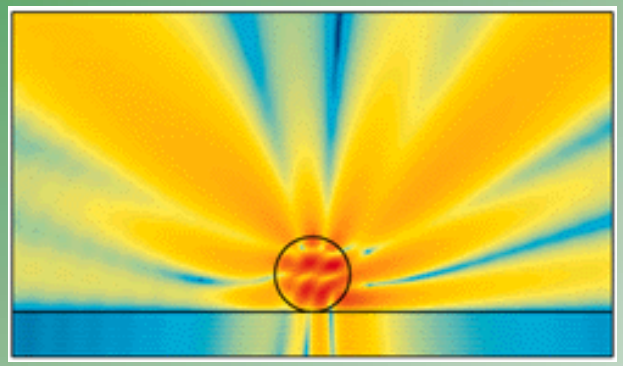


Model Development EM Flex Application and Overview

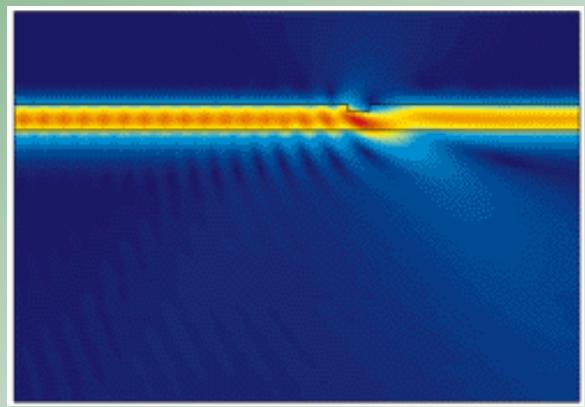
Maxwell's Equations

$$\nabla \times \mathbf{H} - \frac{\varepsilon}{c}\frac{\partial \mathbf{E}}{\partial t} = \frac{4\pi\sigma}{c}\mathbf{E}, \quad \nabla \times \mathbf{E} + \frac{\mu}{c}\frac{\partial \mathbf{H}}{\partial t} = 0$$

$$\nabla \cdot \mathbf{E} = 0 \quad \nabla \cdot \mathbf{H} = 0.$$



Scattered Field Plot



Guided Wave Scattering by a single defect

- Uses time-domain finite element solution to Maxwell's Equations
- Can process fields at optical wavelengths
- Capable of modeling TEM, TE, and TM polarizations
- Typical Applications:
  - Optical Scattering
  - Photolithography
  - Integrated Optics

Summary

- NDE Technologies are under development for several types of EBCs
  - For SiC/SiC Composites
  - For Oxide/Oxide Composites
  - For Si3N4 Monolithics
- Elastic optical laser scattering is under development to characterize EBC coatings for determining uniformity of thickness, detecting and sizing delaminated regions, estimating size and extent of FOD
  - Results to date suggest sensitivity to thickness variations e.g. erosive wear
- A New laser-based NDE method, OCT, likely will allow cross-sectional information as well as in-plane information below the surface
- An analytical model for parametric studies of laser back scatter is now in place and is being evaluated