Lightweight, Scalable Manufacturing of Telescope Optics

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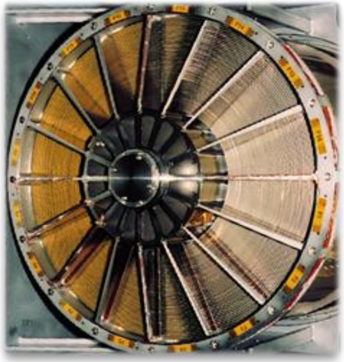
October 1, 2013

SBIR Phase I: S2.04-0446
Contract# NNX13CM21P

Need for Lightweight Telescope Optics

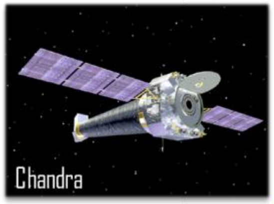
- Decrease the weight of current Wolter Type I optics to allow for greater shell packing and thus increase effective X-ray collection area (i.e. increase the optical surface area per unit mass)
- Reduce the requirements and cost of telescope launch vehicle

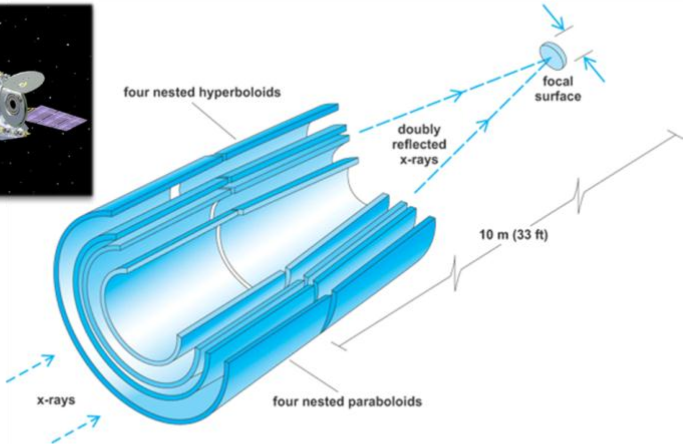
XMM Newton



Current State of the Art X-ray observatory (XMM Newton) utilizing 58 nested reflector shells; largest reflector 70cm diameter.

Note the increased number of shells compared to that of Chandra resulting in greater optical area and thus greater X-ray collection





Chandra X-ray observatory utilizing 4 nested zerodur optics with the outer shell measuring 1.2 meters in diameter.

Cross sectional view of Wolter I optic showing grazing angle reflection and nested reflector capability

Benefit of Electroformed Optic

- Individual mirror thickness reduced by greater than an order of magnitude (1mm vs. 20mm)
- Reduced mirror thickness allow for a greater number of shells to be nested

Disadvantage of Electroformed Optic

- Density of Ni compared to zerodur
- Figure accuracy not as good as zerodur

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Electroformed nickel replication (ENR)

Repeat

Benefit of the Electroforming Process

- Well suited for precision replication (widely used in optical manufacturing)
- Superpolished mandrel is reuseable, can be "touched up" as necessary

Disadvantage of Electroformed Optic

- Density of Ni compared to zerodur (8.9g/cm^3 vs 2.5 g/cm^3)
- Figure accuracy not as good as zerodur

NiCo alone is too heavy for X-ray telescope missions

There exists a need to replace much of the NiCo with a less dense material

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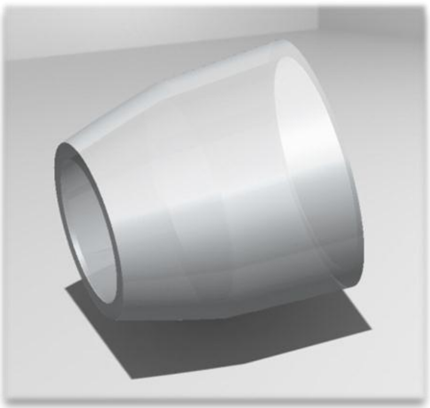
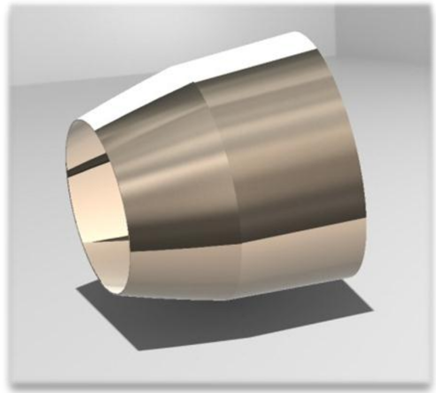
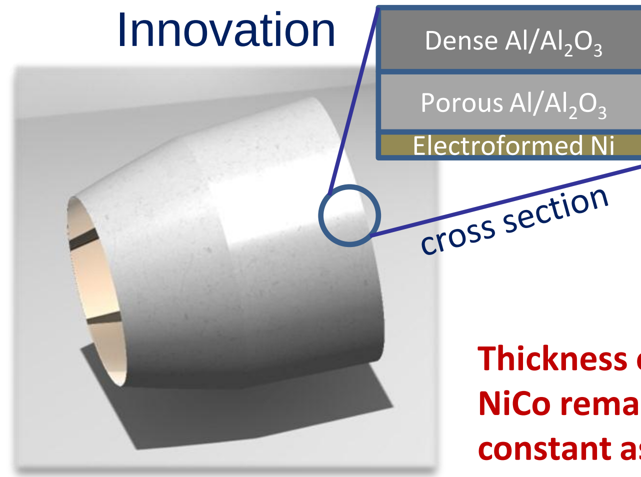
Current Standard	Current State of the Art	Proposed Innovation
		
20mm Zerodur	1mm NiCo	≤100µm NiCo 200µm Al_2O_3

Thickness of NiCo remains constant as shell diameter increases

Comparison : Mass of Wolter I Optic with a 70cm diameter, 60cm long

Current Standard	Current State of the Art	Proposed Innovation
68.7 kg	11.8 kg	1.9 kg

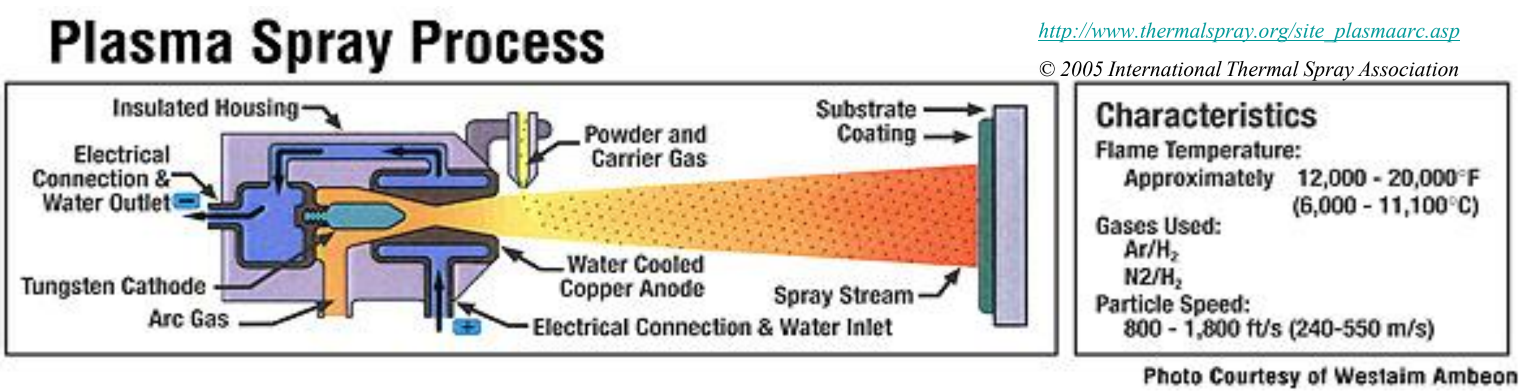
Proposed Innovation

- Replace zerodur optic with NiCo shell and thermal spray ceramic support structure
- Utilize NiCo electroforming to replicate the surface micro-roughness of the mandrel
- Combine a graded-density lightweight ceramic support coating to hold figure accuracy and supply rigidity for handling

Thermal Spray Processes

Twin Wire Arc | Flame / Combustion | Atmospheric Plasma Spray | High Velocity Oxy Fuel | Cold Spray | Detonation Spray

Associated with more than 100 variables

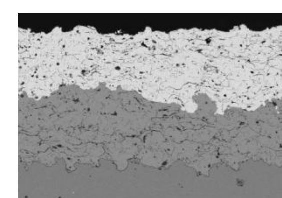


Spray Conditions:
- Torch Settings
- Powder
- Substrate Condition
- Spray Pattern

In Flight Particles:
- Temperature
- Velocity
- Trajectory

Coating Build-up:
- Splat Morphology
- Microstructure
- Porosity
- Interlamellar Contact

Properties:
- Mechanical
- Thermal
- Relibility



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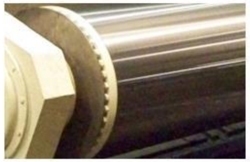
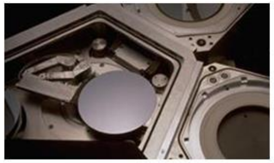
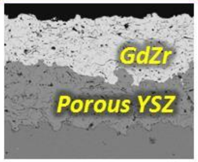
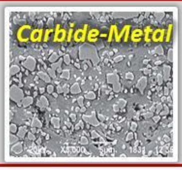
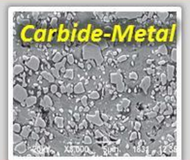
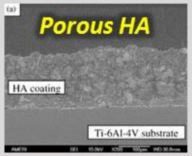
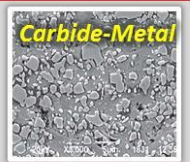
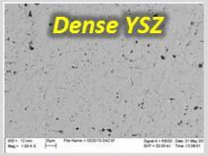
Wide Range of Thermal Spray Coated Components

	Energy - Gas Turbine Engine	Industrial machinery	Aviation Engine / Landing Gear	Bio-implants	Metal / Paper Manufacturing	Electronics Manufacturing
APPLICATIONS						
Thermal Spray Processes						
COATING MATERIAL & MICROSTRUCTURE						
PHYSICAL CHARACTERISTICS	Thickness Weight Porosity	Thickness Crack Porosity	Thickness Crack Weight	Thickness Defect Density Roughness	Thickness Crack Roughness	Thickness Defect Density
PROPERTIES & PERFORMANCES	Residual Stress Adhesion Sintering/Aging Conductivity Toughness	Residual Stress Adhesion Strength Toughness Wear	Residual Stress Adhesion Strength Toughness Wear	Residual Stress Adhesion Toughness Phase Stability	Residual Stress Adhesion Strength Toughness Wear	Residual Stress Adhesion Erosion Phase Stability Thermal Expansion

Materials Selection

- Wide array of materials to select from
  - Metals, ceramics, polymers, composites
- Ability to tailor the material to not only match the expansion but also provide compliance via defects (thermal cycling compliance)

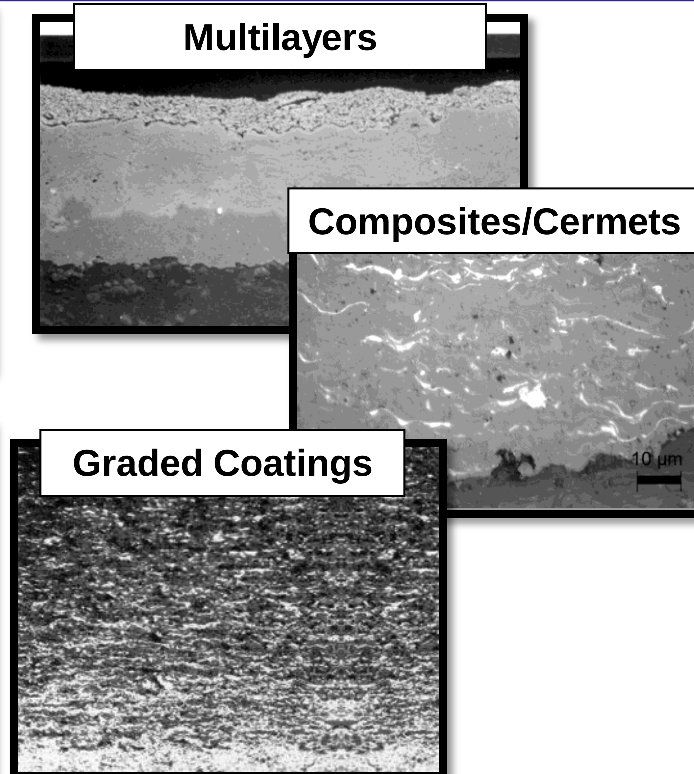
Process Parameters

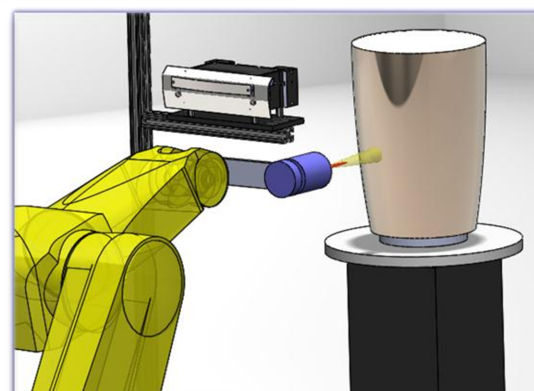
- Ability to tailor the microstructure, density, and interface through use of graded layers
- Ability to control deposition temperature
  - Robot raster speed
  - Secondary cooling

NiAl deposited onto canvas

Component Manufacturing

- Ability to deposit onto large cylindrical geometries
  - Easily scalable
  - Deposit directly onto electroformed shell
- Cost effective and efficient
- Established industry base, does not require large capital expense for application





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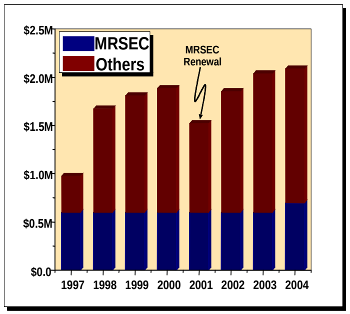
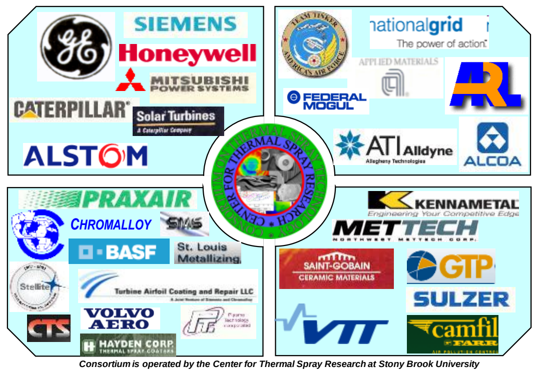
ReliaCoat Emerged from the Center for Thermal Spray Research

STONY BROOK
STATE UNIVERSITY OF NEW YORK



Value Added Benefits from Core NSF Funding



Stony Brook-Caterpillar Team

Companies involved in field trips

CHROMALLOY NEW YORK · Universität Stuttgart · HAYDEN CORP. · Alcoa Howmet · CATERPILLAR · CTS · SULZER · JÜLICH · PRAXAIR TAFA · VOLVO AERO · FEDERAL MOGUL · Stellite · ALSTOM · PRAXAIR · MITSUBISHI POWER SYSTEMS

ReliaCoat Technologies

Founded May 2009

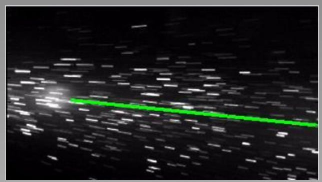
Expanded to new location Summer 2012

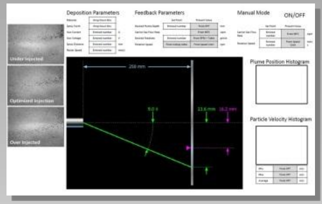
Advanced tools, software, and technology services company

Advanced Hardware & Software Technologies

Linking Advanced Science to Industrial Products

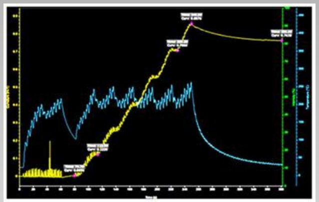
Injection Monitoring & Feedback





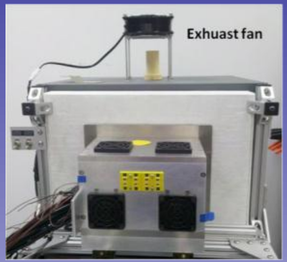
- Injection depth measurement
- Closed-loop carrier gas flow control
- Closed-loop feed rate control

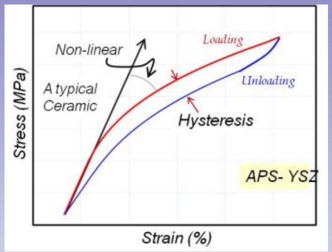
In-Situ Coating Property Sensor



- In-situ residual stress evolution
- Elastic modulus
- Monitoring coating build-up

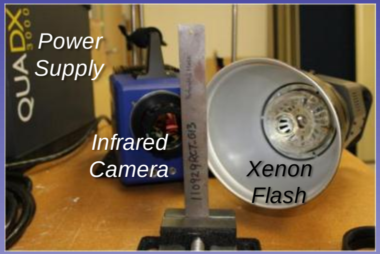
High Temp Ex-Situ Coating Property

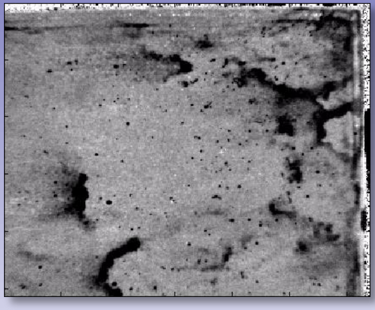




- High temperature coating compliance
- Nonlinear anelastic behavior
- Thermo-cyclic residual stress evolution

NDE: Flash Imaging Tomography





- Non-destructive , non-invasive coating structure assessment
- Coating crack & delamination detection

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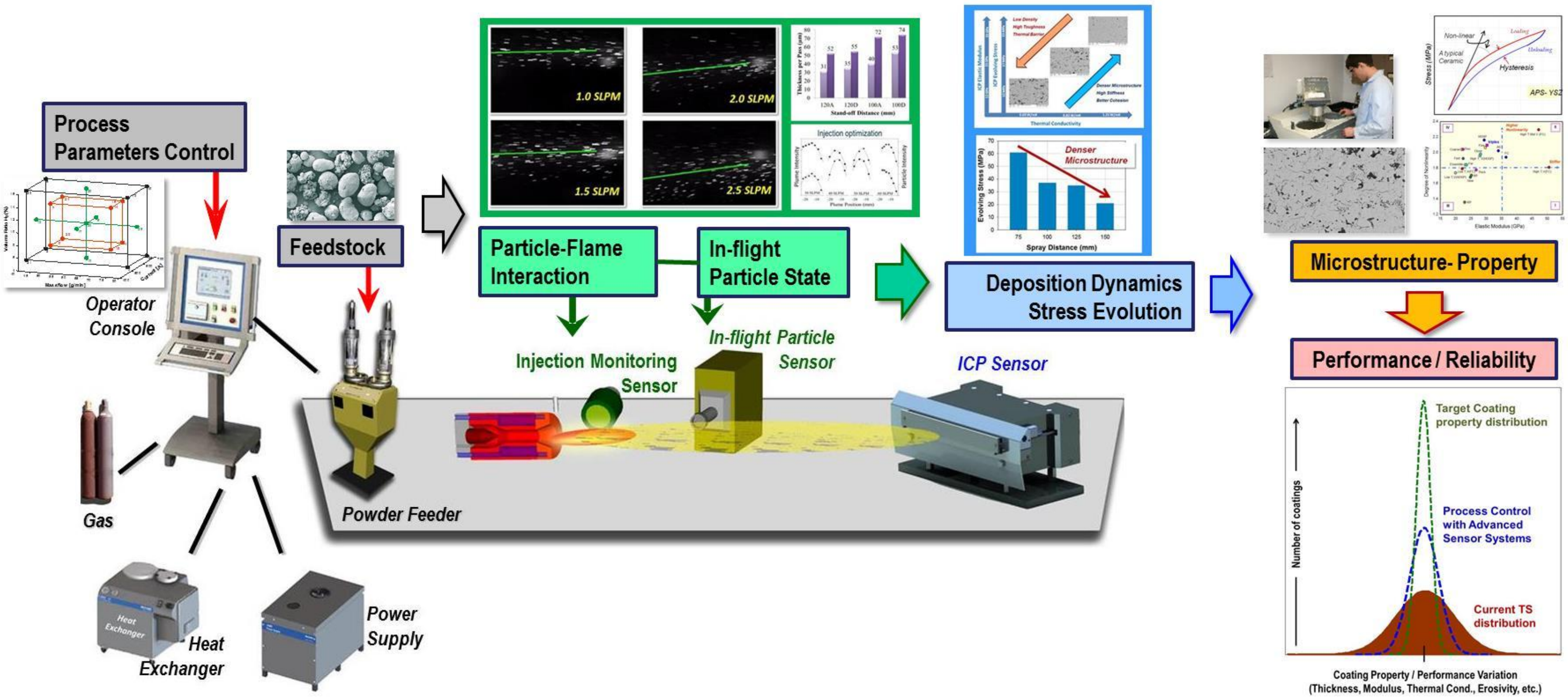
Tools for Measuring Deposit Evolution and Coating Properties



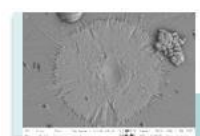
Particle State

- **Particle Velocity**
  - Kinetic Energy
  - Fluid dynamics
- **Particle Temperature**
  - Oxidation/decomposition
  - Rapid cooling/phase transformations

Local Deposition Temperature

- Intersplat bonding strength
- Wetting/ adsorbate- condensates
- Residual Stress (quenching-peening)

Materials intrinsic Properties



- Substrate-splat – adhesion interface
- Splat-splat-intersplat interfaces
- Interpass interfaces
  - Elastic –plastic behavior
  - High strain – strain rates
  - Heat transfer

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Material Compatibility
- Thermal mismatch

Minimal Coating Residual Stress
- Separated optic shape retention

Coating Adhesion
- Bond strength

Minimize Thermal Input to Mandrel
- Figure accuracy

No Damage from Particle Impact
- Optical surface distortion

Environmental Considerations
- Vacuum
- Outgassing

Prototype Multilayer Coated Electroformed Hard X-ray Telescope
(NASA/MSFC and Brera Obs.)

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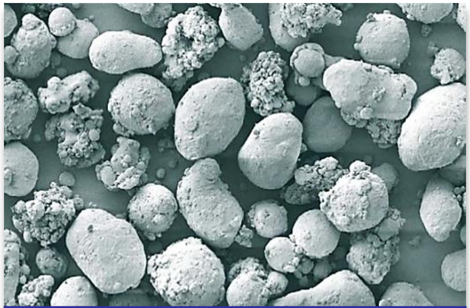
Defined Challenges	Proposed Mitigation Strategies
Light weight, rigid & high toughness carrier layer	▪ Base structure of Al_2O_3 or other porous ceramic coating ▪ Al_2O_3-Aluminum composite/functionally graded structure

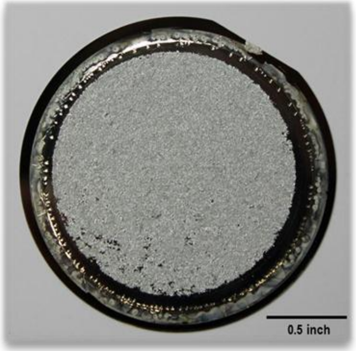


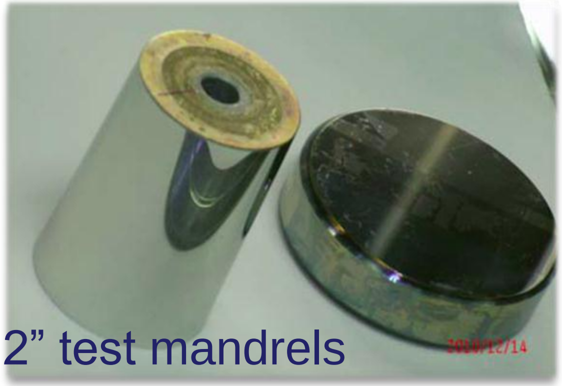
Aluminum Powder

Fine powder size to minimize particle energy

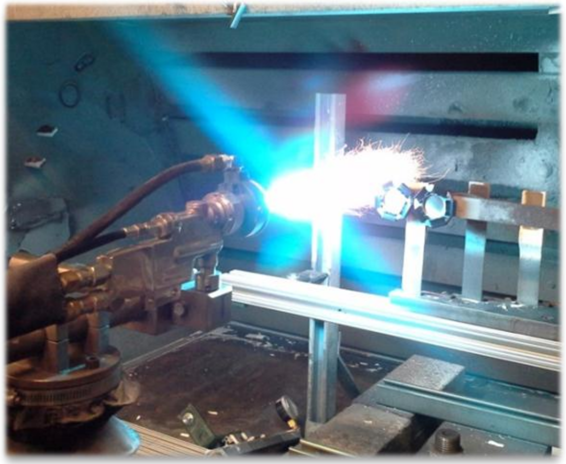
Initial Test Substrates

Evaluate potential particle damage using nickel and aluminum foil



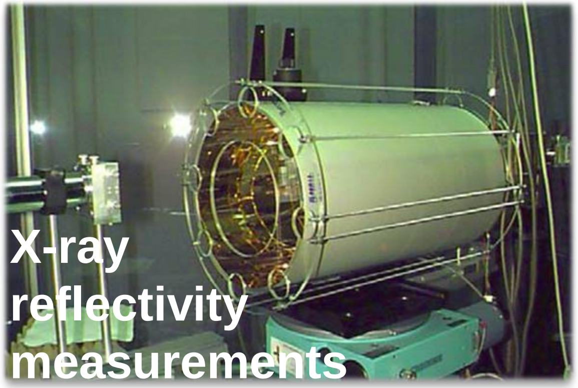


2” test mandrels



Flame Spray

Plasma Spray



X-ray reflectivity measurements

Process development using NiCo plated silicon wafers (due to mandrel availability), continued testing on flat and conical mandrels to evaluate X-ray performance

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