SAND2008-1506C

Graded-Density Thermal Spray Coatings for Light Gas Gun Flyer Plates

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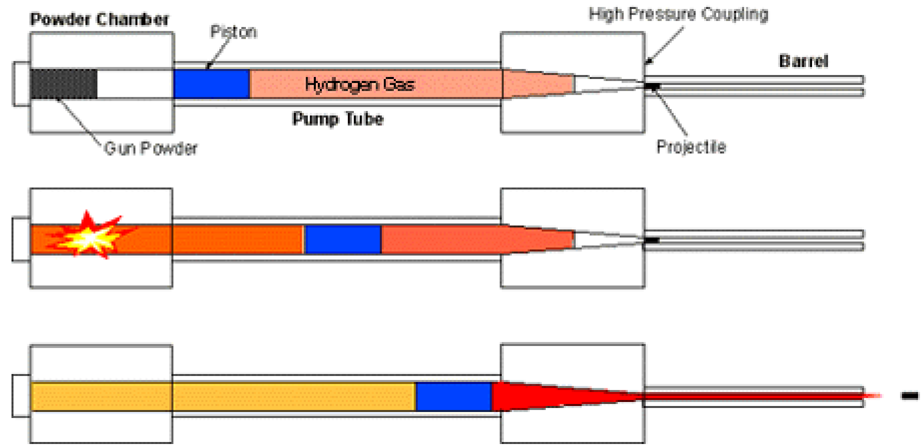
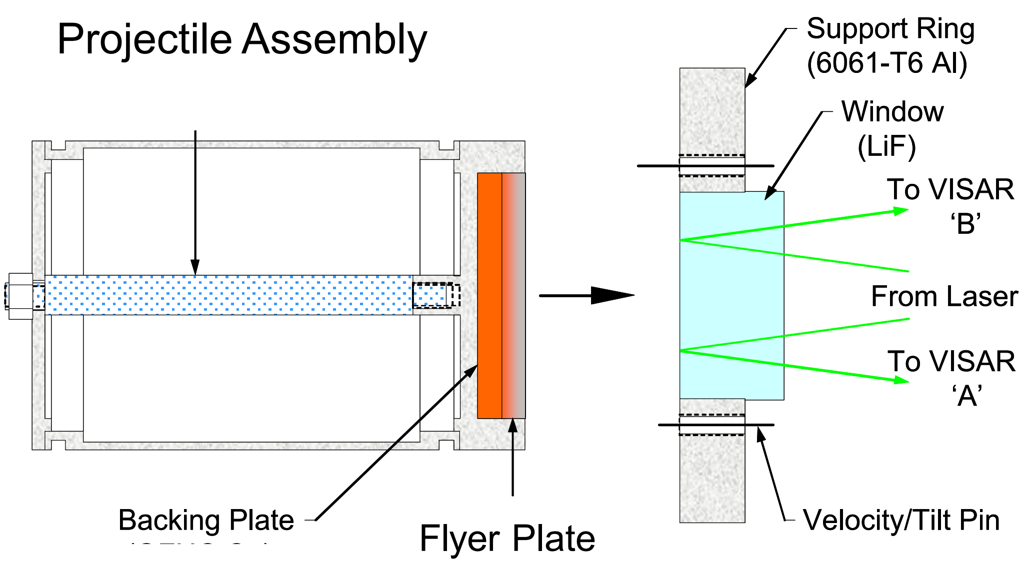
Application: Flyer Plate for a Light Gas Gun

Light gas guns are used to study high speed impact phenomena, such as:

- Formation of impact craters by meteorites
- Fundamental Theories for Fragmentation from warhead/armor interactions and orbital debris impact events.
- Hypervelocity Research for space asset survivability
- Compressive and Fracture Strength Properties of Materials



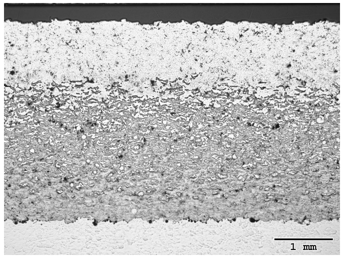
Projectile Assembly



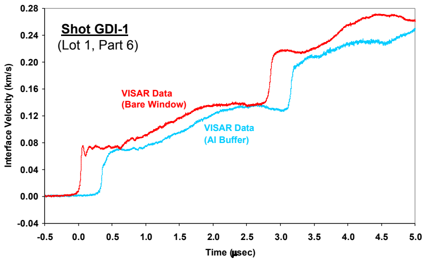
Sandia's Two Stage Light Gas Gun

Goal: Given a desired shock wave profile, predict the needed microstructure and create a flyer plate with that microstructure in the laboratory.

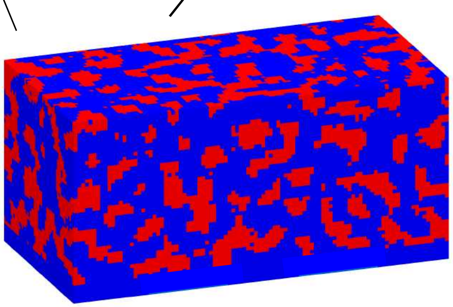
Processing



Microstructure



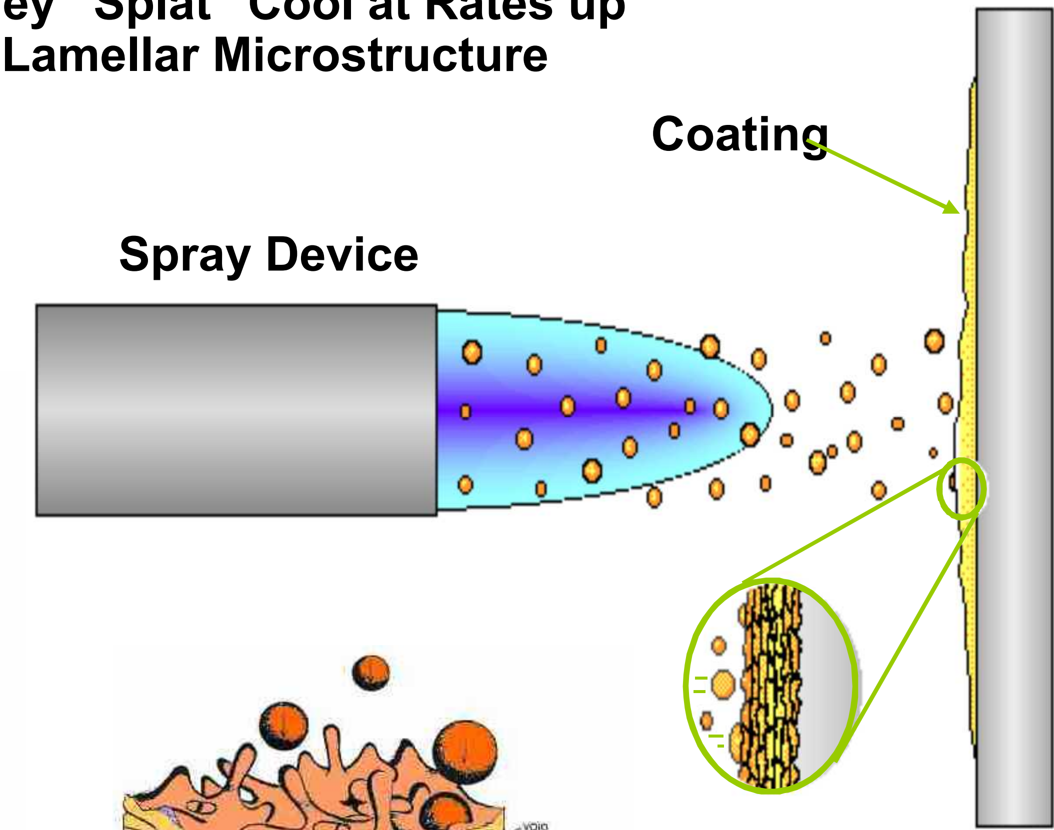
Properties

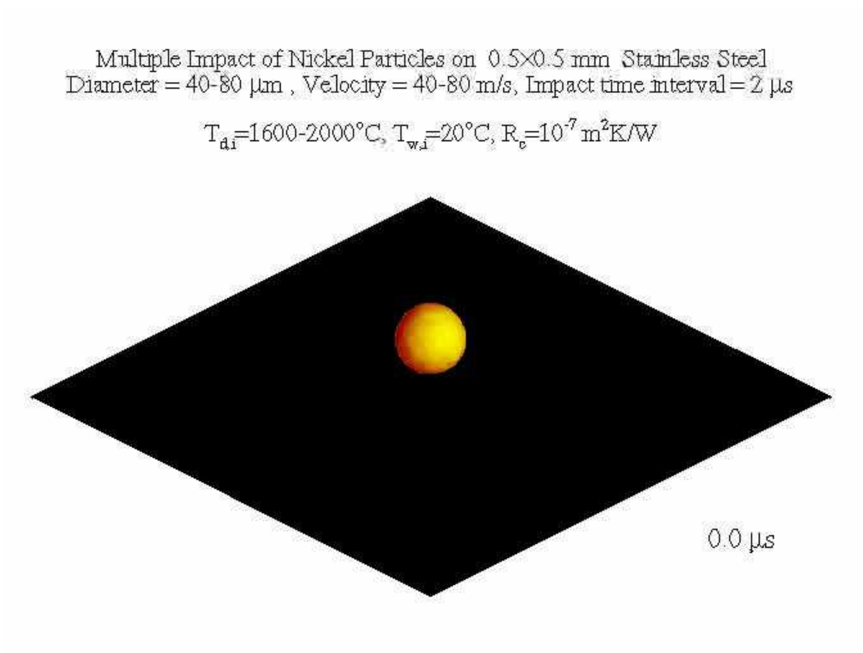


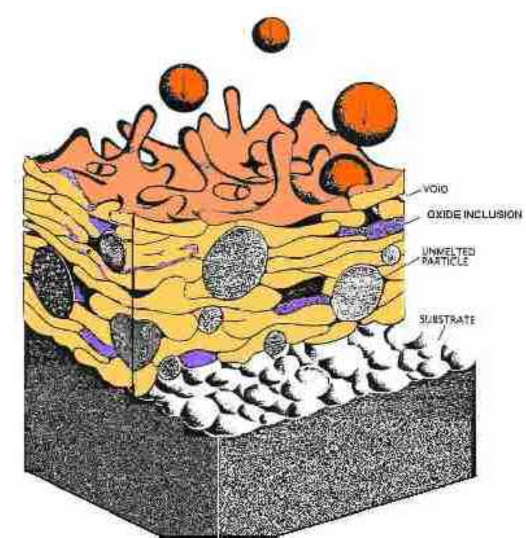
Materials Modeling Enables This Goal

What is Thermal Spray?

~ 10 - 100 µm Molten or Semi-Molten Droplets are Sprayed onto a Target Surface Where they "Splat" Cool at Rates up to 10^4 -10^8 K/sec Forming a Lamellar Microstructure

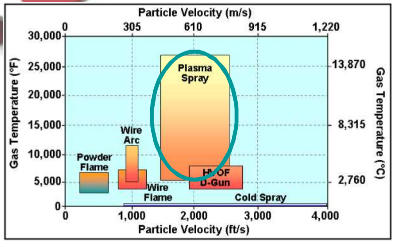


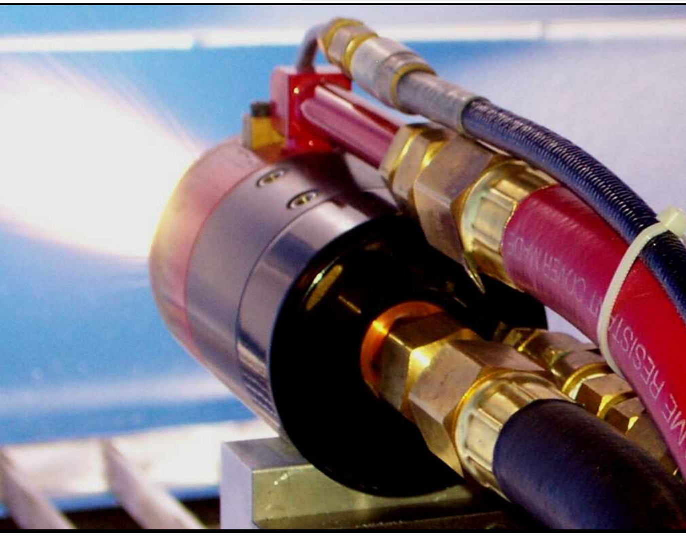




*Droplet Impact Simulation by Prof. J. Mostaghimi, et al, Univ. of Toronto, 1998.

Plasma Spray



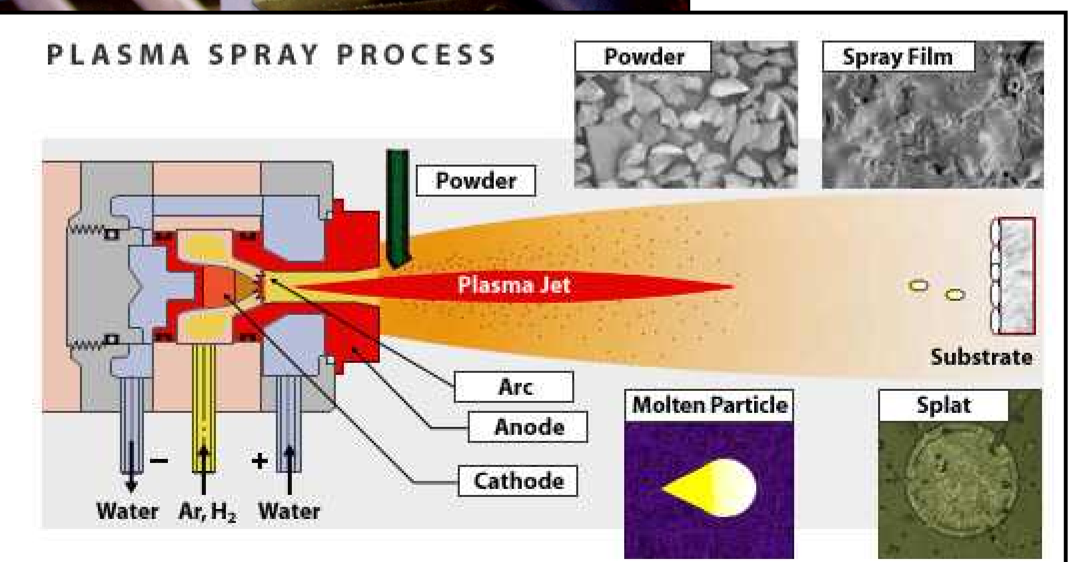


Air Plasma Spray

- DC Plasma heat source
- Metals, refractory metals, glasses, & ceramics
- Droplet deposition
- Most common plasma spray process
- I, V, & Gas Composition affect T_p & V_p

"Vacuum" Plasma Spray

- Plasma spray at ~ ½ atmosphere (380 torr)
- Thermal barrier coatings for gas turbine engines



Very Low Pressure Plasma Spray

- Plasma spray at 1.0 Torr (0.001 atm)
- Emerging Technology
- ~ 12 VLPPS systems in the world
- SNL has only VLPPS system in U.S.
- ***Droplet Deposition***
- ***& Vapor Deposition!***
- ***High density, oxide free coatings***
- ***Thin coatings (< 50 microns)***

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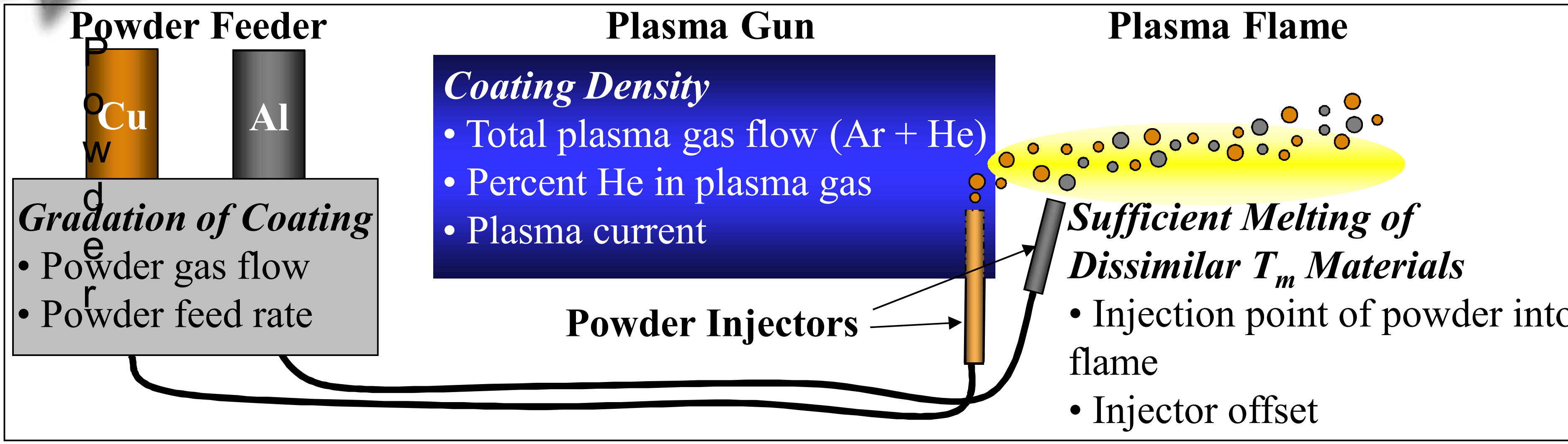
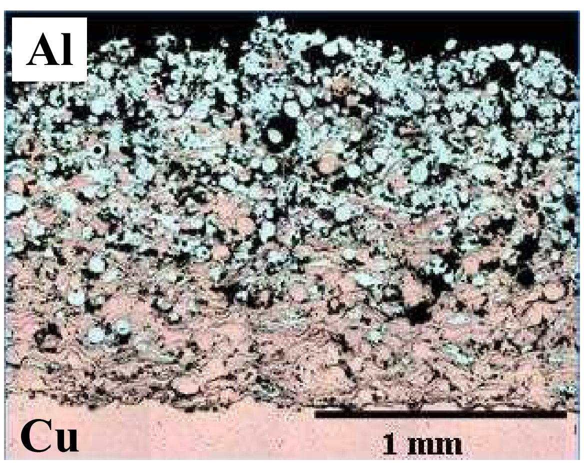
Control of plasma spray process parameters enable "designer" flyer plates to be prepared.

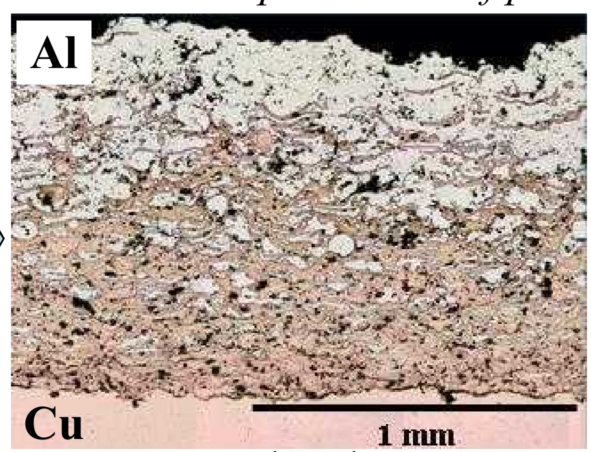
Coating properties were optimized by analyzing the effects of specific process parameters.



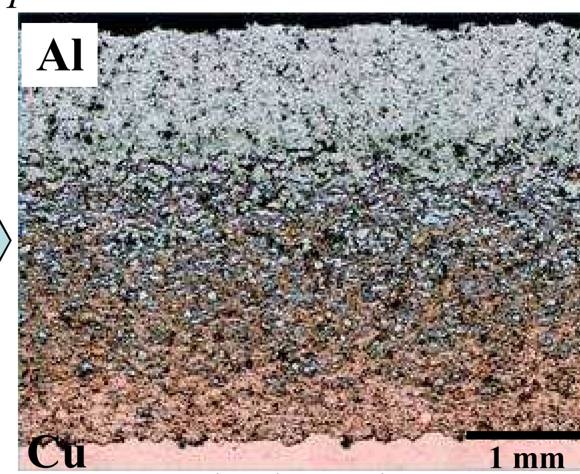
Resultant microstructures show optimization of process parameters.



Initial Coating

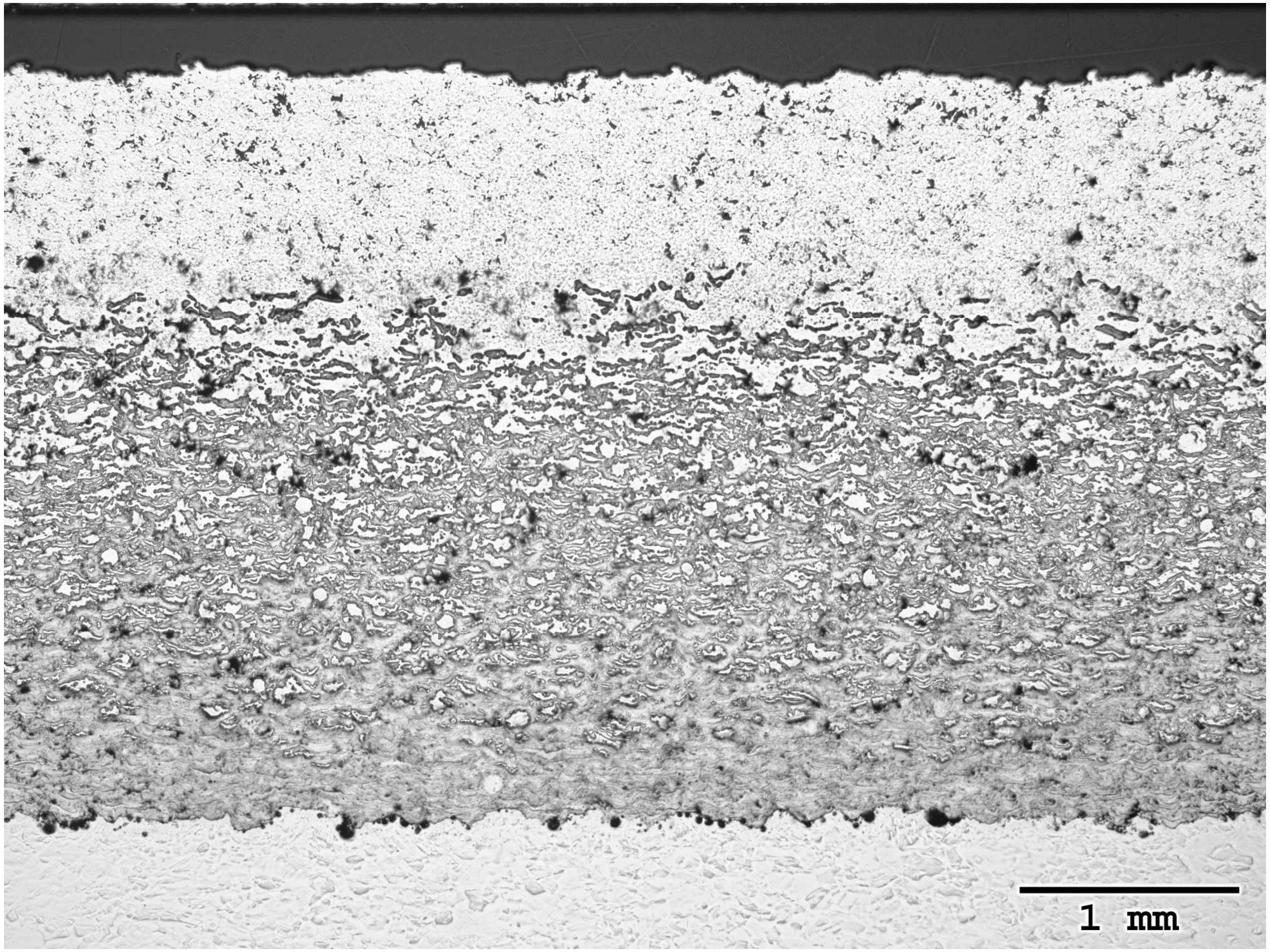


Process development decreased porosity and reduced unmelted particles



Final coating

Graded Density Flyer Plate

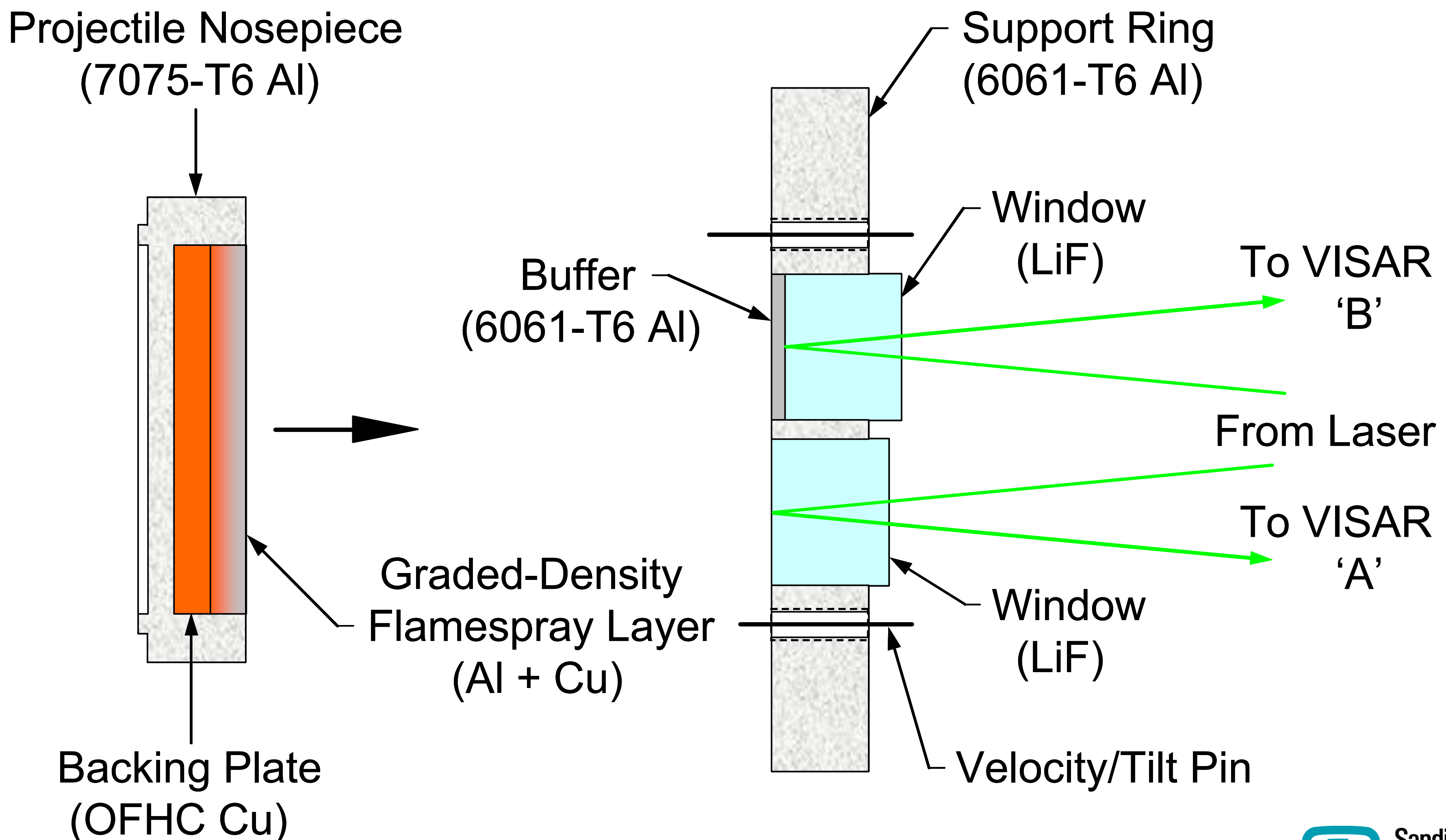


Total thickness ~3.34 mm
Graded layer ~2.56 mm
Aluminum top layer ~0.78 mm

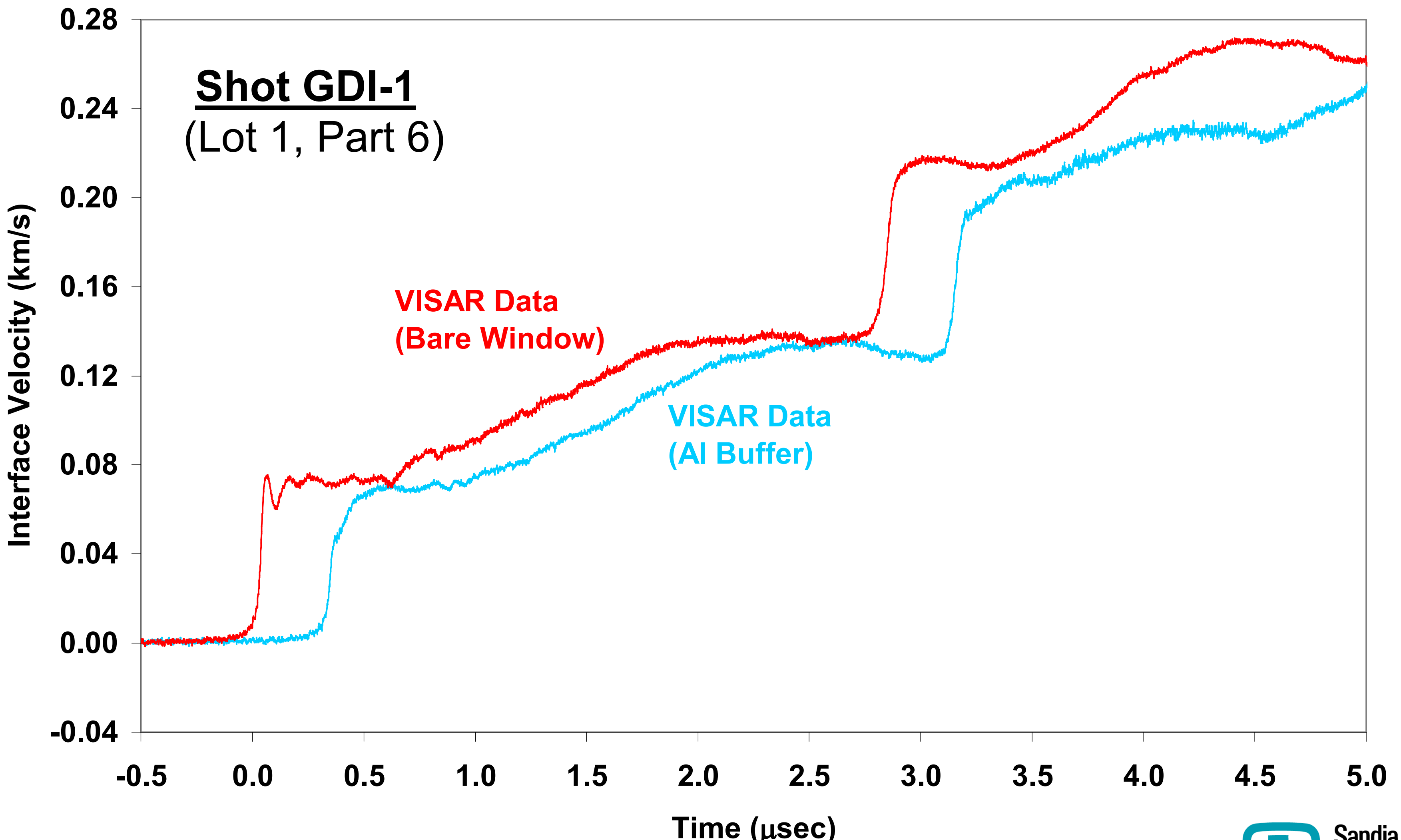
Nominal Test Conditions

- *Shock/isentropic compression* ***VISAR measurements on*** *buffered and unbuffered lithium fluoride windows*
- *Graded-Density Impactor*
  - ***aluminum + copper***
  - ***launch velocity = ~0.30 km /s***

Test Configuration – Shot GDI-1



Shot GDI-1



Shot GDI-1
(Lot 1, Part 6)
VISAR Data
(Bare Window)
VISAR Data
(Al Buffer)
Interface Velocity (km/s)
Time (μsec)
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
-0.04
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

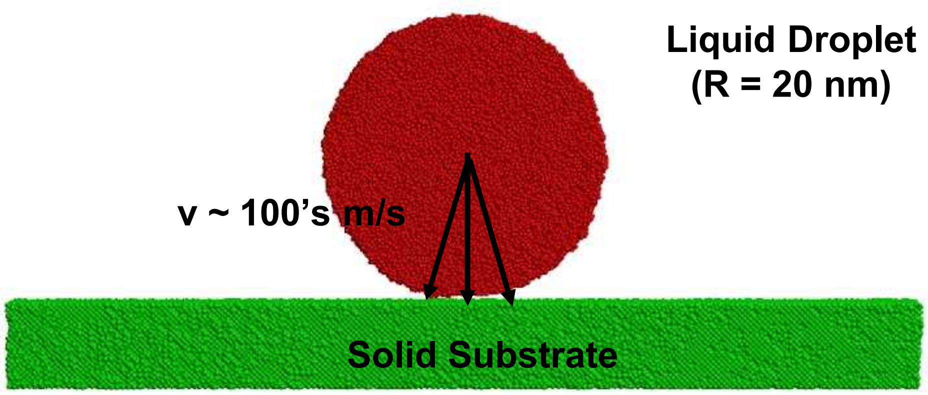
Fundamental Modeling of Flamespray Droplet Deposition

- **Significant continuum modeling exists for droplet deposition**

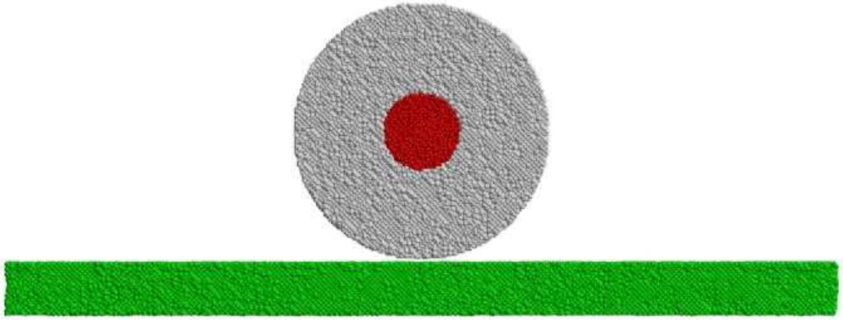
- ***Primary shortcoming identified: chemical effects (e.g. contact line behavior must be revealed with greater accuracy)***

- **Solution: use atomic scale simulation to study (with very high physical fidelity) molten droplet deposition onto a solid substrate**

- **Specify deposition conditions precisely (droplet size, velocity, temperature, phase, impurities)**

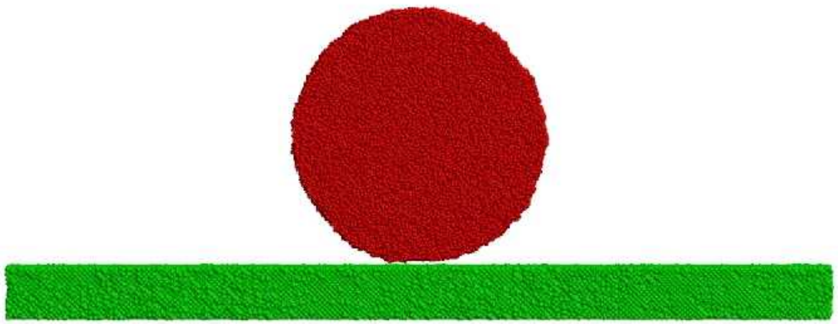


Fundamental Modeling of Flamespray Droplet Deposition



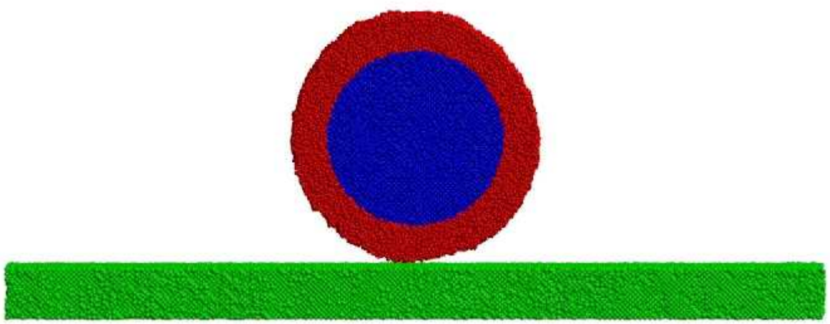
Partially Solidified (longer flight time)

white - solid 'skin'
red - liquid 'core'



Fully Molten on Impact

red - liquid



Partially Melted (low torch E)

red - liquid 'skin'
blue - solid 'core'

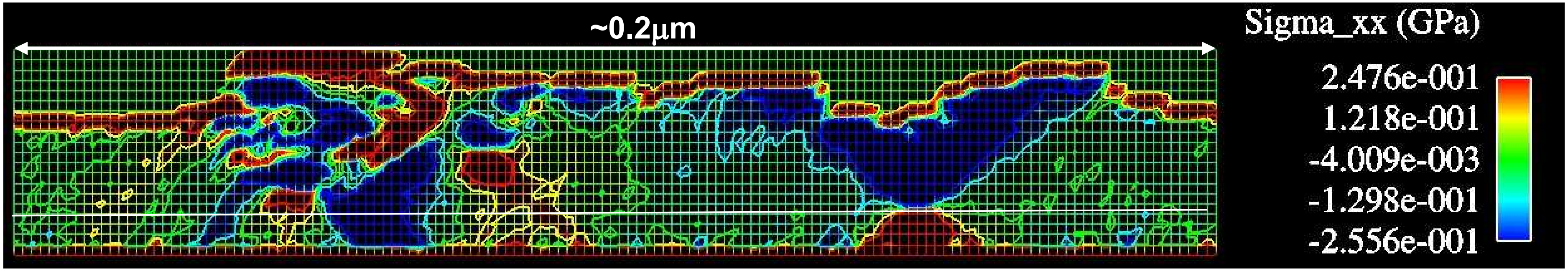
***Result*: Atomic scale resolution deposition simulations guide development of larger scale structure generation models, connecting flame-spray microstructures to processing conditions.**

Calculating Residual Stress in a Deposited Film

- Grid system into volume elements
- Self-consistent method for computing stress in each element

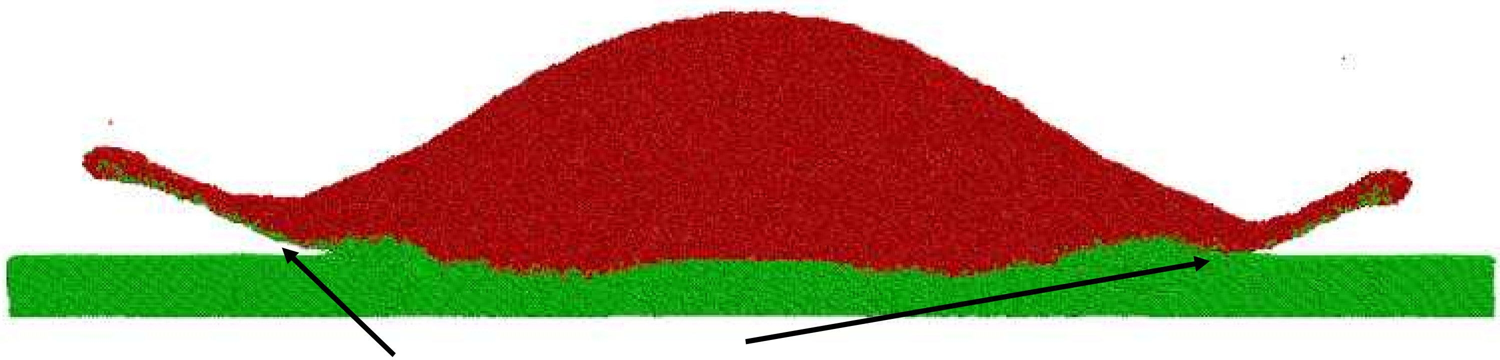
Visualize in *Ensight*

Cross-section image of film and stress distribution between -250 and +250 Mpa.



***Result*: This reveals how processing parameters affect residual stress, providing valuable information for deterministic engineering of stress in flame spray deposited films.**

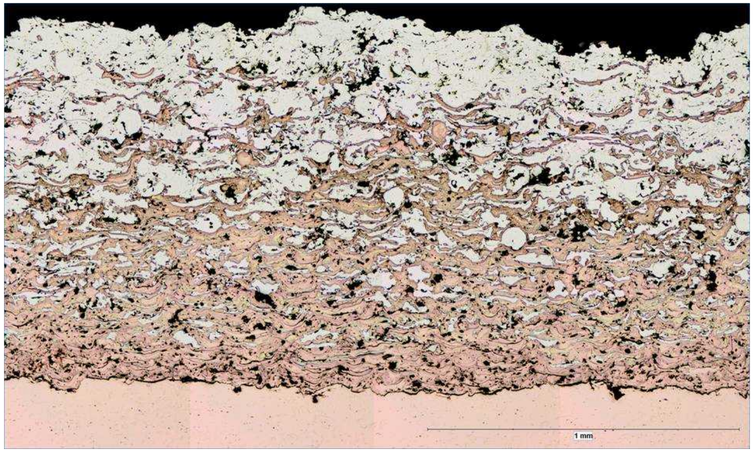
Fundamental Modeling of Flamespray Droplet Deposition



Complex chemical/physical effects naturally captured in this scale of simulation: **fragmentation** for appropriate combinations of size, velocity, and wettability

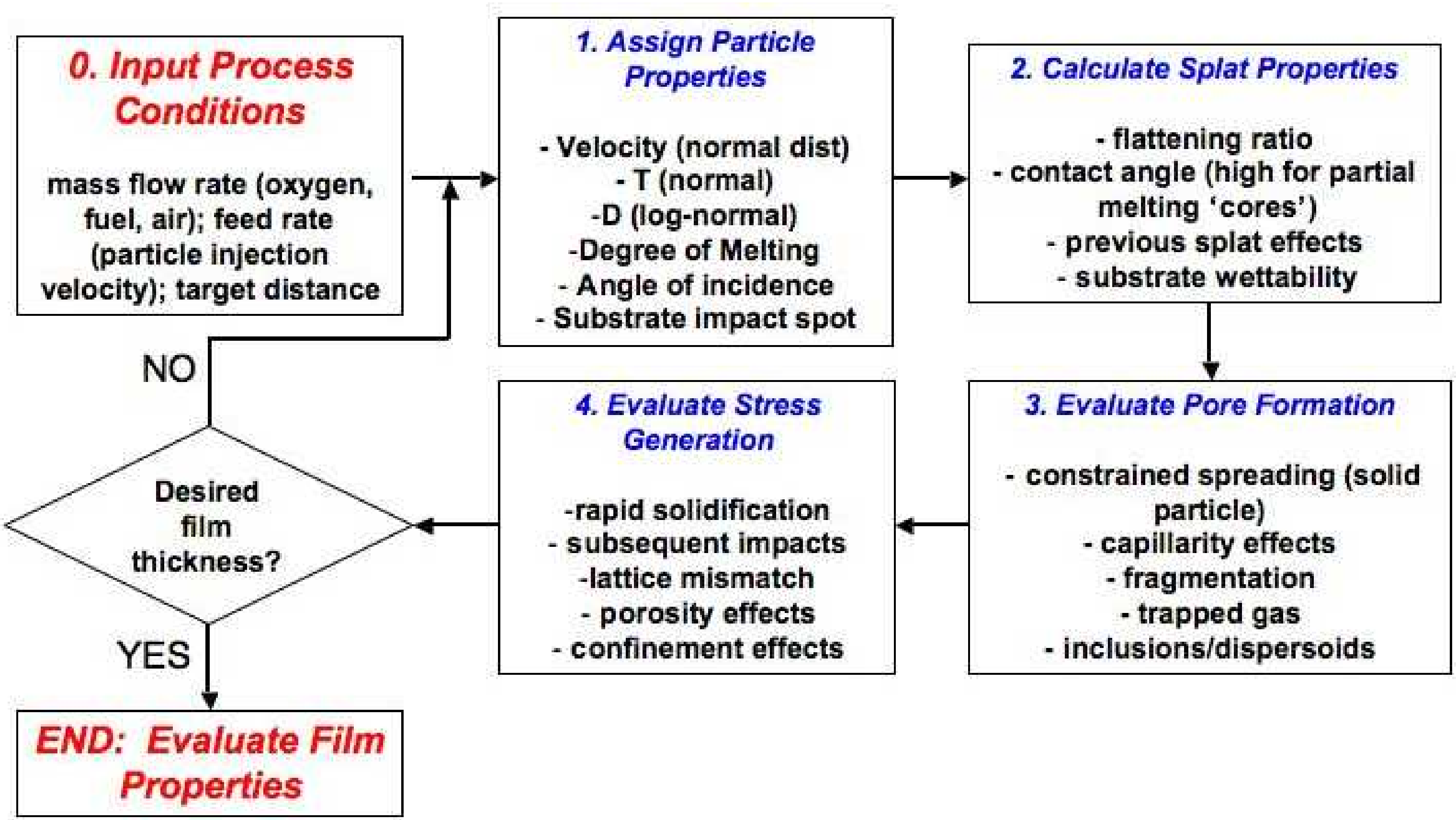
Result: **Detailed structure/processing relations developed from processing experiments in combination with atomistic simulations must be incorporated into coating build-up model**

Coating Microstructure Generation Modeling

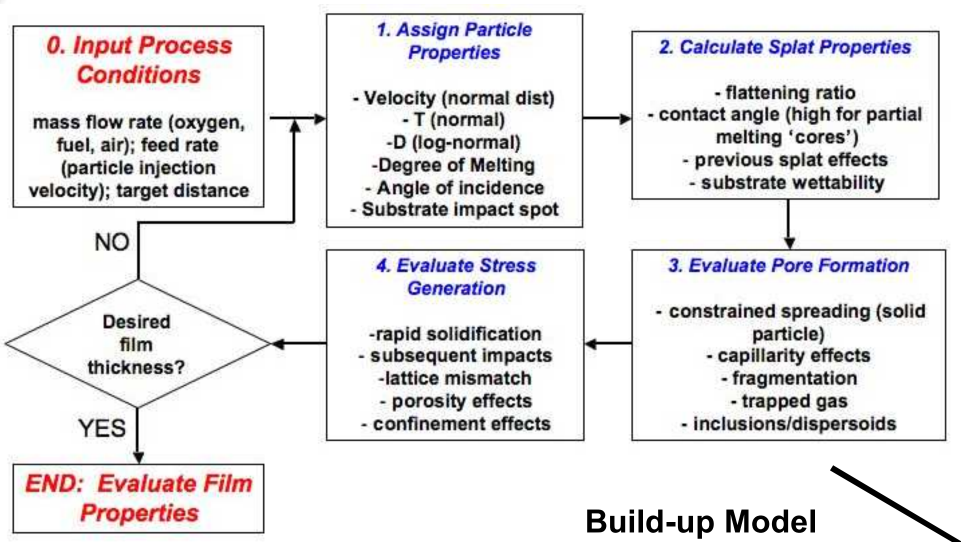


We require a larger length scale "coating build-up" model capable of producing microstructures based on input processing conditions using rules developed from experiment and simulations.

Coating Microstructure Generation Modeling

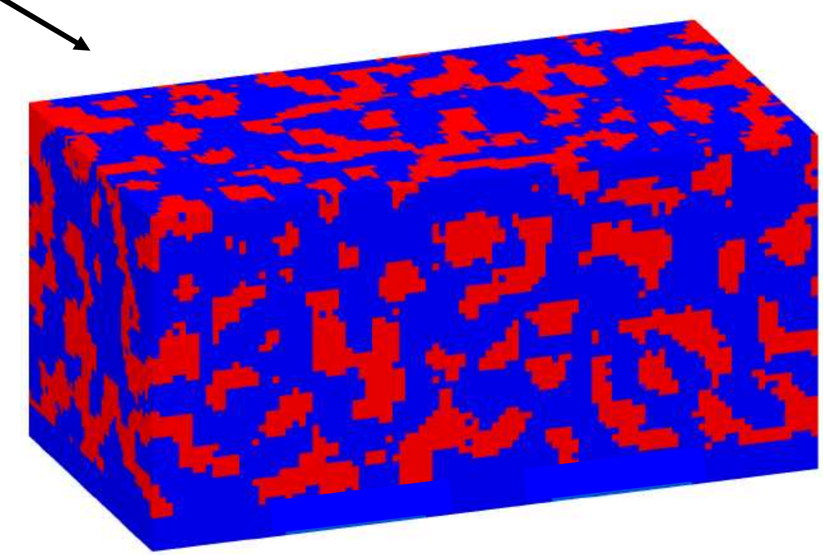


FY07 Result: Coating Microstructure Generation Modeling



Build-up Model

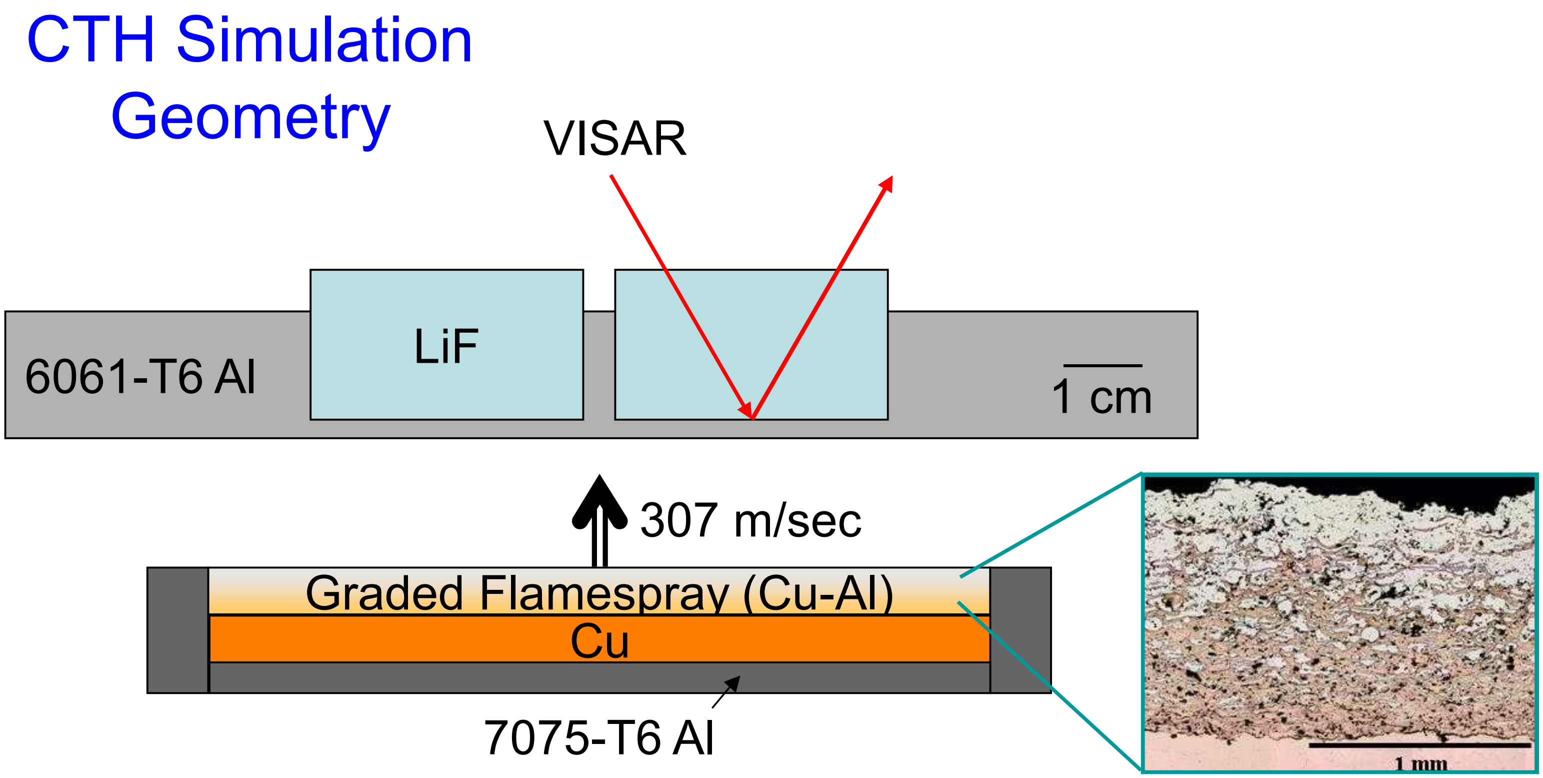
Generated Microstructure



Result: The capability to generate model coatings permits interaction with developing capability to model the response of such coatings to high strain rate deformation, thereby ***completing the process-structure-properties information loop.***

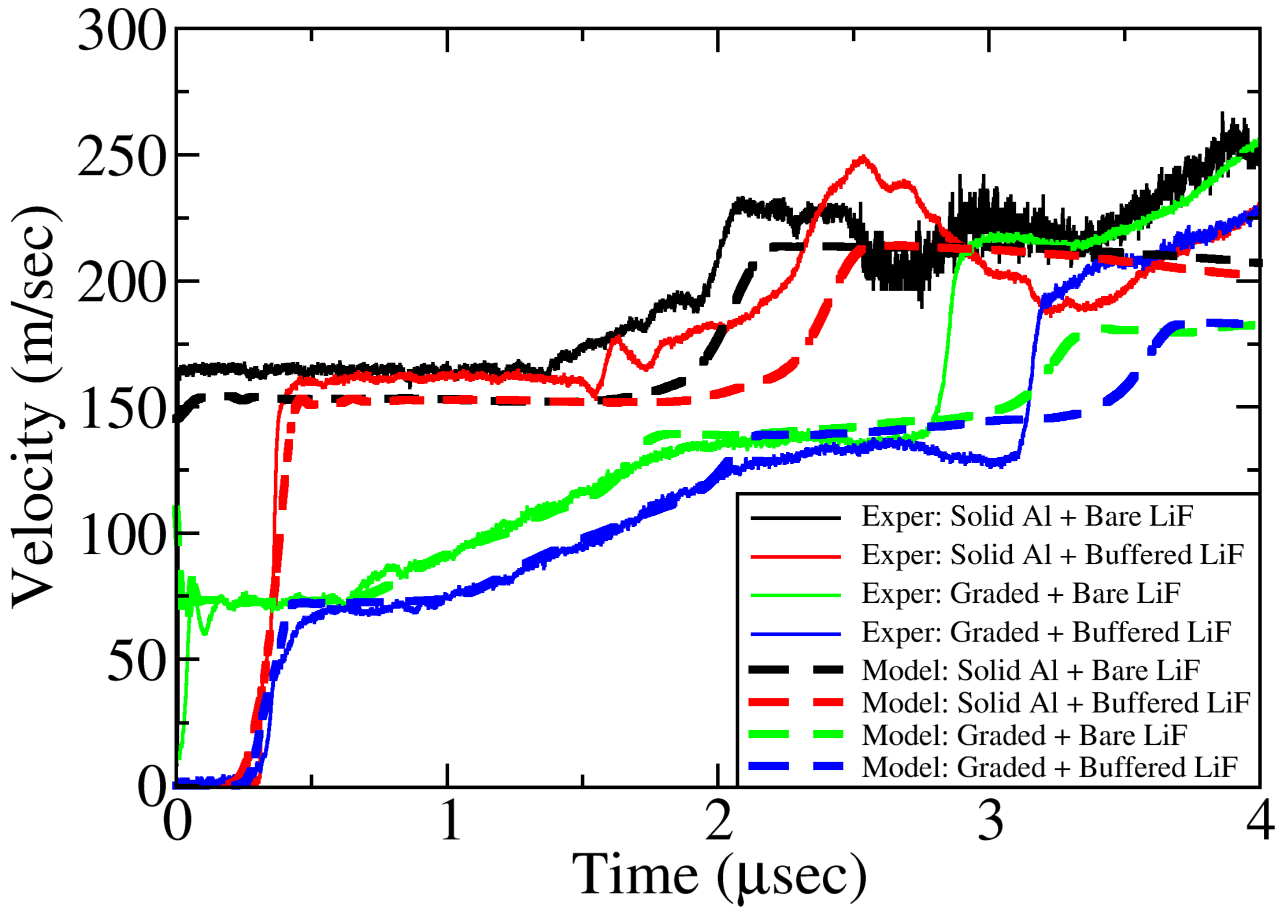
Comparing Model Shock Response to Experiment for GDIs

- ***We have implemented a microstructure aware shock performance model to couple to experiments.***



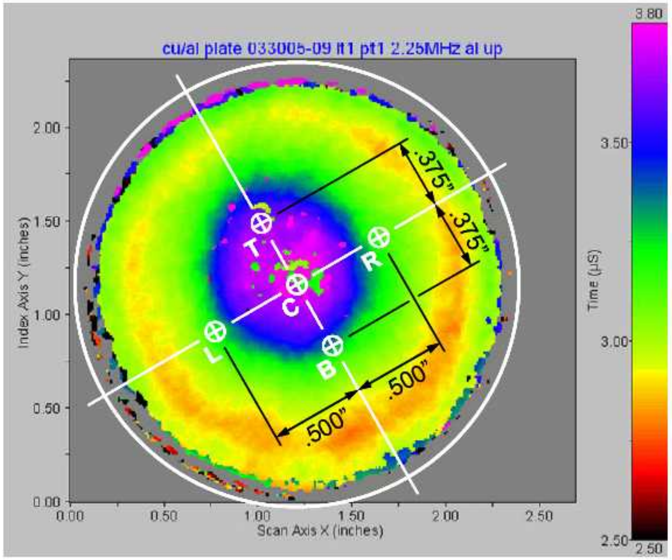
Microstructure Aware Shock Model Validation

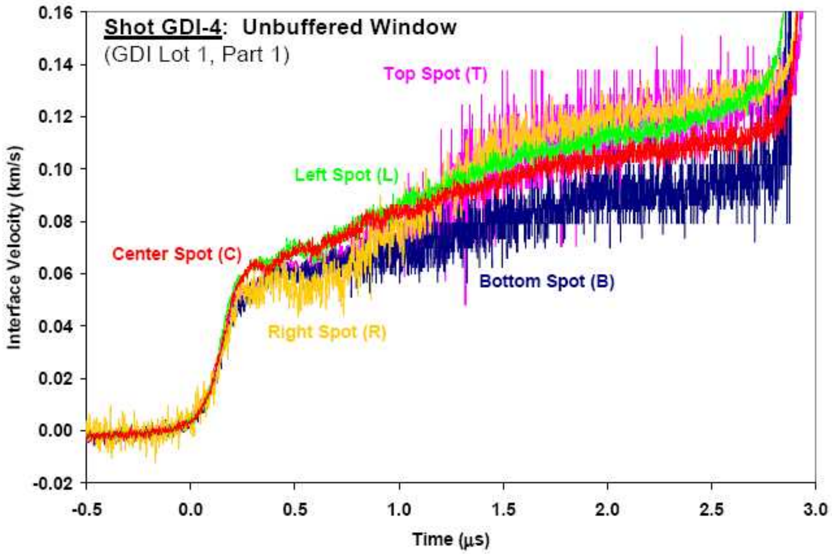
- ***Compare model results to shock experiments for regular and graded density impactors***

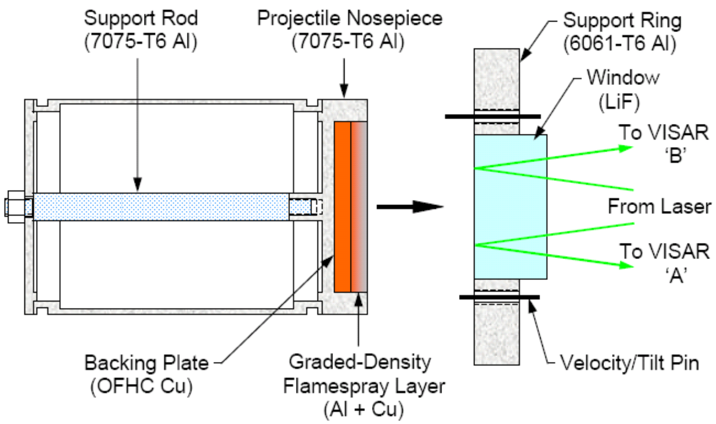


Model Validation

Uniformity of Flyer Plates is a Challenge







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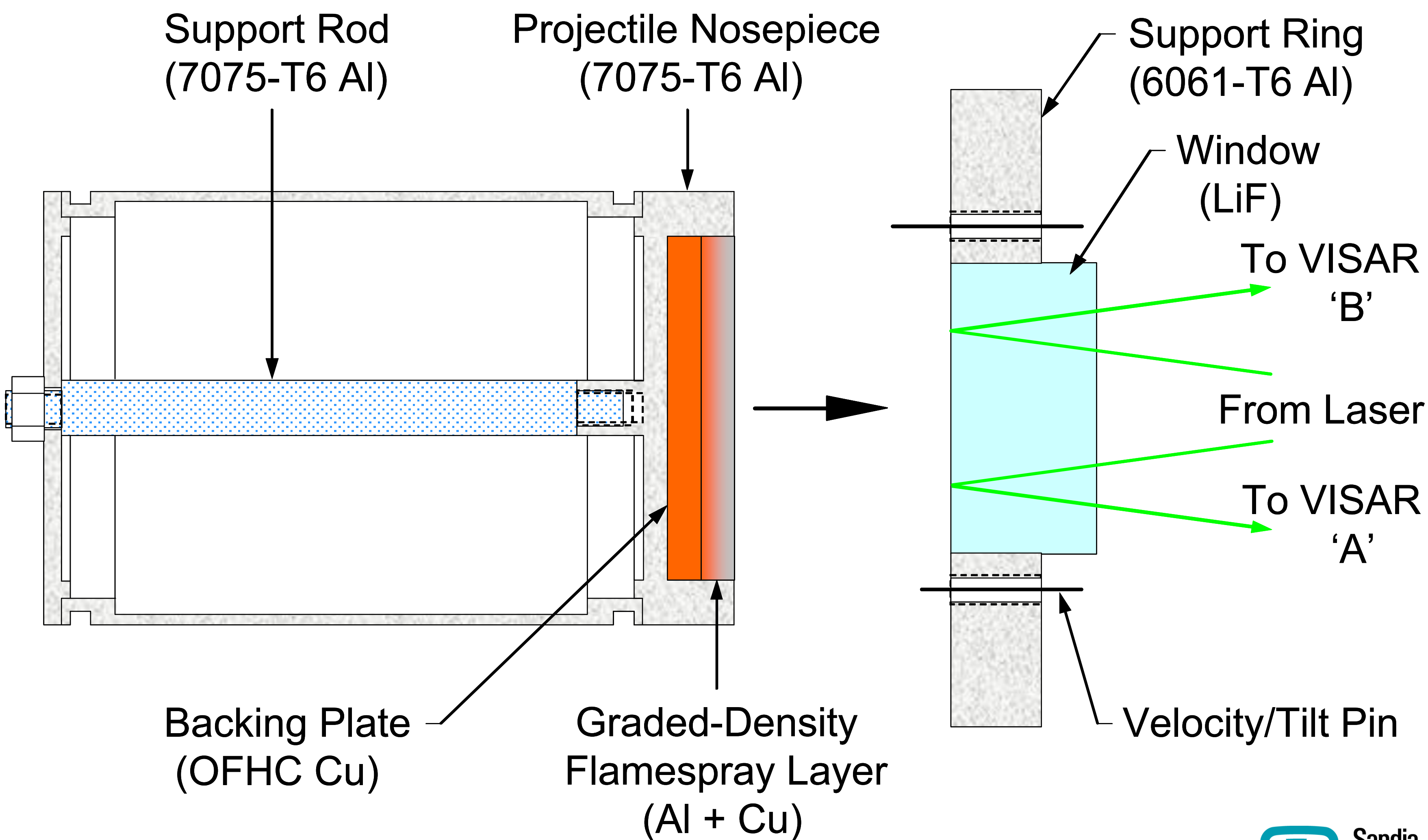
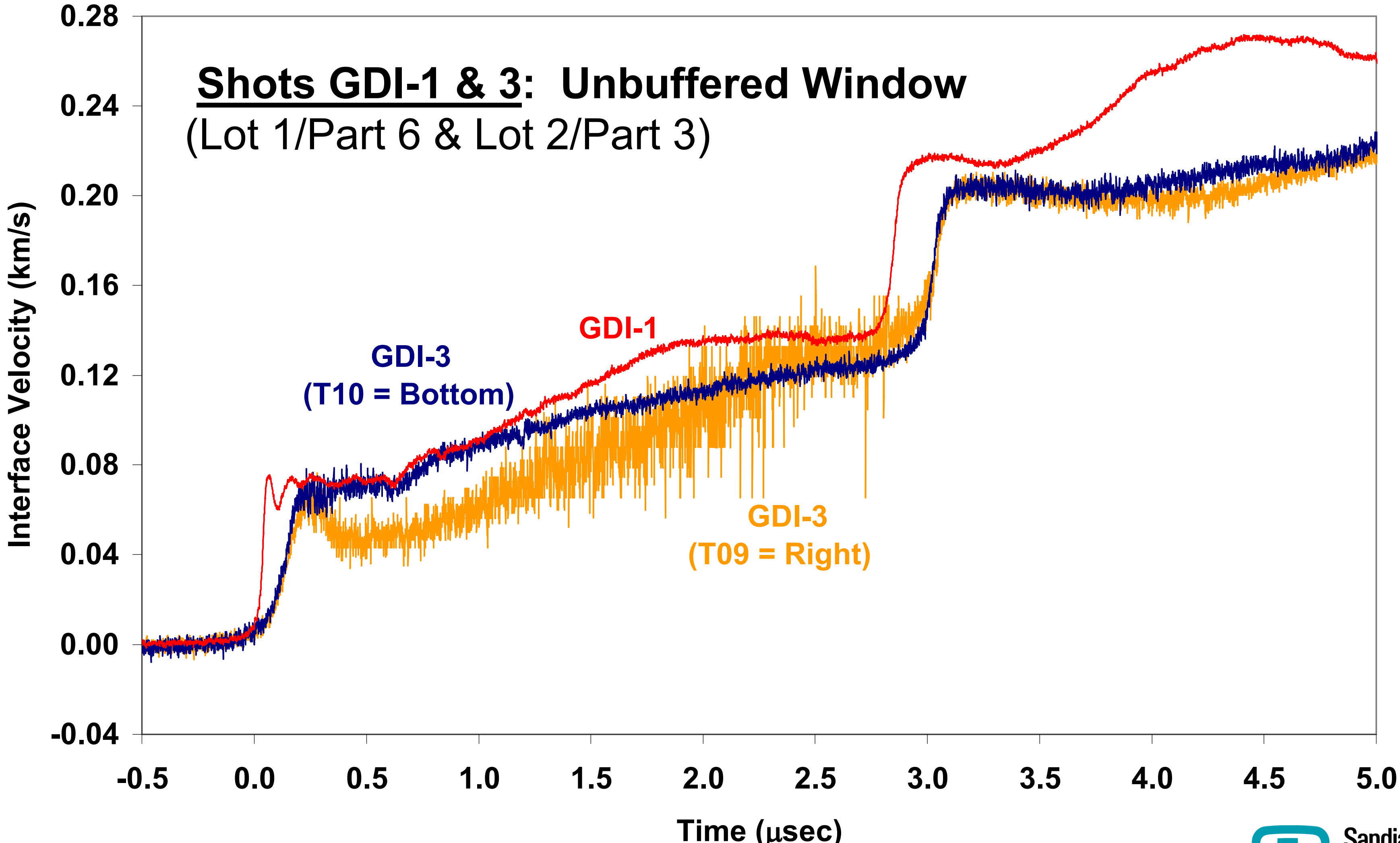
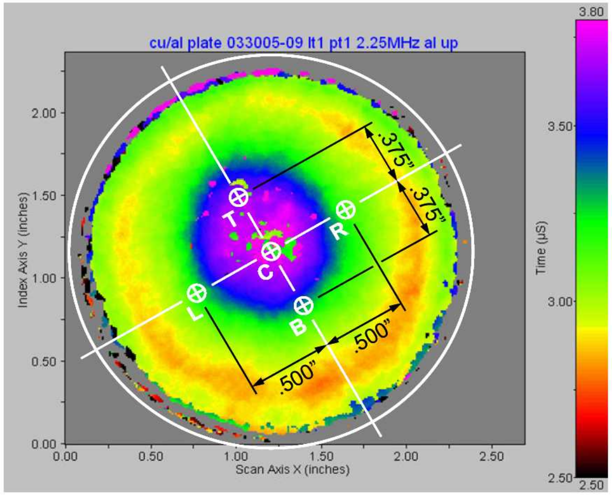
Test Configuration – Shot GDI-3



Shots GDI-1 and 3

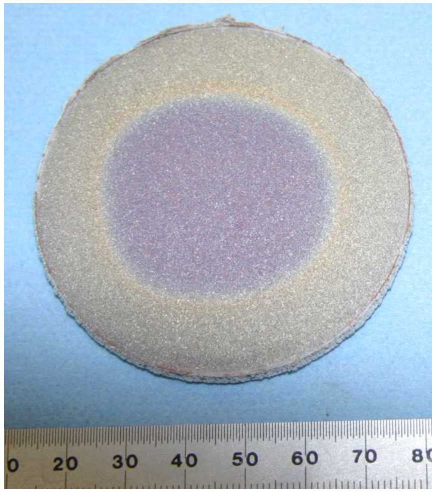


Source of flyer plate non-uniformity has been identified and corrected (we think)!

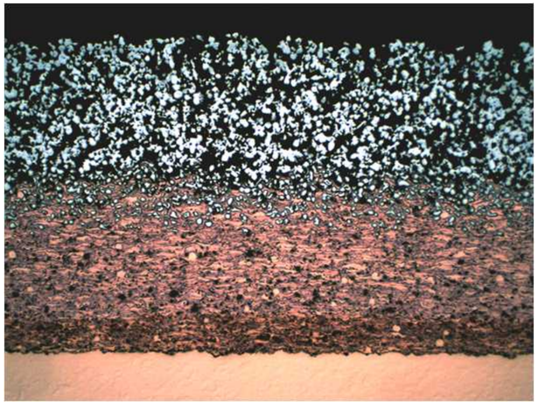


Ultrasonic time of flight scan showing non-uniformity in early GDI flyer plates

Oxidation within the coating has been identified as the most likely source of non-uniformity.



New flyer plate showing thermal oxidation on underside of graded density coating



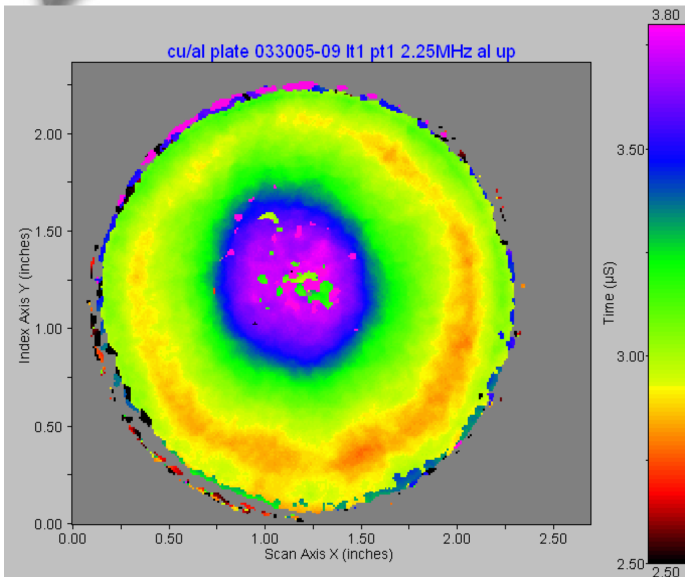
Cross section of uncooled flyer plate showing thermal oxidation near substrate interface.

Note: Continued process development is underway to reduce porosity in Aluminum layers.

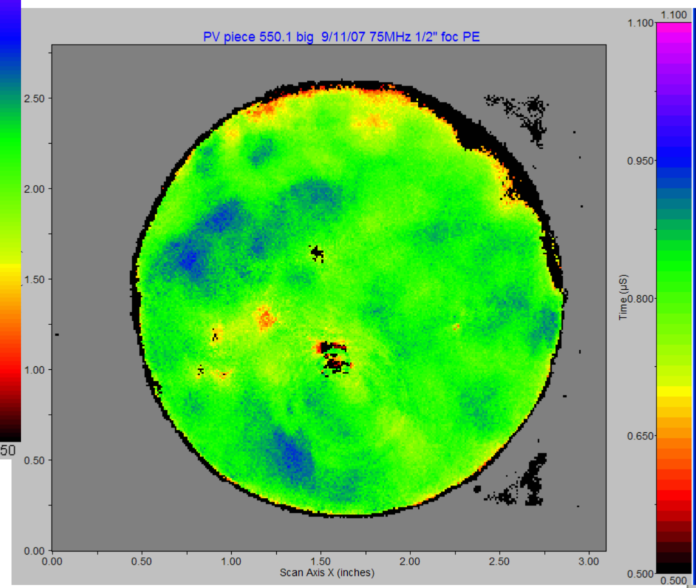
***Solution*: New spray pattern and fixturing allows flyer plates to be prepared more quickly and with improved temperature control.**

Time-of-Flight Comparisons

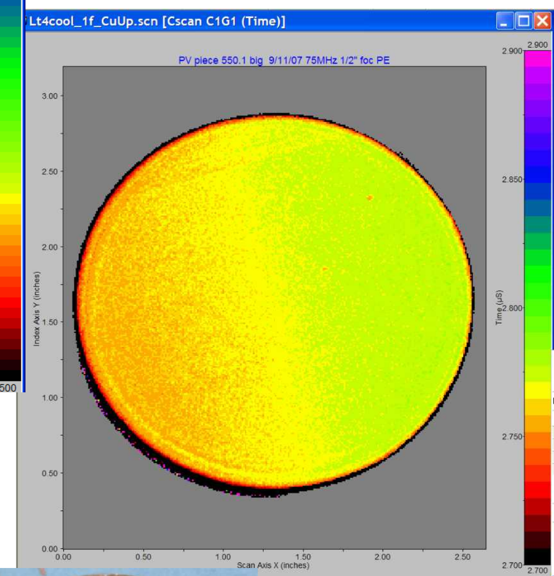
Early Non-Uniform Flyer Plate



New spray approach w/o cooling



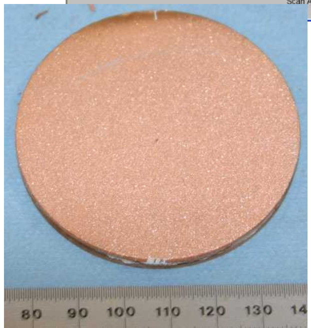
New spray approach with cooling



Distinct attenuation pattern

Random Attenuation Patterns

Time of flight scans show that new flyer plates are significantly more uniform than earlier flyer plates.



Oxide free flyer plate, showing underside of graded density coating

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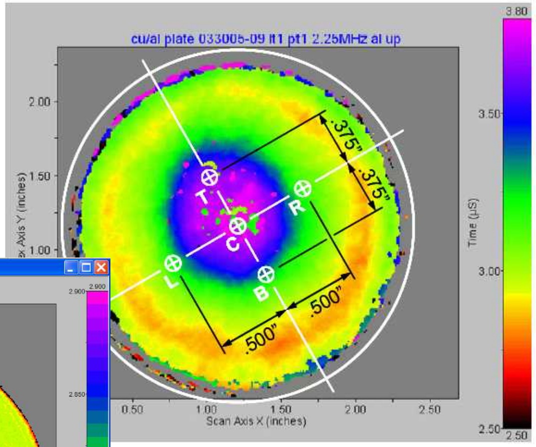
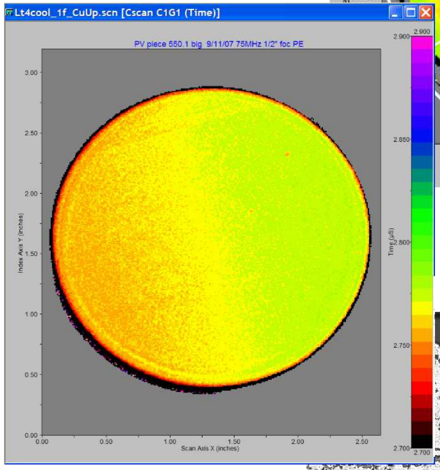
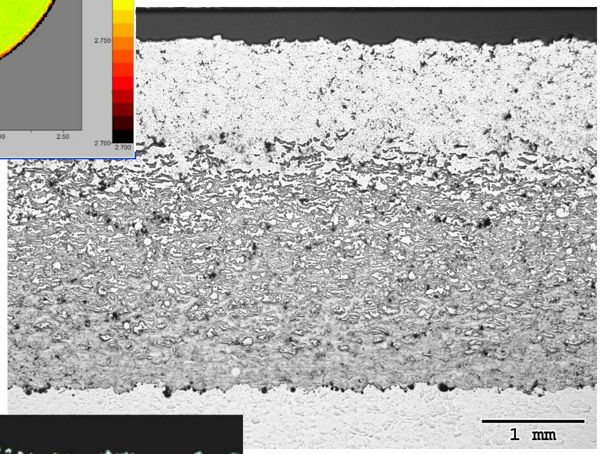
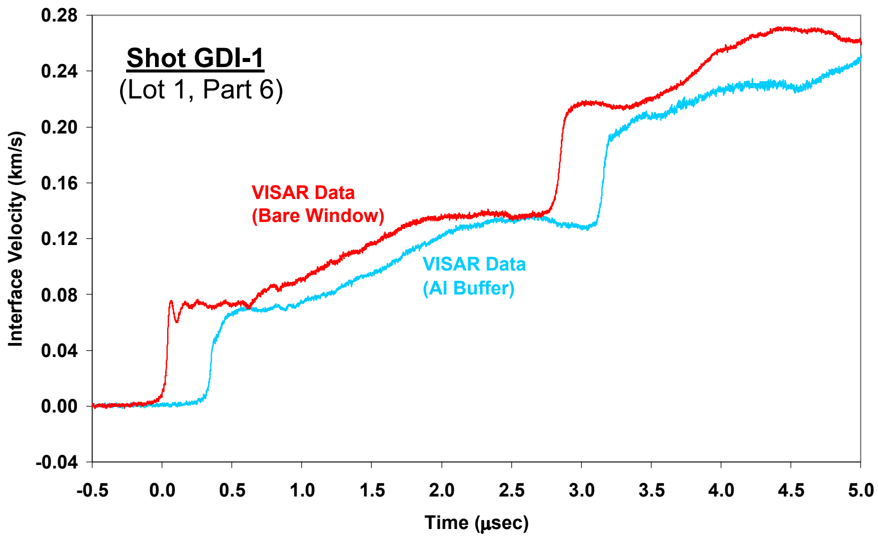
Summary

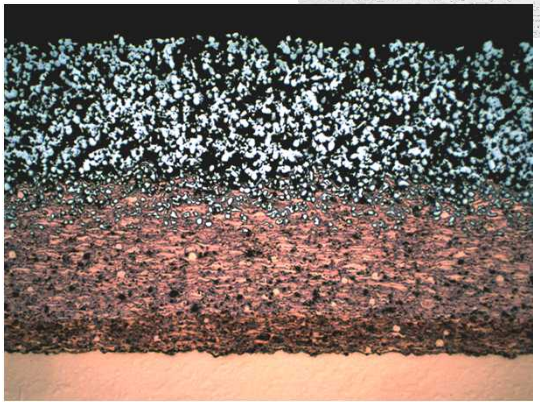
- Graded density coatings prepared.
- Linearly ramping loading demonstrated.
- Source of non-uniformity identified.
- Process improved to reduce non-uniformity.
- Samples are being prepared for more light gas gun testing to demonstrate spatial uniformity.
- Ability to predict flyer plate properties demonstated.











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