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Fabrication of Yttrium-Aluminum-Garnet:Dysprosium Phosphorescent Coating Using the Aerosol Deposition Technique

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What is Dysprosium Doped Yttrium-Aluminum-Garnet (YAG:Dy)

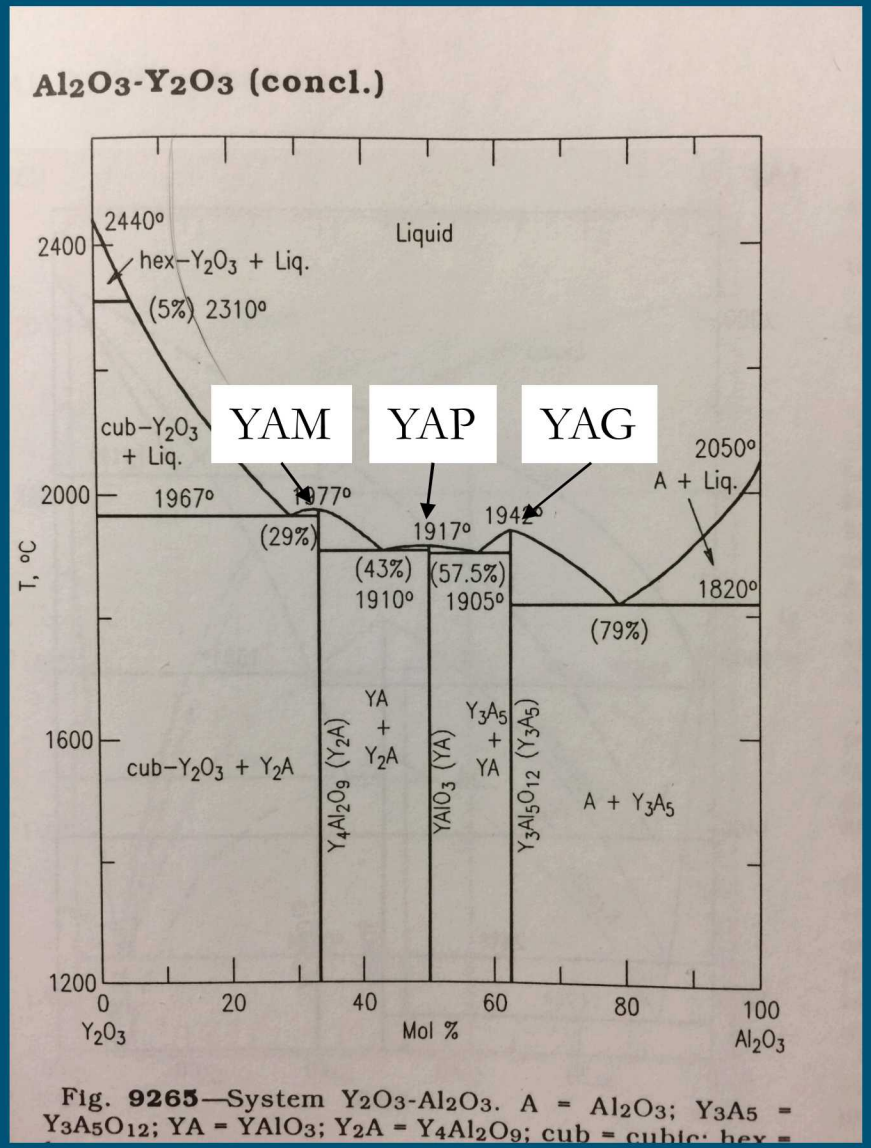


Fig. **9265**—System Y_2O_3-Al_2O_3. A = Al_2O_3; Y_3A_5 = $Y_3A_5O_{12}$; YA = $YAlO_3$; Y_2A = $Y_4Al_2O_9$; cub = cubic; hex =

- YAG:Dy is a ceramic matrix material that is doped with 1-3% Dysprosium to give phosphorescent properties
- Single crystal YAG is transparent to a wide range of wavelengths and used in high energy laser systems
- Dysprosium phosphorescence gives off a light spectrum when excited by a laser according to
  - The resulting spectrum can be correlated to temperature

Current Limitations of Phosphor Coatings

Thermographic phosphors look to replace IR sensing technology:

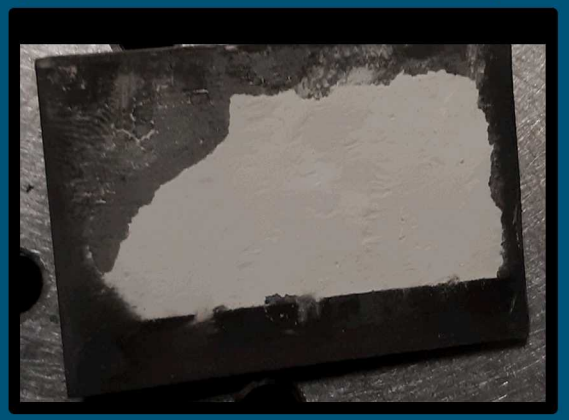
- Emissivity differences can alter IR measurements
- Less signal is lost to surrounding blackbody radiation at these phosphorescent wavelengths (450-490nm) compared to IR (>700nm)

Current state-of-the art YAG:Dy coatings use binders (paints and epoxies) or melt deposition processes:

- Temperature is limited to pyrophoric limit of binder
- Sintering and plasma spray techniques use high temperatures which induce damage to substrates and coatings.

Epoxy Mixed Phosphor

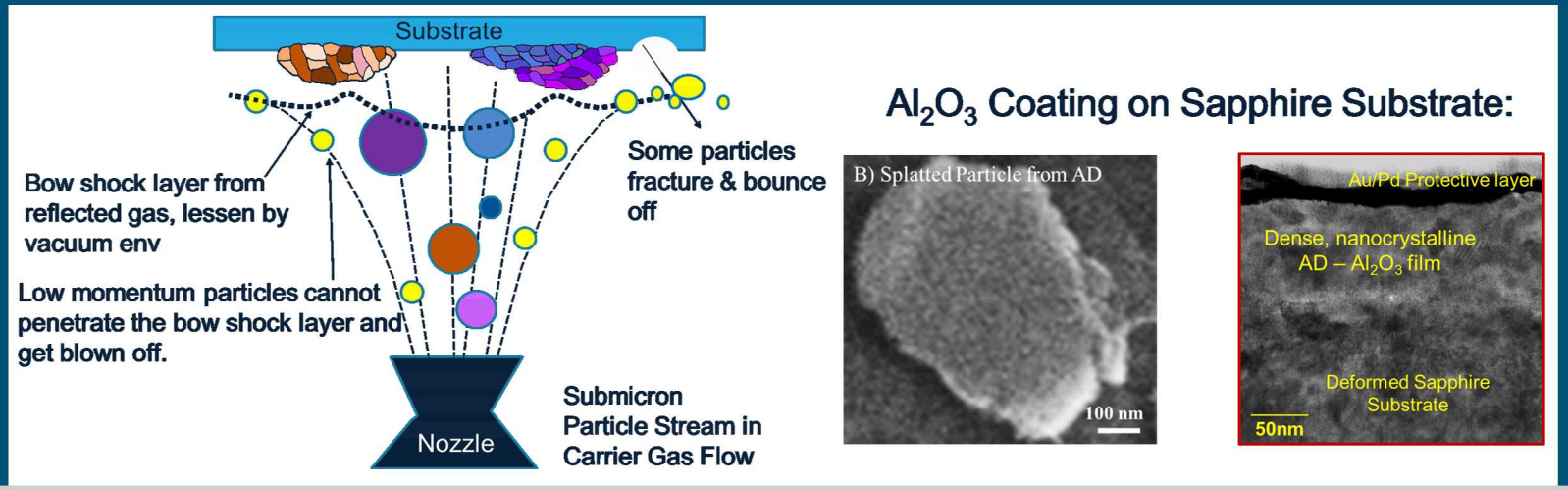
Ethanol Mixed and Dried



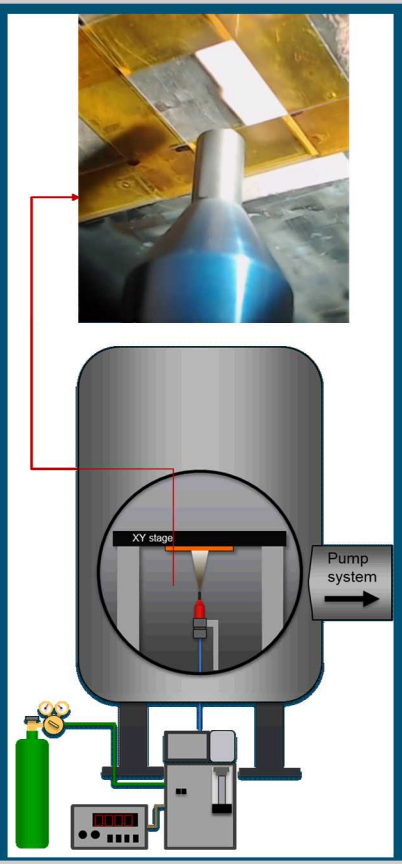
Aerosol Deposition Process

Aerosol Deposition (AD) is a room temperature impact consolidation process that uses micron sized dry powder to create dense coatings of ceramics, metallics, and other materials.

- Nitrogen or Helium carrier gas to form aerosol
- Particles impact substrate at supersonic velocities
- Impact induces plastic deformation and mechanical bonding
- Feedstock can be mixed and co-sprayed to produce unique properties of mixed ceramics



Sandia's AD Chamber:



Resulting microstructures are highly dense, consist of crystallite sizes in the 10's of nanometers, and typically contain large residual compressive stresses.

*Work on AD Al_2O_3 courtesy of Pylin Sarobol *Schematic of AD process courtesy of Jesse Adamczyk

Aerosol Deposition and Optical Transparency

- Light scattering occurs at crystallographic defects such as pores and grain boundaries. Mie scattering.
- Reducing defect size results in better transmission of light through the crystal.
- Heat treatment could reduce defect size while increasing grain size to reduce light scattering.

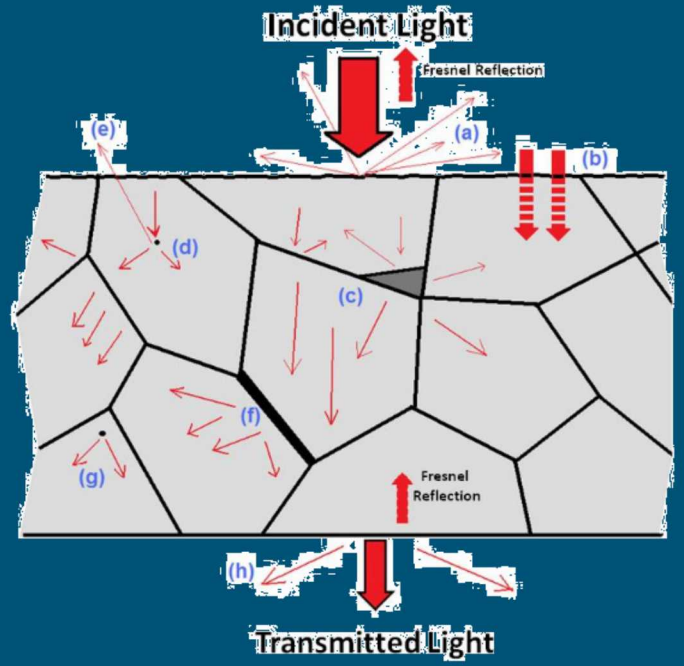


Figure courtesy of: S. Saurabh (2013), "Characterization of Light Scattering in Transparent Polycrystalline Laser Ceramics."

Optical Transparency of AD Al_2O_3

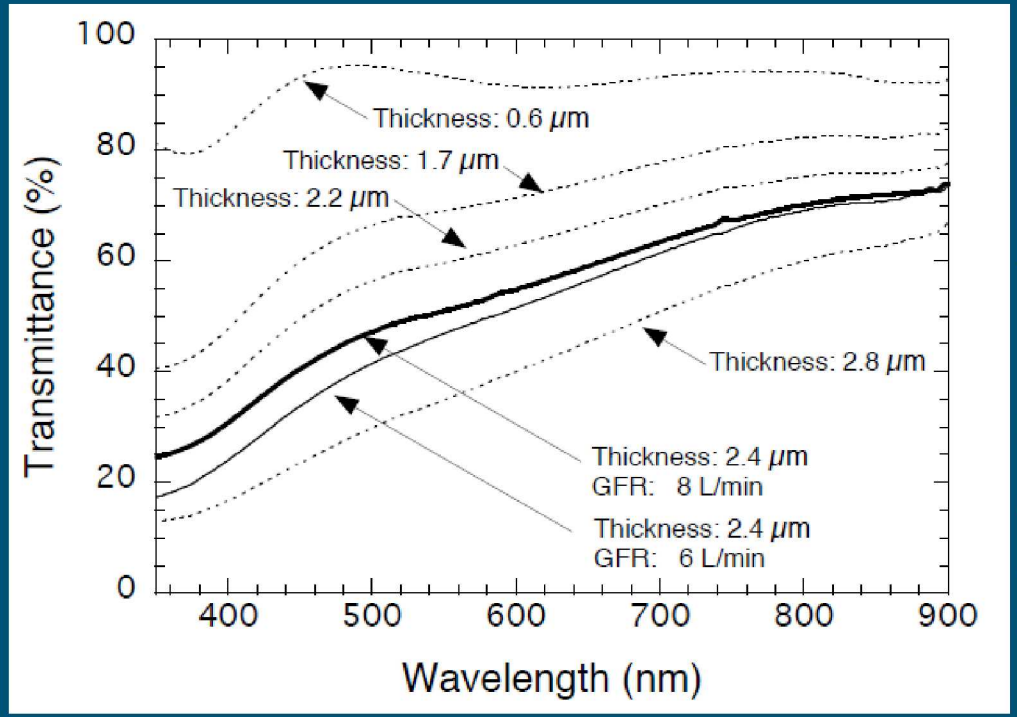
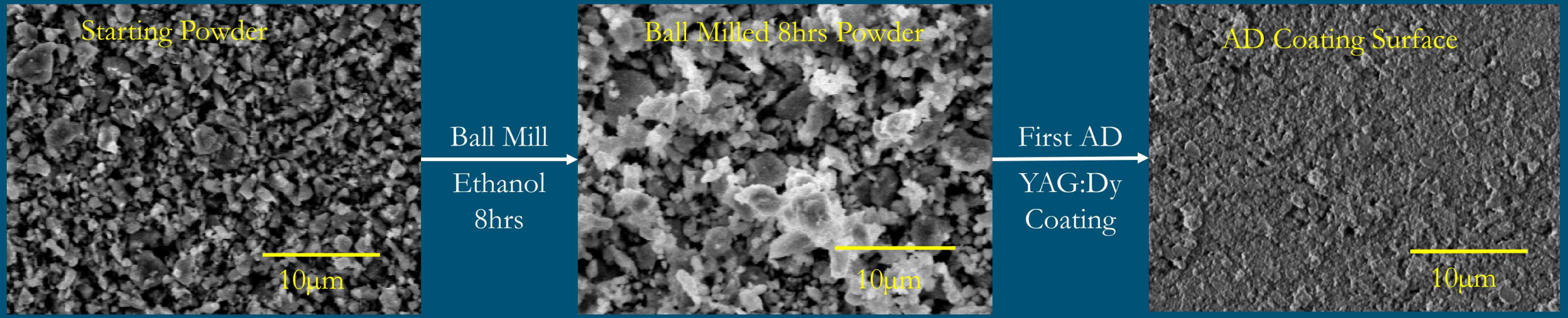


Figure courtesy of: Sato, Yuuki et al, Fabrication of Al_2O_3 Films Using Aerosol Deposition Method and Their Characterization, Conf. Ser.:Mater. Sci. Eng, **18**, 2011.

Initial Powder Preparation Prior to Aerosol Deposition

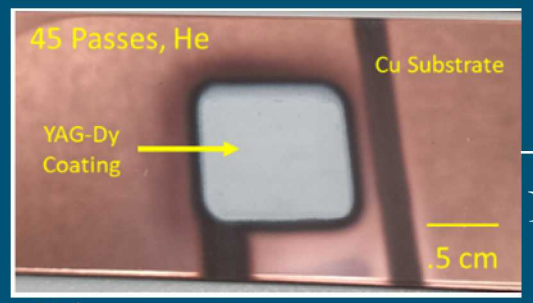
- Initial powder preparation has been shown to greatly increase deposition rate and coating quality
- Initial 1µm powder was Ball Milled using a Pulverisette 7 in ethanol at 900RPM for 20 min.
- Resulting powder was dried and deagglomerated by rolling



YAG:Dy Coatings Fabricated Using Aerosol Deposition

- Powder velocity is an essential parameter for dense transparent coating
- Converging nozzle can only reach Mach 1 gas velocities
  - Produced very porous coating, easily washed away
- Converging-Diverging nozzle produces supersonic velocities
  - Highly dense, semitransparent coating

Porous YAG:Dy coating fabricated using only converging nozzle.

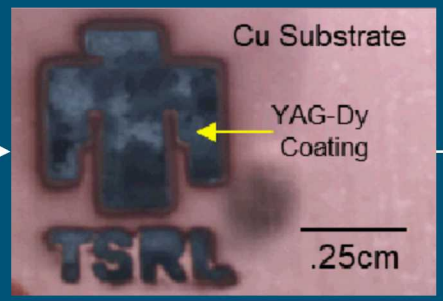


Higher porosity
Likely lower thermal conductivity
Likely lower optical transparency

Higher Velocity

Powder Pre-processing

Dense YAG:Dy coating fabricated using converging-diverging nozzle.

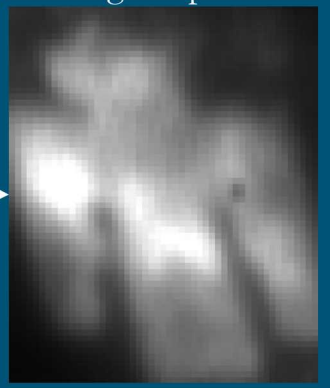


Lower porosity
Likely higher thermal conductivity
Likely higher optical transparency

Laser Excitation

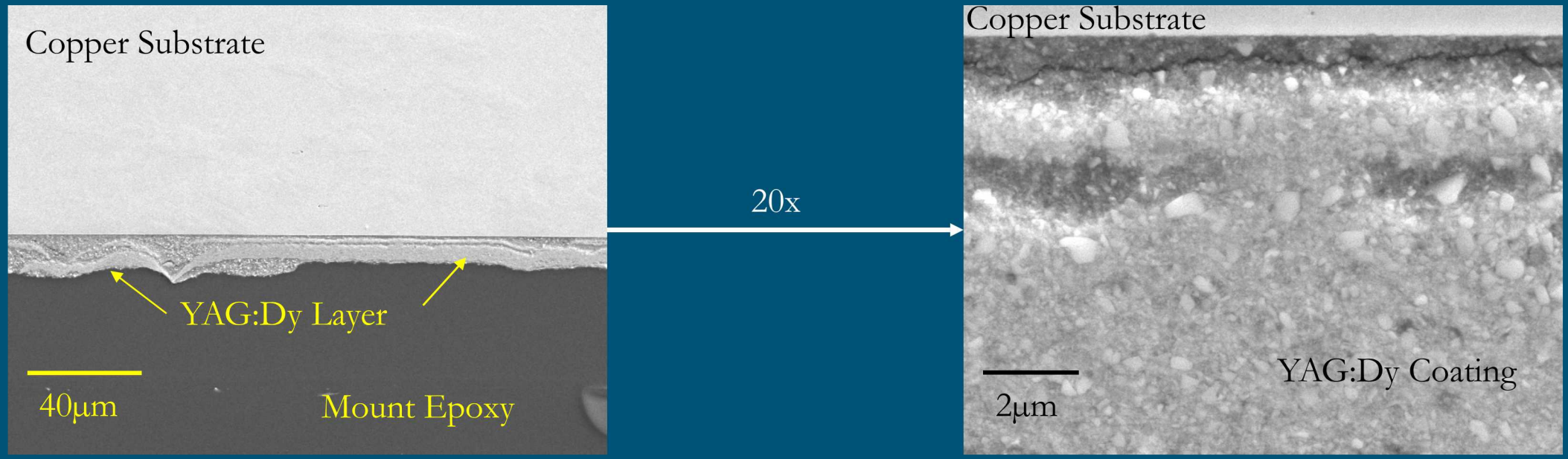
At 723K

Intensity correlated to coating temperature



Substrate oxidation limited temperature test

Microstructural Evaluation of YAG:Dy Coatings Produced with Converging-Diverging Nozzle



Two distinct regions of varying microstructure:

- Loose, large particle compaction
- Dense small particles with matrix of deformed material

- Some cracking observed at the substrate-metal interface

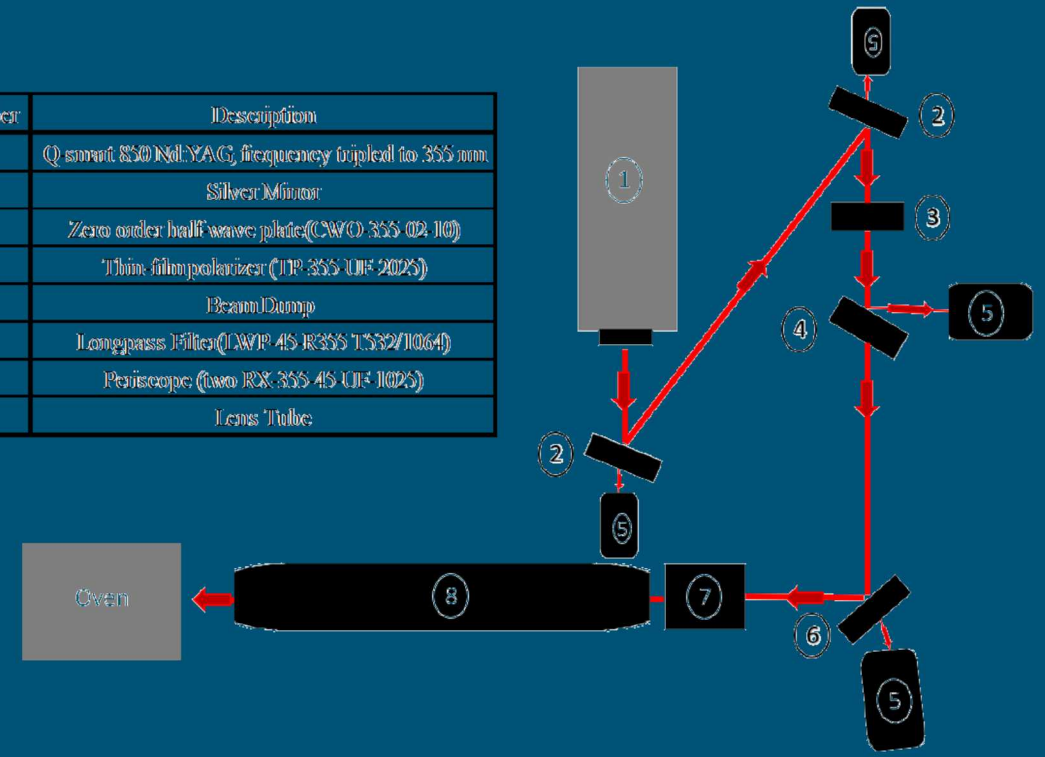
Microstructural Evaluation of YAG:Dy Coatings

Analysis of phosphorescence of AD YAG:Dy coatings is conducted using two color pyrometry

A laser is used to excite phosphor coating

Two high speed cameras capture intensity in 2-Dimensions at 455nm and 497nm

ID Number	Description
1	Q smart 850 Nd:YAG, frequency tripled to 355 nm
2	Silver Mirror
3	Zero order half wave plate(CWO 355 02 10)
4	Thin film polarizer (TP 355 UF 2025)
5	Beam Dump
6	Longpass Filter(LWP 45 R355 T532/1064)
7	Periscope (two RX 355 45 UF 1025)
8	Lens Tube



Figures courtesy of Wendy Flores-Brito and Kate Hoffmeister

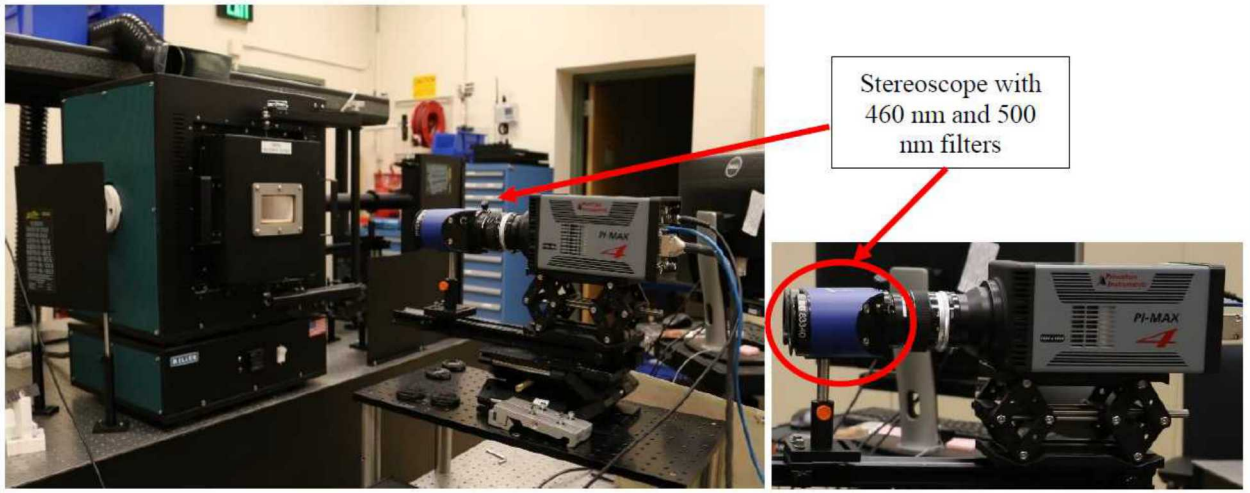
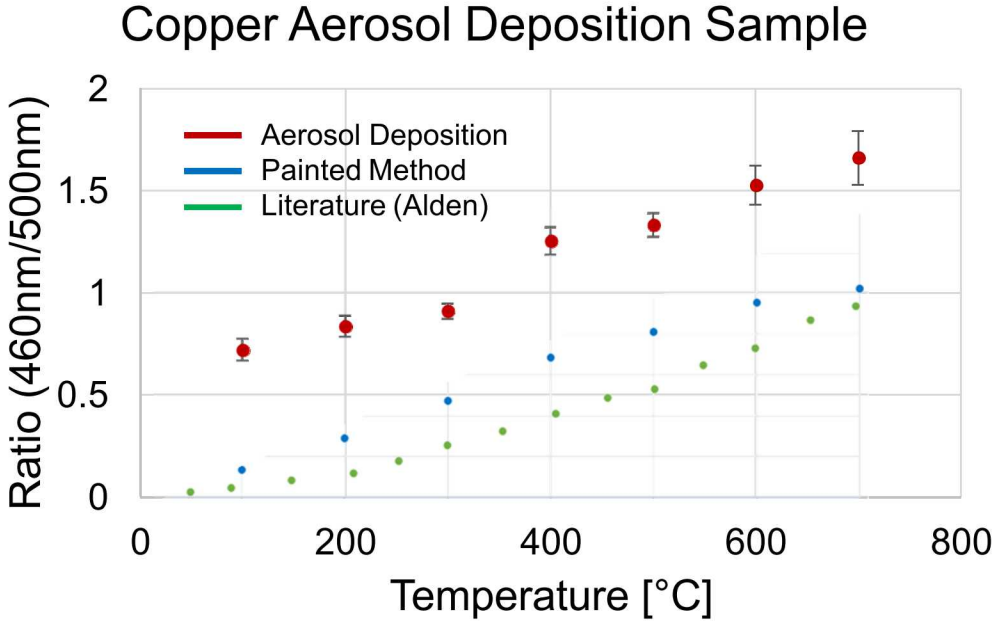
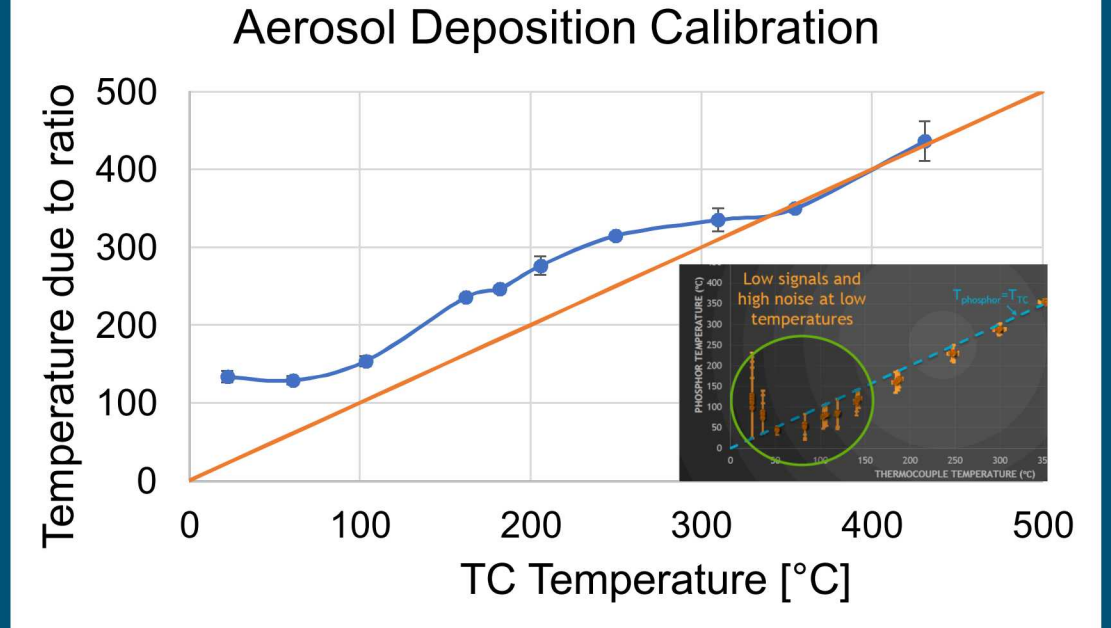


Fig. 7 PI-MAX4 aimed at the sample inside the oven.

Thermographic Phosphor Calibration Curves for Aerosol Deposition





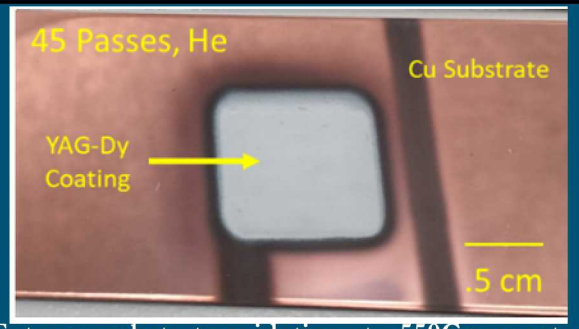
- AD Coatings show deviation from linear calibration curve at lower temperatures (similar to all other methods)
- Wavelength ratio different for AD coatings compared to epoxy/literature values
  - This could indicate interference/interaction differences with light

Figures courtesy of Wendy Flores-Brito and Kate Hoffmeister

2-Dimensional Analysis of Aerosol Deposited YAG:Dy

Aerosol Deposition (773K) | Epoxy (673K)

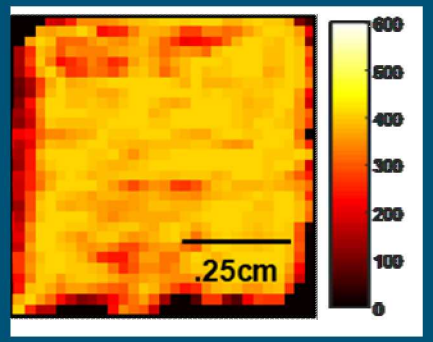
A)



Extreme substrate oxidation at ~550C prevented higher temperature testing

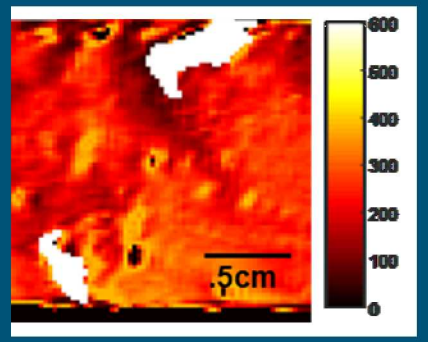
B)

C)



~250μm/pixel

D)



(A) Aerosol Deposited YAG:Dy coating on copper substrate exposed to 773K. (B) Epoxy-YAG:Dy coating exposed to 673K. (C) 2-D temperature profile for AD YAG coating. (D) 2-D temperature profile for Epoxy coating.

*Temperature profiles courtesy of Thermal Test Facility (1532)

- 2-D Temperature profile obtained for less dense coating
- Measurement stopped at 773K due to extreme oxidation of copper substrate
- Epoxy mixed YAG:Dy coatings pyrolyzed at 673K

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Thank You
Questions