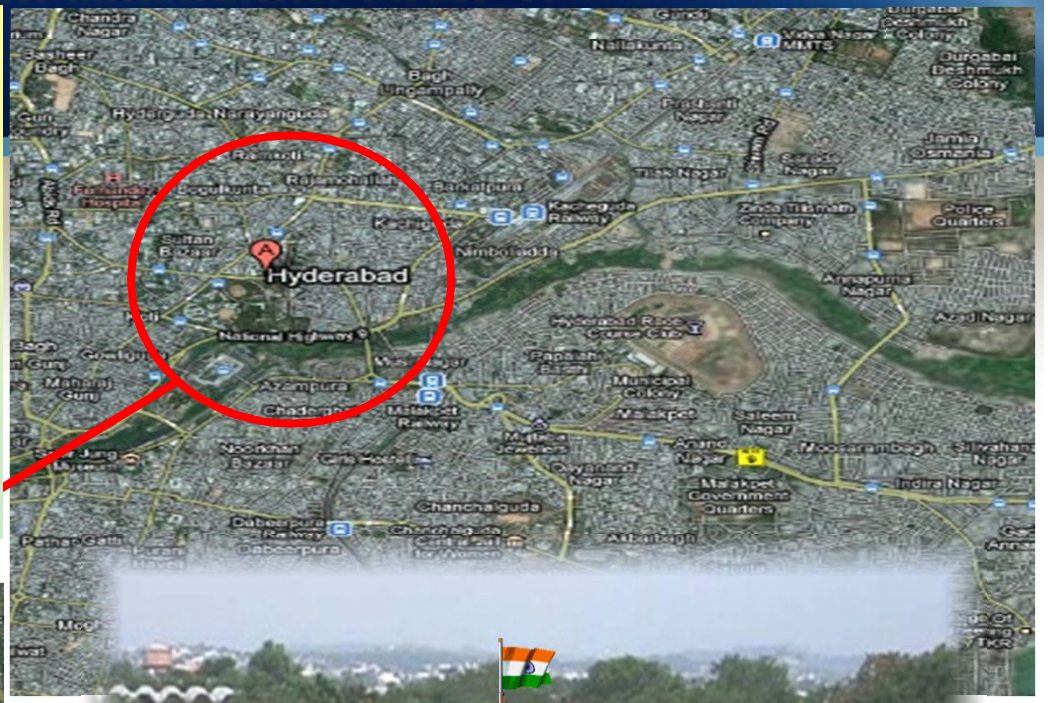
Improvements in Gas Turbine Performance via Novel Plasma Spray Coatings Offering Protection Against Ingested Species

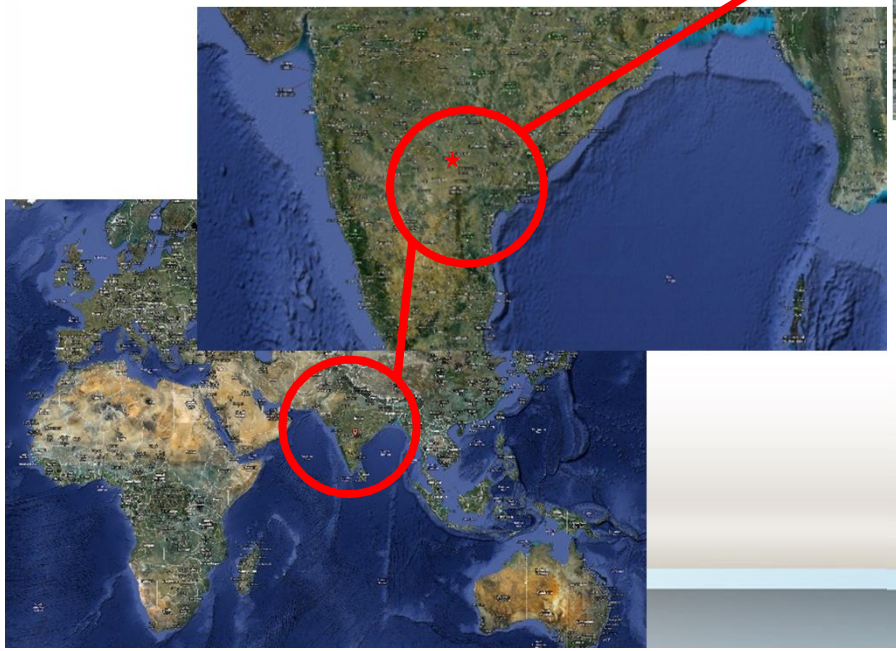
Funded by

UK-India Research Initiative on Advanced Manufacturing

International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI)

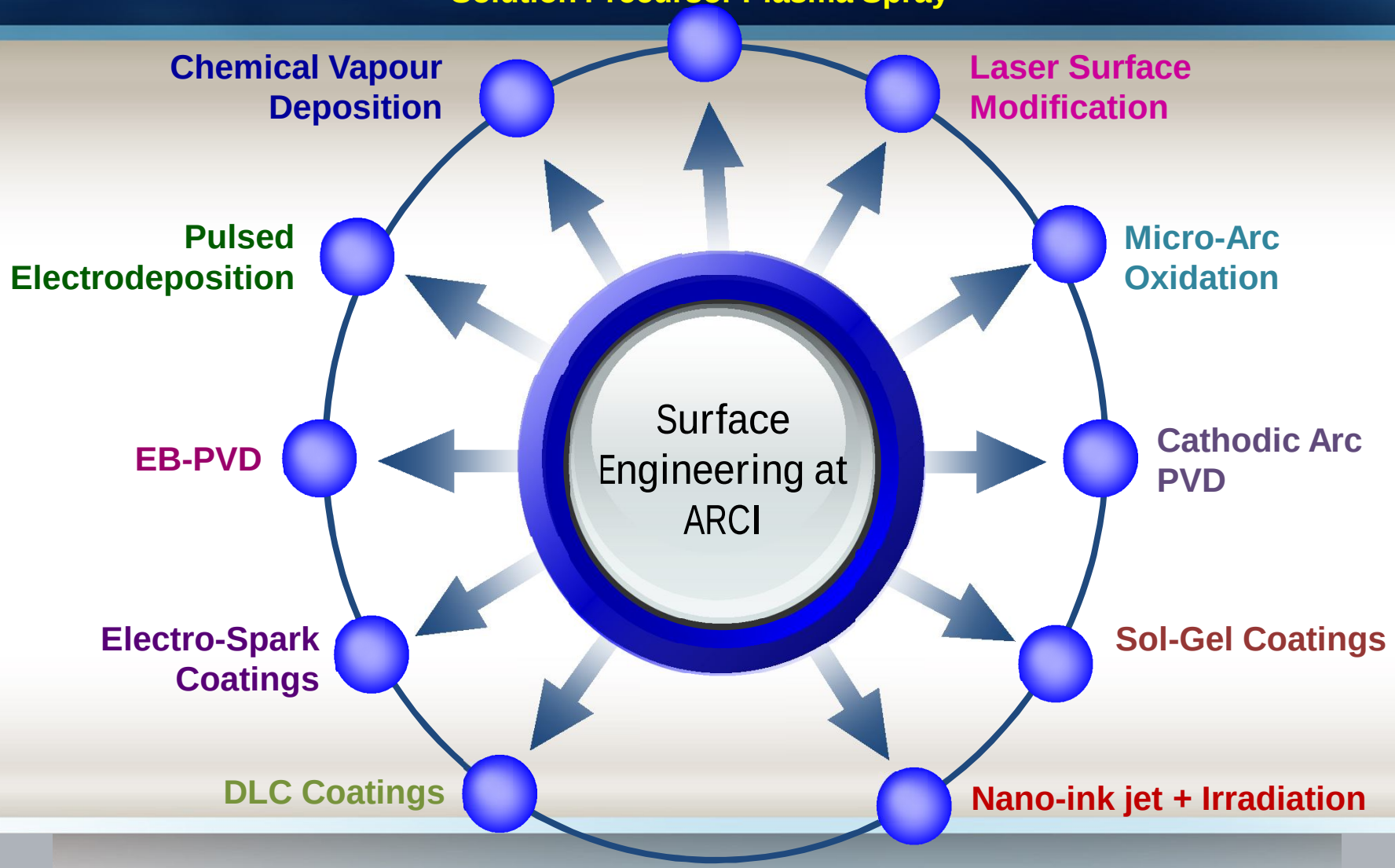
- **Research institute with specific focus on advanced materials' research**
- **Industry-centric; like a "half-way house" for transitioning research to real applications (pilot scale production, equipment building, technology demonstration & transfer)**
- **National leadership position in several domains of core competence, particularly Surface Engineering**





Surface Engineering @ ARCI : Vast Portfolio .....

Detonation Spray
Cold Spray
Atmospheric Plasma Spray
Solution Precursor Plasma Spray

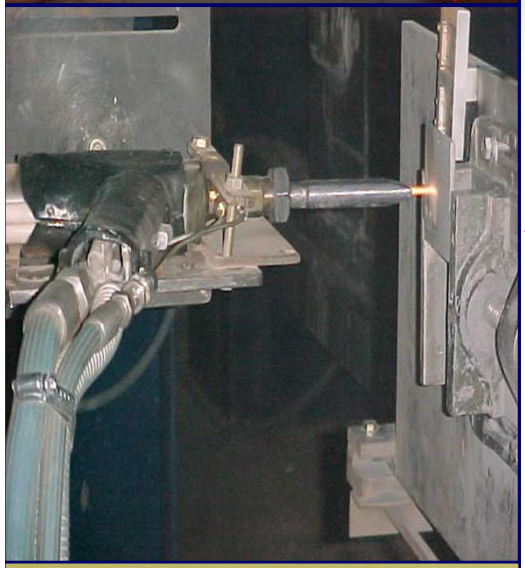


Translating Research to Practice

Micro Arc Oxidation Coating on Under Barrel Grenade Launcher

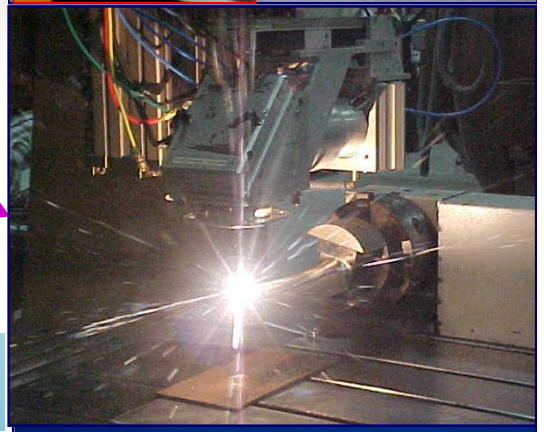
Detonation Spray Coating Technology

SURFACE ENGINEERING PROGRAMS



Cold Gas Dynamic Spraying

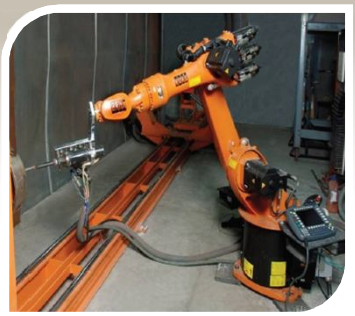
Laser hardening of steam turbine blades



Thermal Barrier Coatings for Gas Turbine Engine Components

Nanocomposite Coatings for Cutting Tools

TBC processing: Unique capabilities



Cold Spray Coating

Detonation Spray Coating

Conventional Atmospheric Plasma Spray

Solution Precursor Plasma Spray

Electron Beam Physical Vapor Deposition

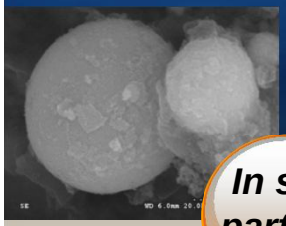
Bond Coat

Vacuum Plasma Spray

<u>Mandate</u>: Specific focus on SPPS based processing for depositing CMAS resistant coatings and also, compare with VPS

Bond Coat + Ceramic Top Coat

TBC processing by SPPS: Exciting possibilities

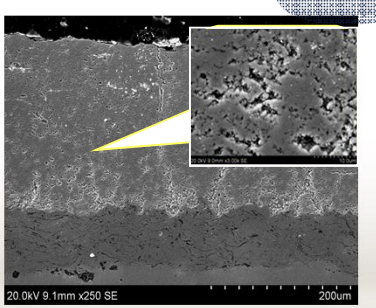


Precursor chemistry

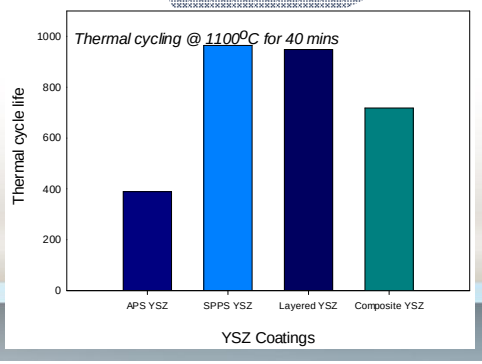
In situ particle

Splats

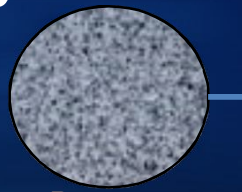
Coating characteristics



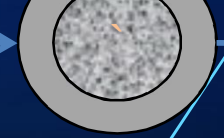
Coating performance



Precursor Droplet



Evaporation

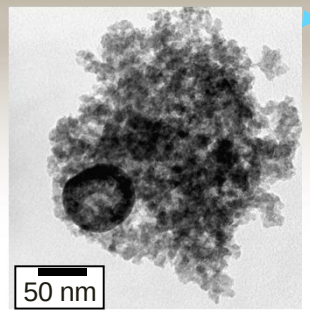


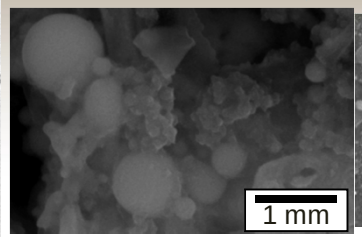
Breakup, Gelation, precipitation

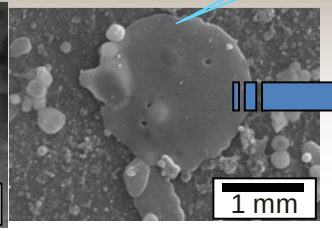
Pyrolysis

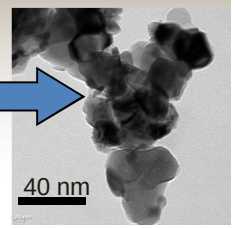
Sintering/ Melting

Splats







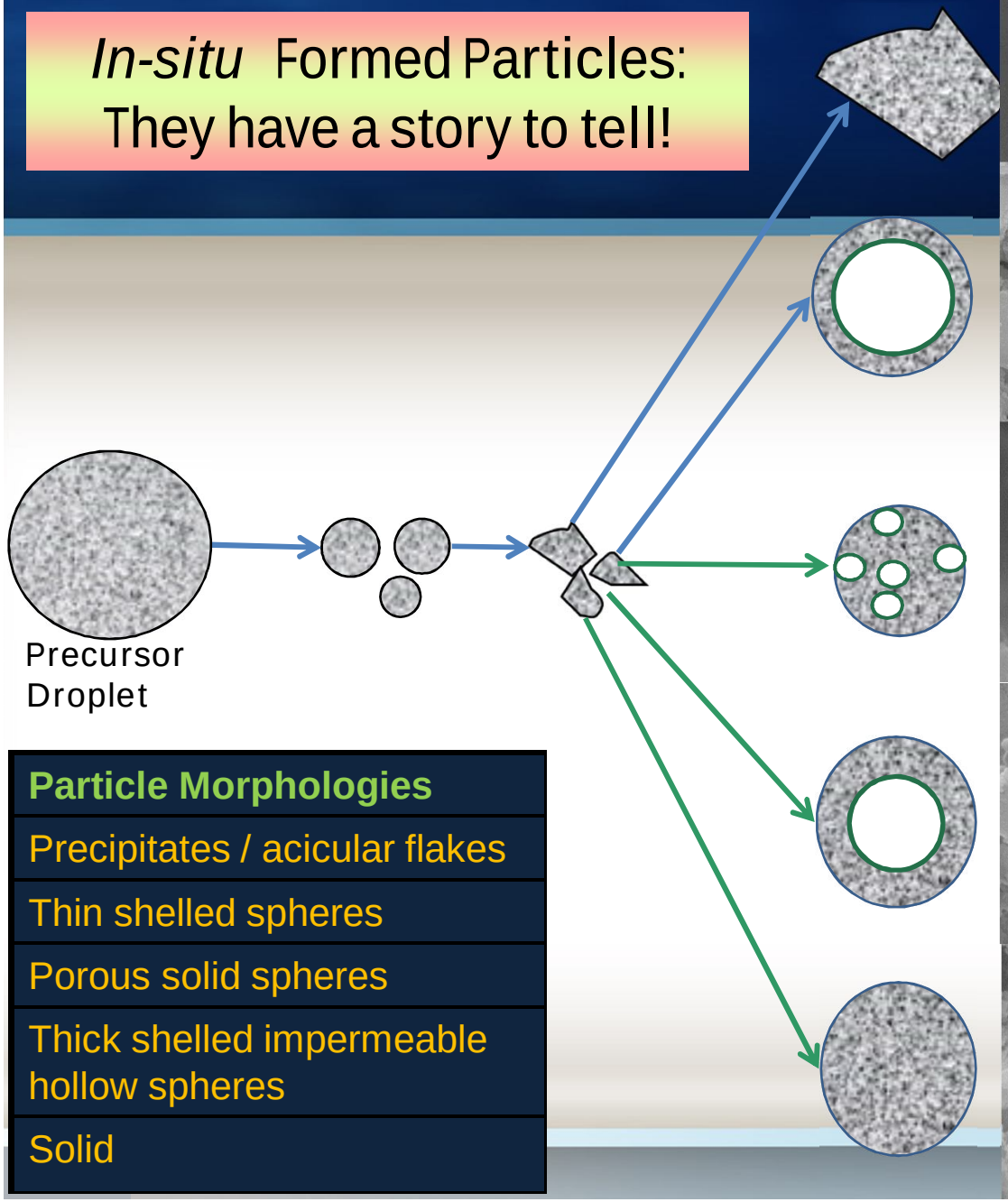


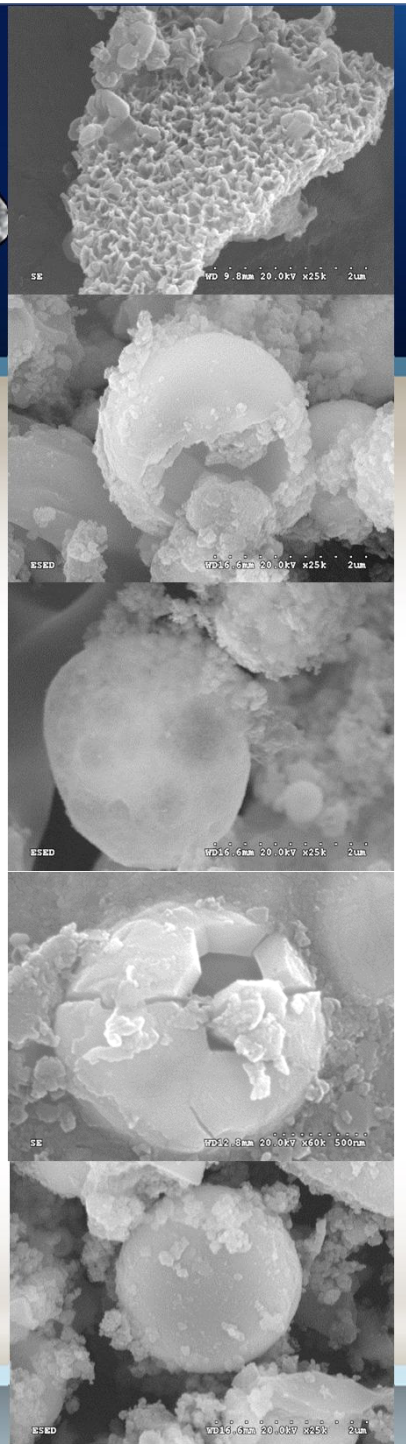
Improved insight into SPPS coatings

- Vertical crack formation & fine pores can be tailored
- Presence of vertical cracks along with optimum porosity assist in enhanced durability of SPPS YSZ TBCs

Different Particle Morphologies

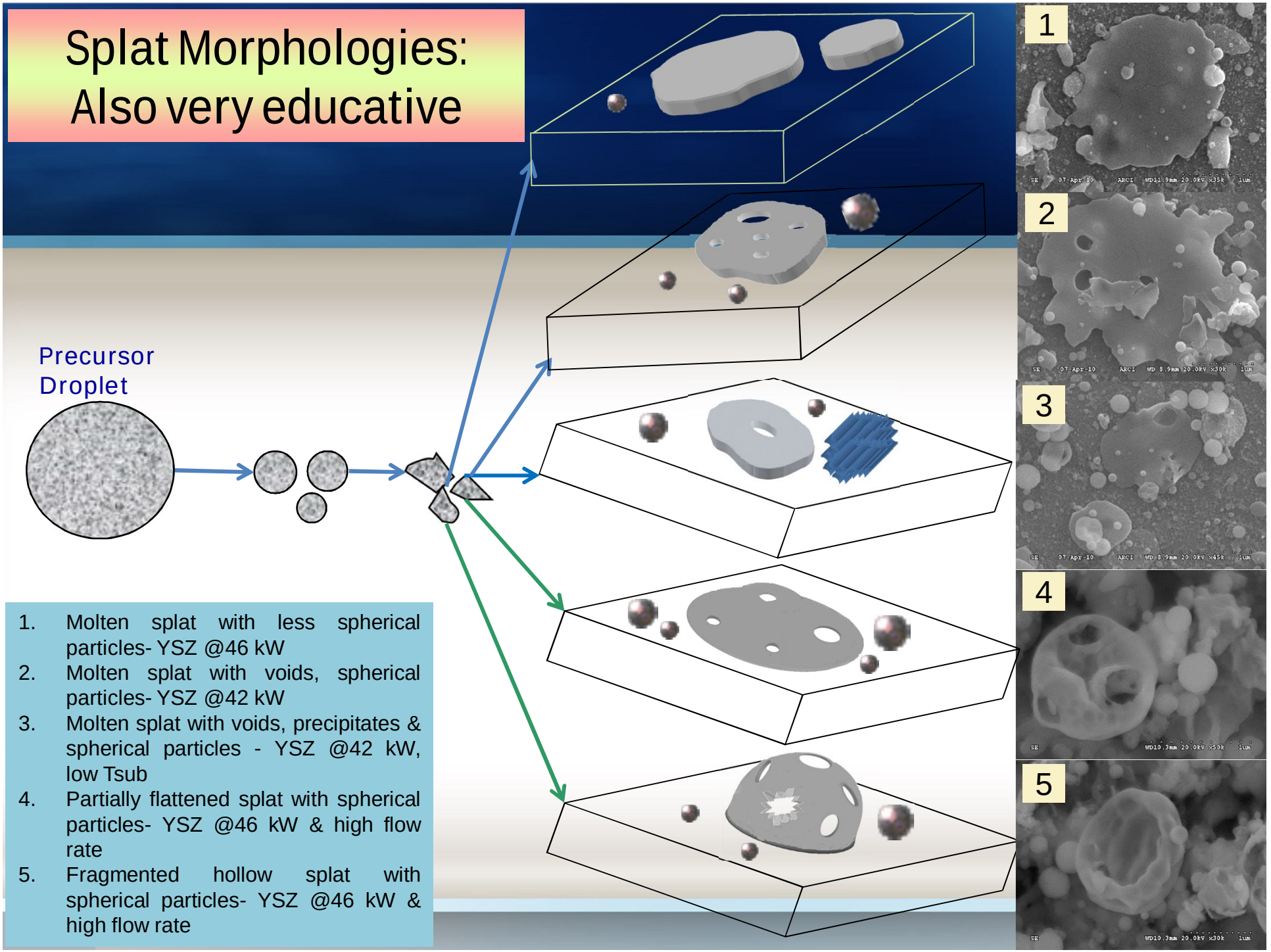
In-situ Formed Particles:
They have a story to tell!





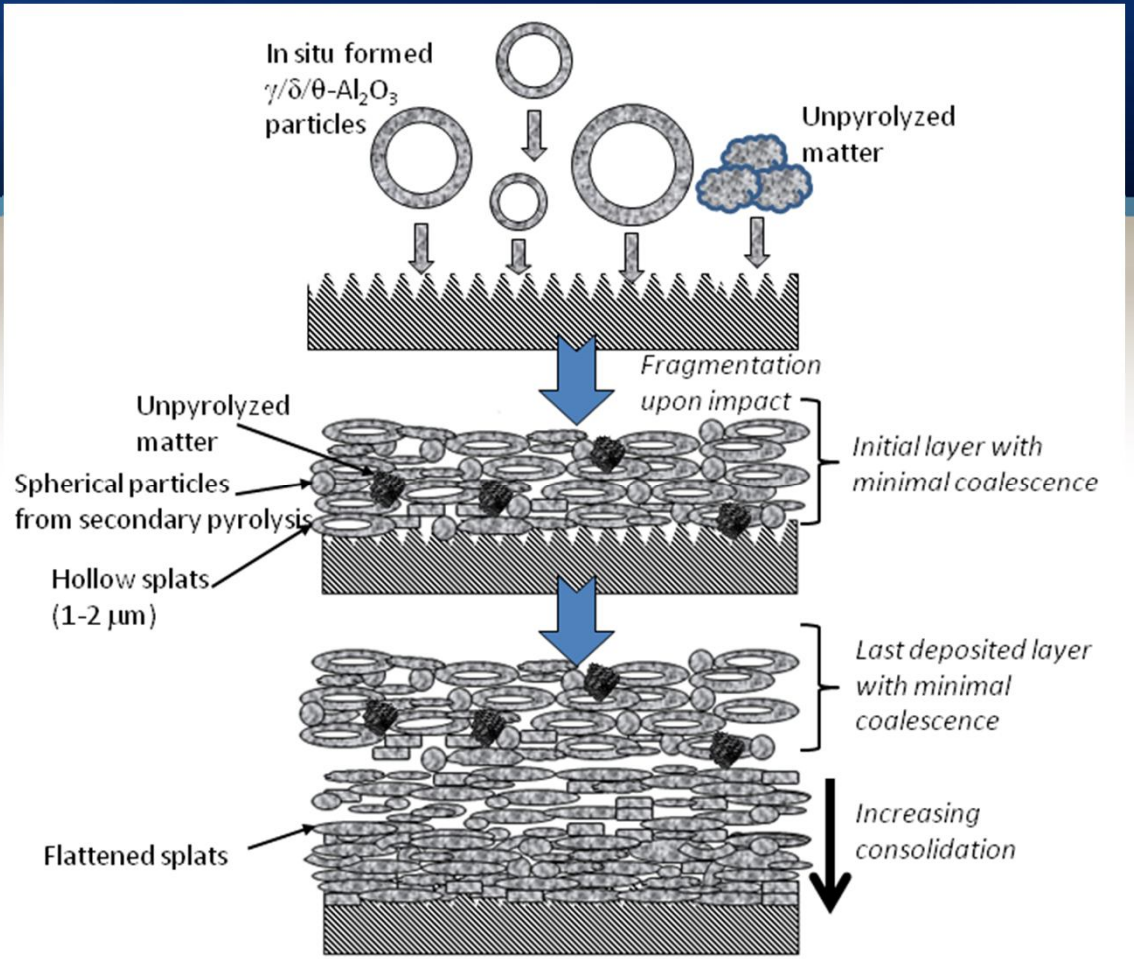
Particle Morphologies	Likely conditions
Precipitates / acicular flakes	Incomplete pyrolysis; Low plasma power; Droplet trajectory missing plasma
Thin shelled spheres	High evaporation rates; Low concentration; Large droplet size; Droplet trajectory missing plasma
Porous solid spheres	High evaporation rates ;Low concentration
Thick shelled impermeable hollow spheres	High evaporation rates ; High concentration; Inhomogeneous precipitation
Solid	Complete melting with volumetric precipitation of droplets at optimum concentration

Splat Morphologies: Also very educative



1. Molten splat with less spherical particles- YSZ @46 kW
2. Molten splat with voids, spherical particles- YSZ @42 kW
3. Molten splat with voids, precipitates & spherical particles - YSZ @42 kW, low Tsub
4. Partially flattened splat with spherical particles- YSZ @46 kW & high flow rate
5. Fragmented hollow splat with spherical particles- YSZ @46 kW & high flow rate

Coating Deposition Mechanism

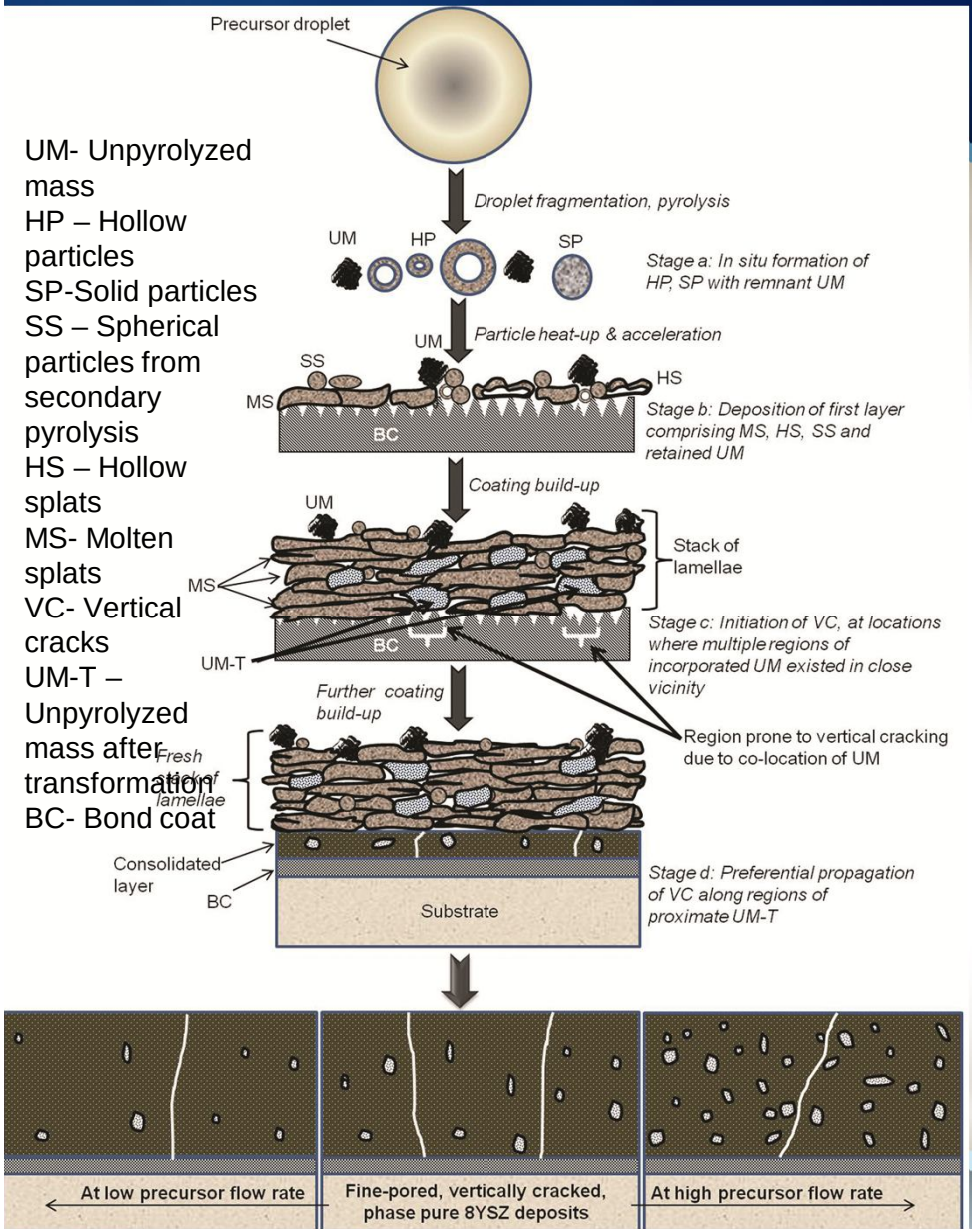


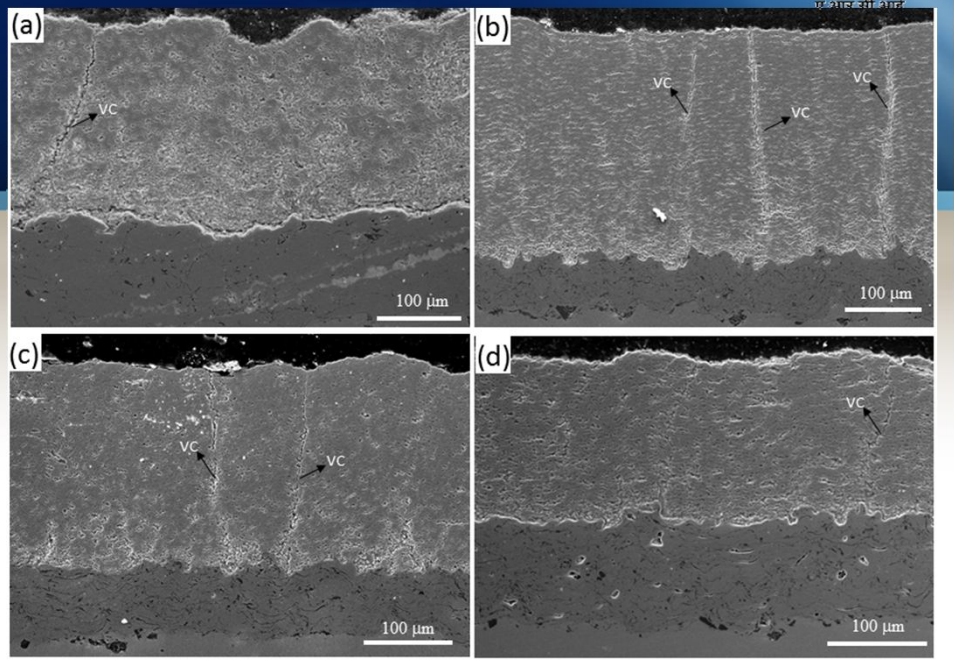
Based on observations from microstructure, morphologies of *in situ* formed particles and splats

J. Eur. Cer. Soc., 33 (2013) 2823–2829

Origin of Vertical Cracks

UM- Unpyrolyzed mass
HP – Hollow particles
SP-Solid particles
SS – Spherical particles from secondary pyrolysis
HS – Hollow splats
MS- Molten splats
VC- Vertical cracks
UM-T – Unpyrolyzed mass after transformation
BC- Bond coat

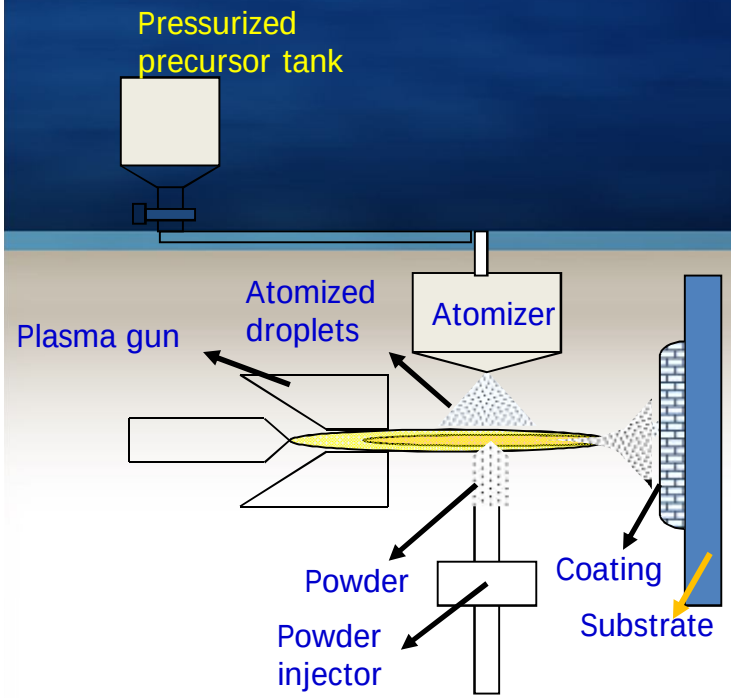


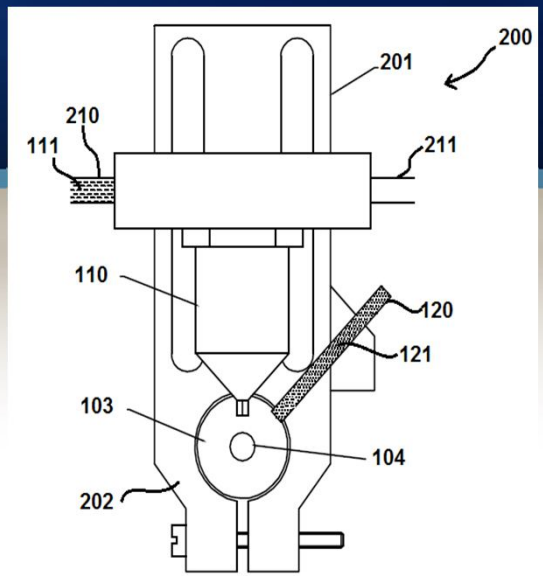


- Incorporation of unpyrolyzed precursor along with splats
- Higher deposition temperature through
  - Substantial exothermic energy (~400 J/g) released during precursor pyrolysis
  - Substrate pre-heating (~500^{o}C)
  - Repeated plasma torch scans
  - Short spray distance

J Am Cer Soc, In Press, 2014

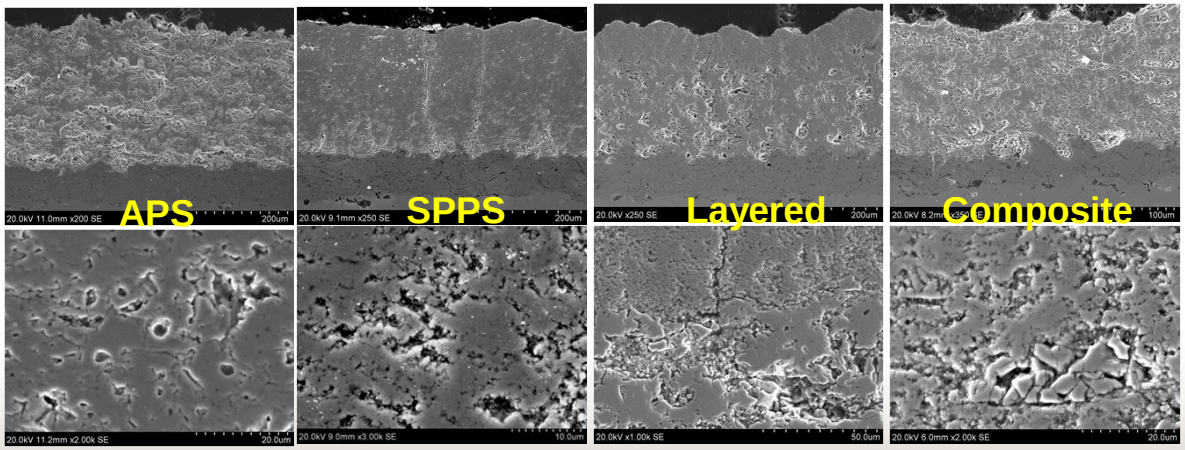
Pushing the Envelope: Can We Hybridize with SPPS?





- Novelty in simultaneous feeding of solution & powder feedstock to tailor unique microstructures - layered, composite and gradient structures

- Nano-sized features from solution precursor and micron-sized from powder feedstock yield bimodal features

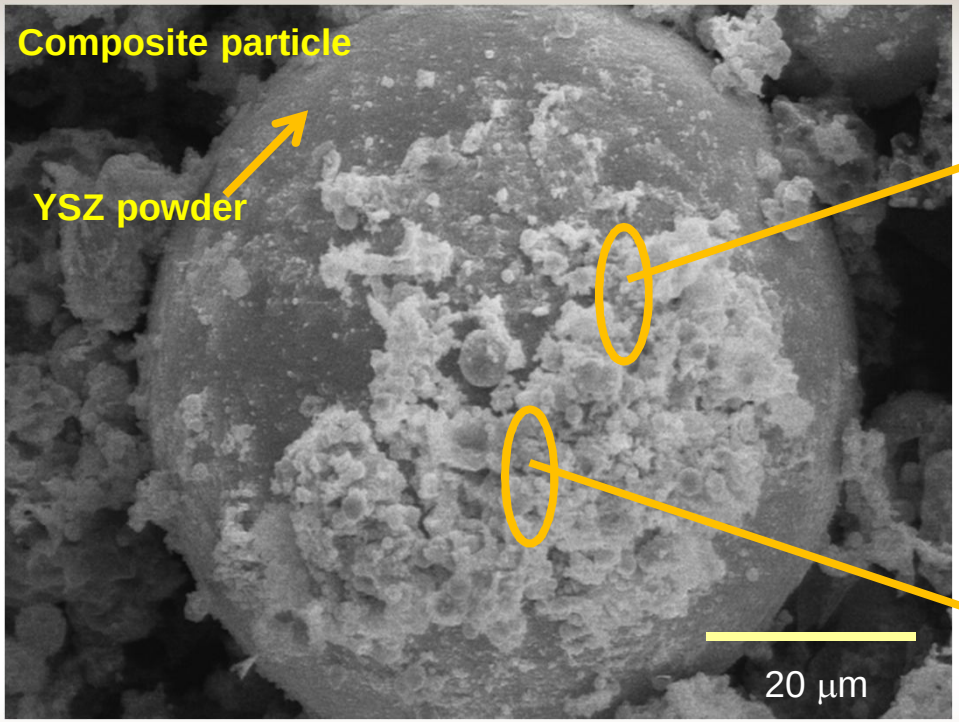


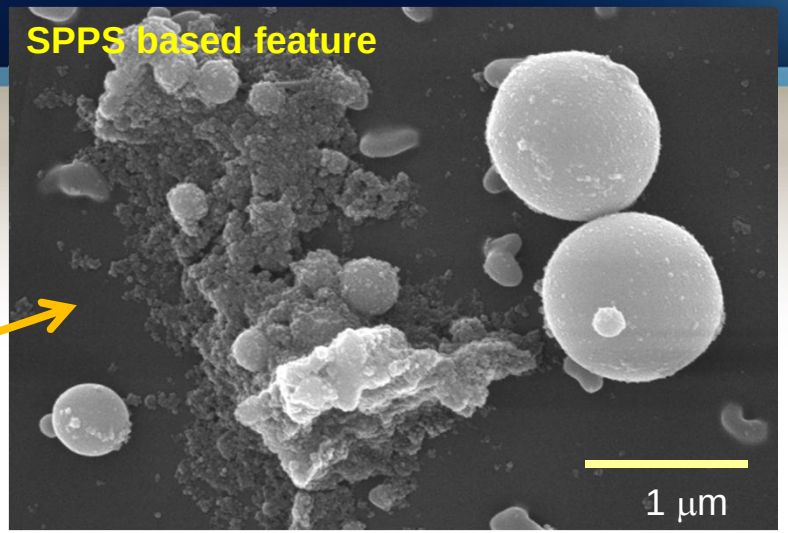
ARCI Patent appl. no.2965/DEL/2011

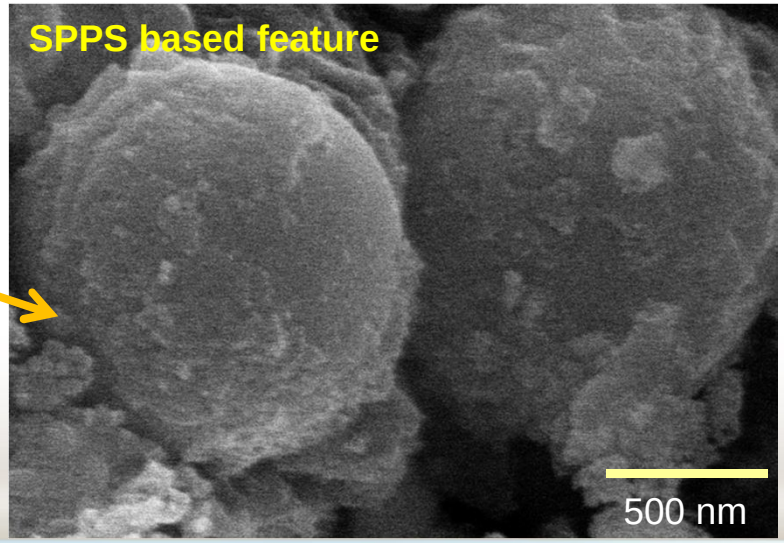
Can We Spray Powders and Precursors Together ?

Journal of Thermal Spray Technology, in press, 2014

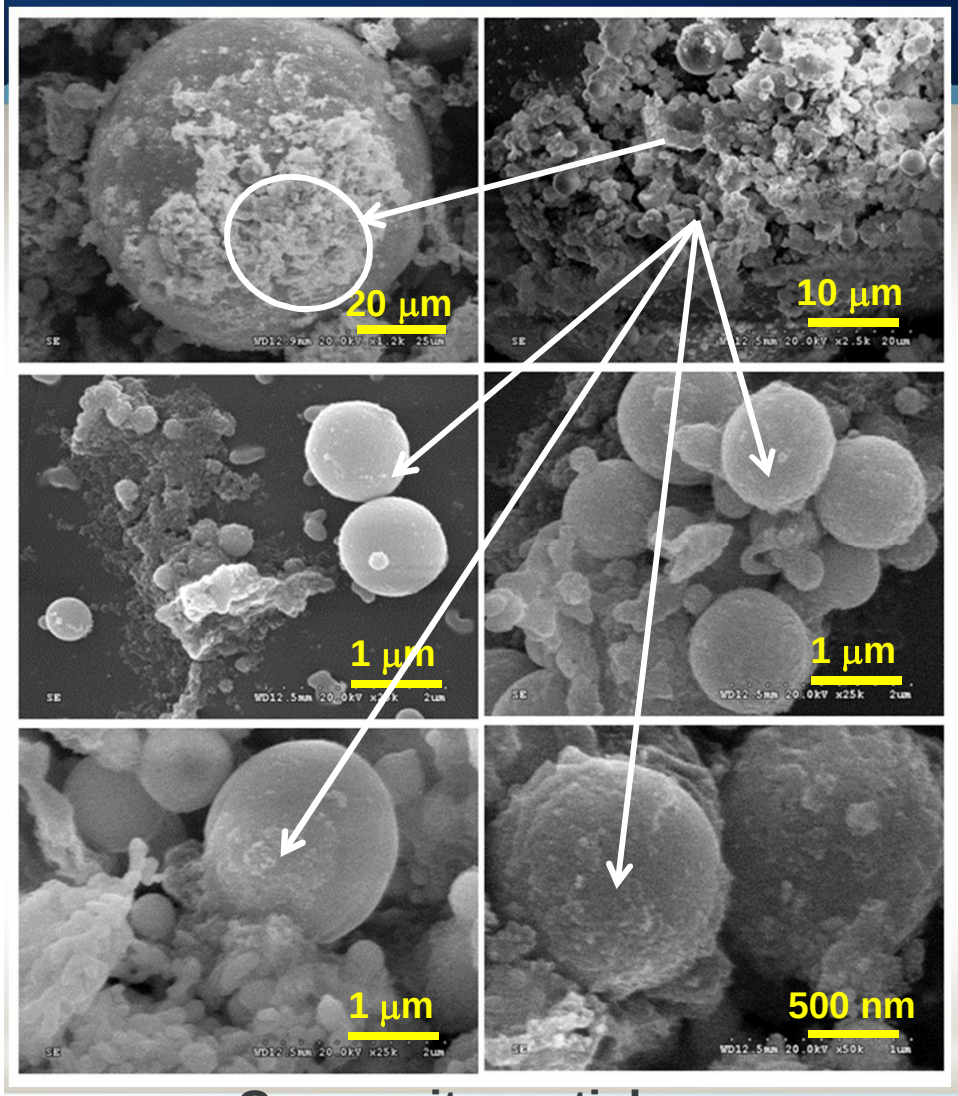
In flight collected composite particles



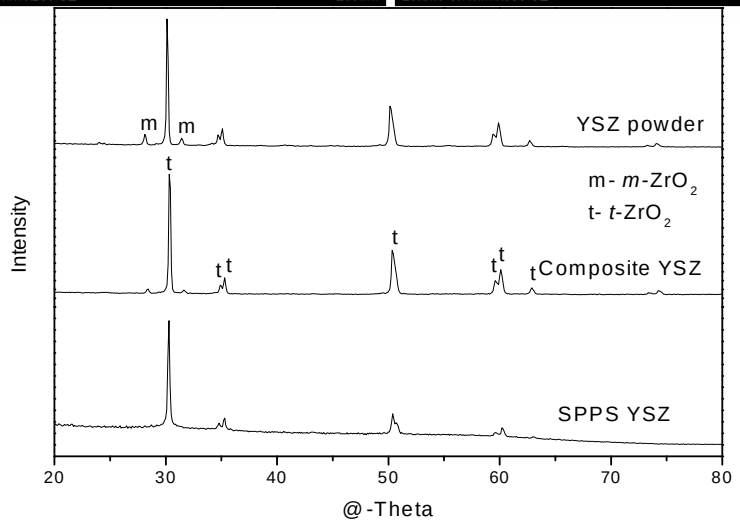




In situ Formed Composite YSZ Particles



Composite particles

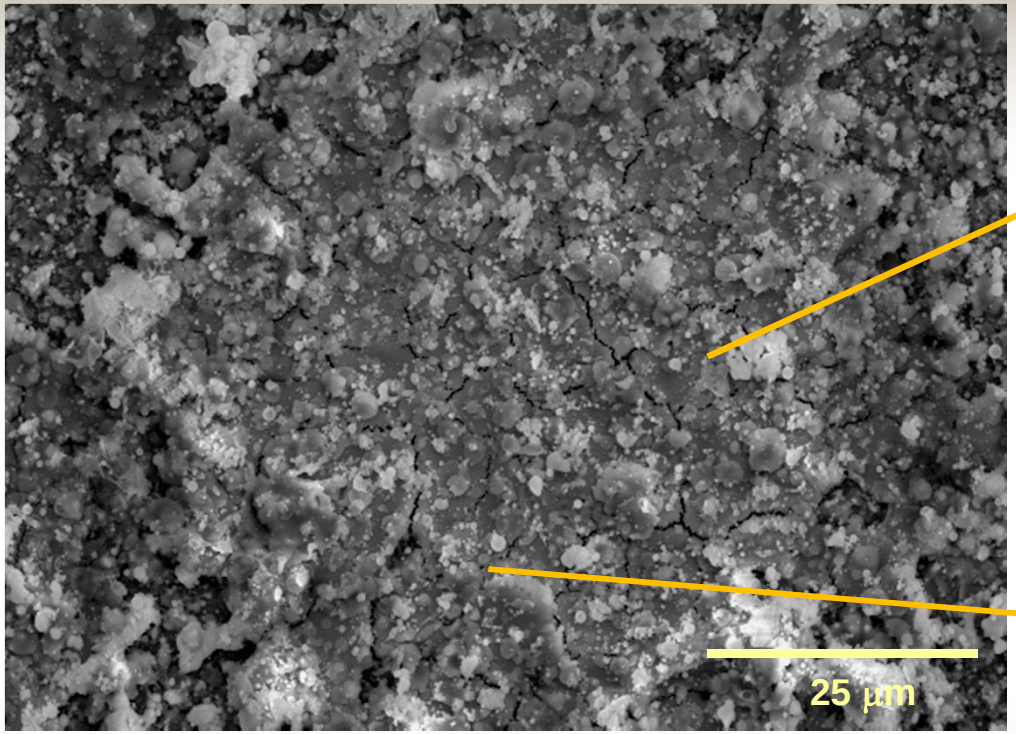


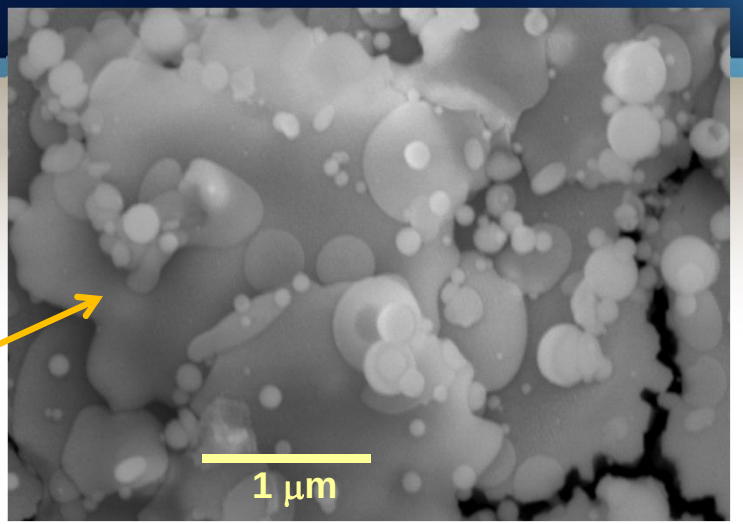
- Over a powder particle (50 μm), many SPPS based gel-like precipitates, broken shells, fine equi-axed grains, agglomerated solid spherical particles, etc were present

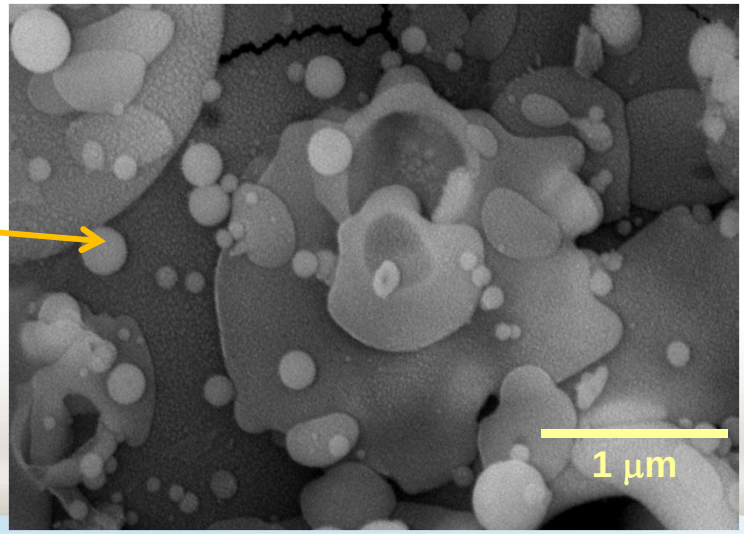
How do "Composite" Splats Form ?

Journal of Thermal Spray Technology, in press, 2014

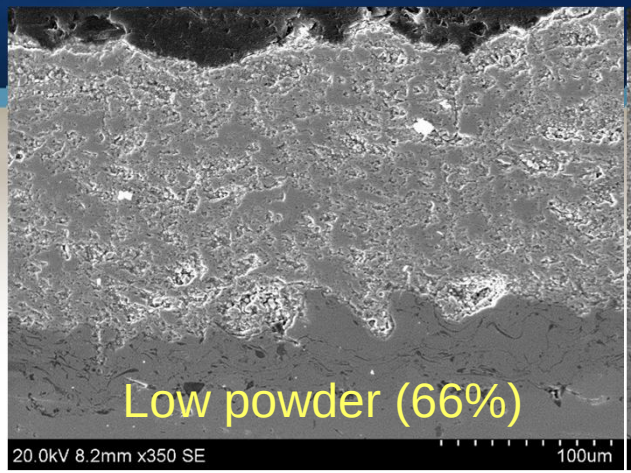
Composite Splats

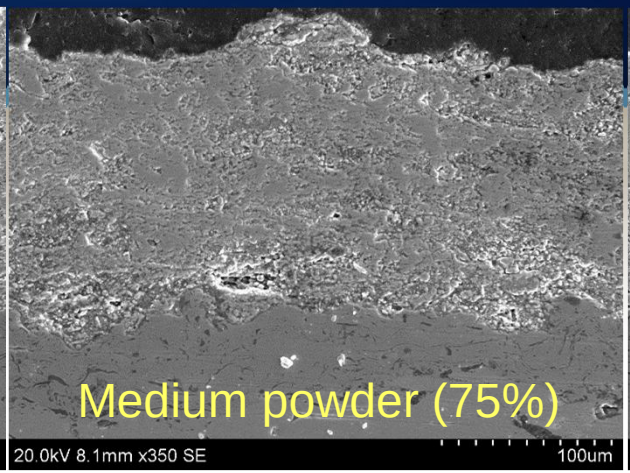


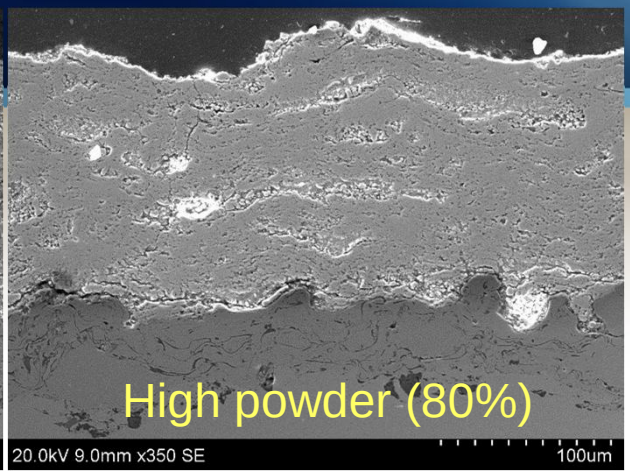


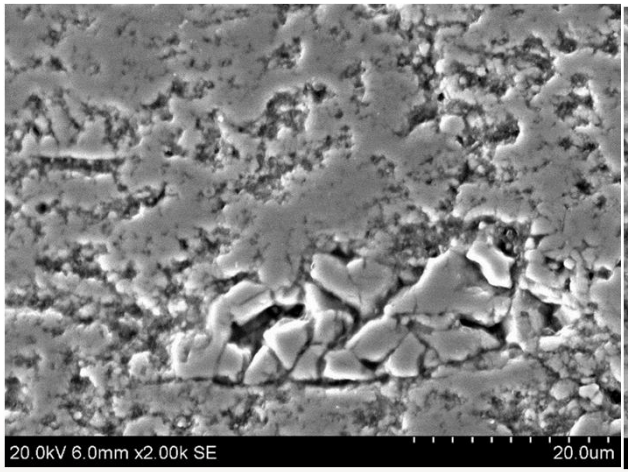


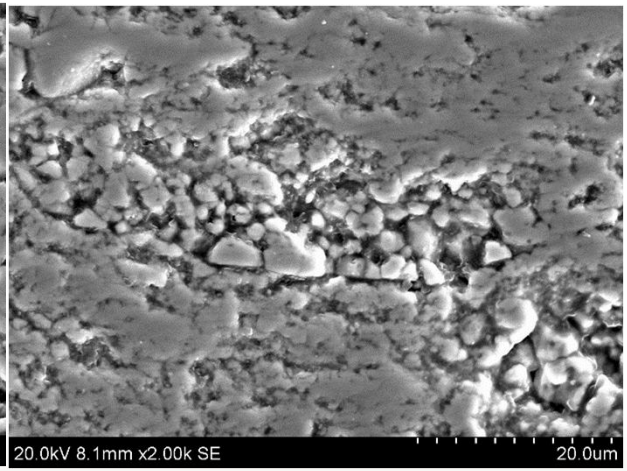
Microstructures of Composite YSZ-YSZ coatings

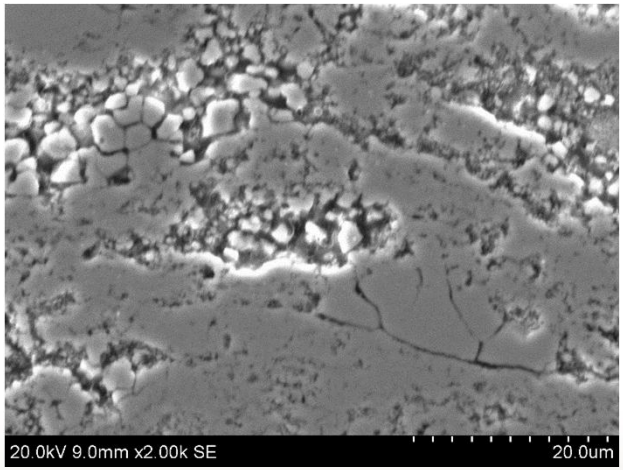






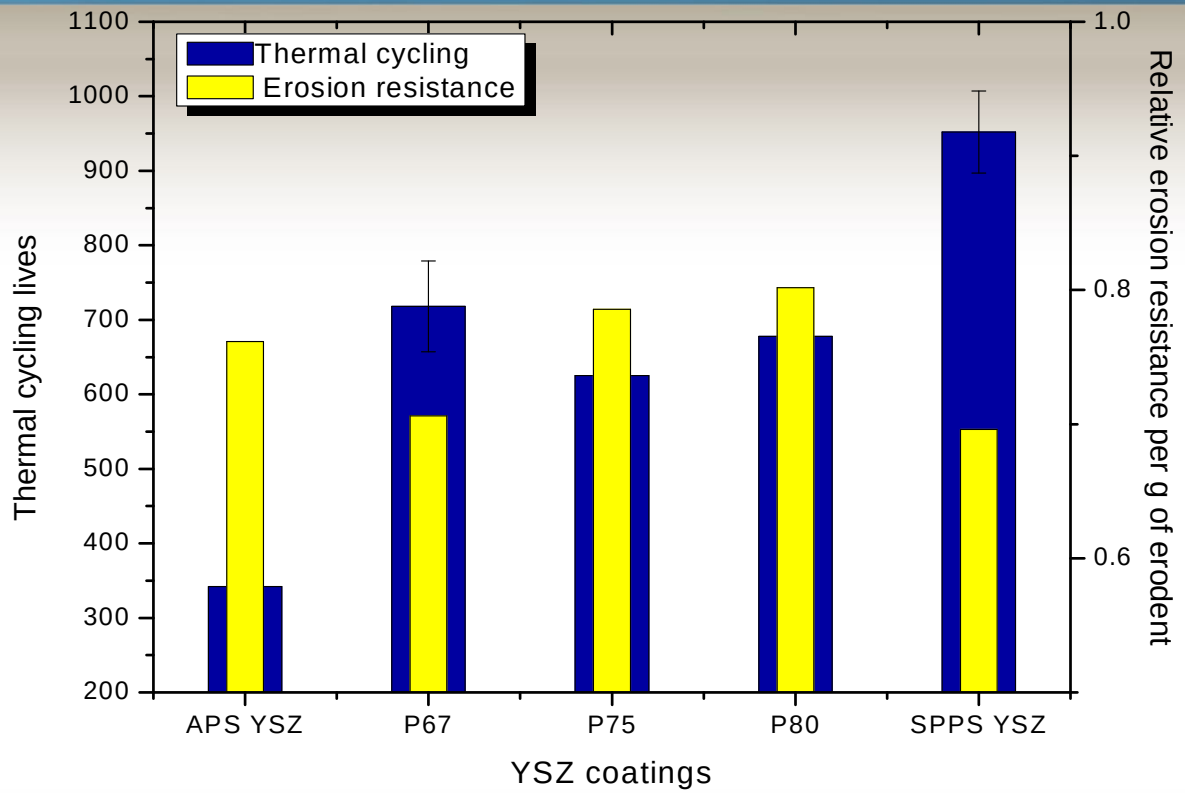






- **Uniform distribution of micron sized and sub-micron sized features in the coating**

Comprehensive Performance Improvement in "Composite" YSZ Coatings

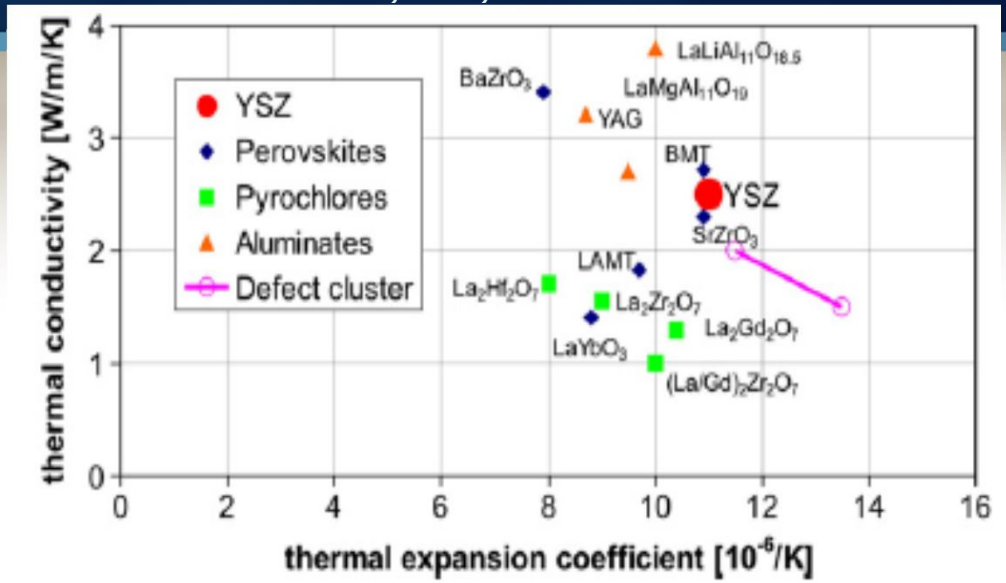


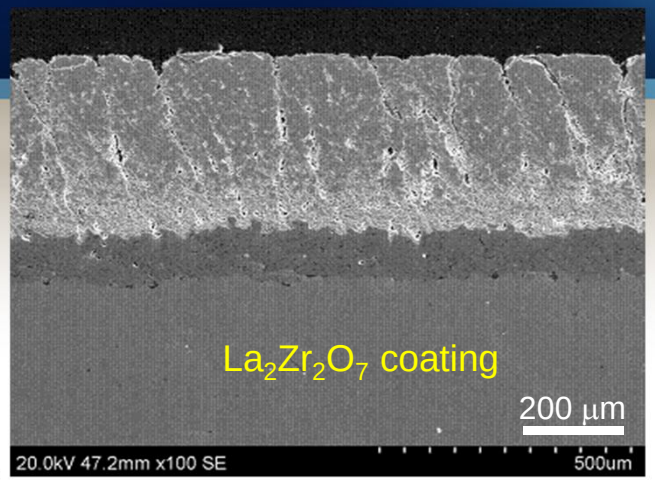
- Exciting combination of thermal cycling and erosion properties
- Some critical applications demand this: land based gas turbines, aero-engines operating in desert environment

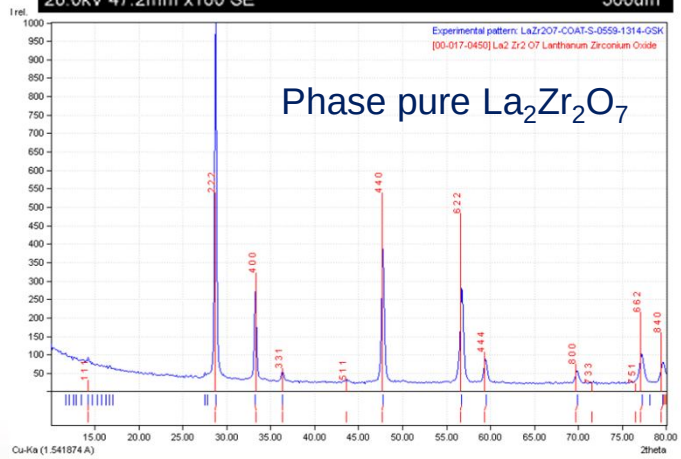
New TBC possibilities with SPPS

David Clarke, Mat. Tod., 2005

Robert Vassen, SCT, 2010





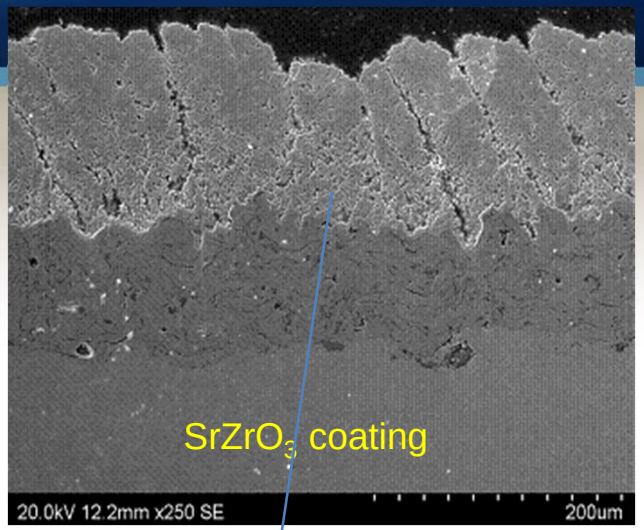


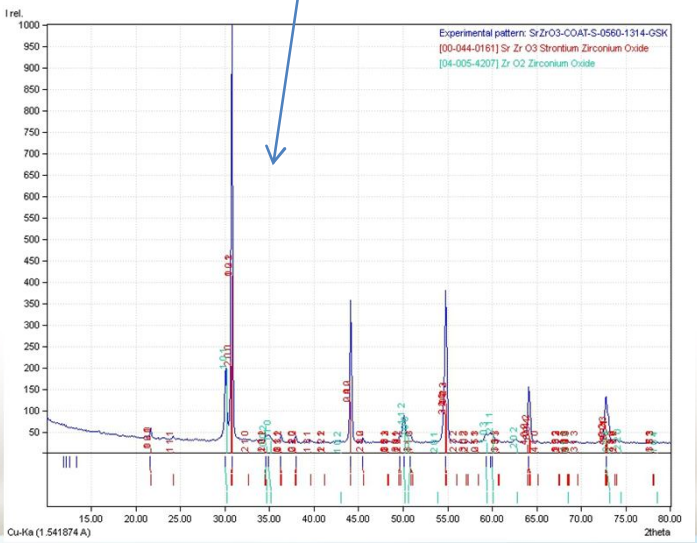
- ❑ **Modifying coating microstructure**
- ❑ **Alternative oxides / alloying / doping**
- ❑ **Nanostructuring of TBC**
- ❑ **Pore morphology**

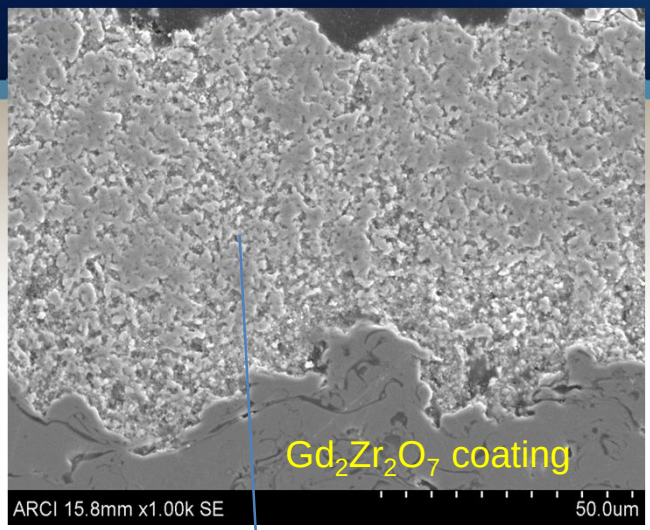
$Ln_2Zr_2O_7$ ceramics (Ln=La, Nd, Sm, Gd) with pyrochlore structure (P-$Ln_2Zr_2O_7$)

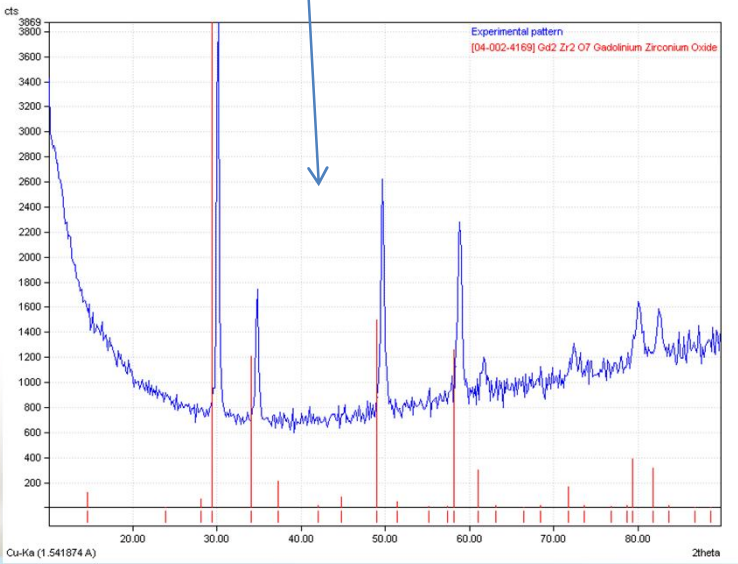
- ❑ SPPS can potentially deposit various novel combination of RE zirconates with additional dopants

New TBC possibilities with SPPS (Contd..)









Looking ahead

- All set for generating SPPS specimens, novel formulations and architectures
- T_o for the project yet to start for ARCI!!; Procurement of consumables could not be initiated
- Preliminary studies on depositing TBCs over alumina substrates carried out but some cracking of ceramic specimen is observed. Immediate plan: varied ceramic substrate thicknesses to be tried

Points to discuss

- Identification of coating chemistry suitable for CMAS resistance
- Availability of ceramic substrates of different thickness (10-20 mm)
- Additional cooling schemes to be tried

Action plan for the next half-year

- Validation of modelling data for solution processing
- Deposition of thick YSZ, $La_2Zr_2O_7$, $Gd_2Zr_2O_7$ coatings on alumina substrates
- Deposition of composite / layered coatings on alumina substrates

Thank You

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