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Impact Response of Thermally Sprayed Metal Deposits

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Sandia National Laboratories

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

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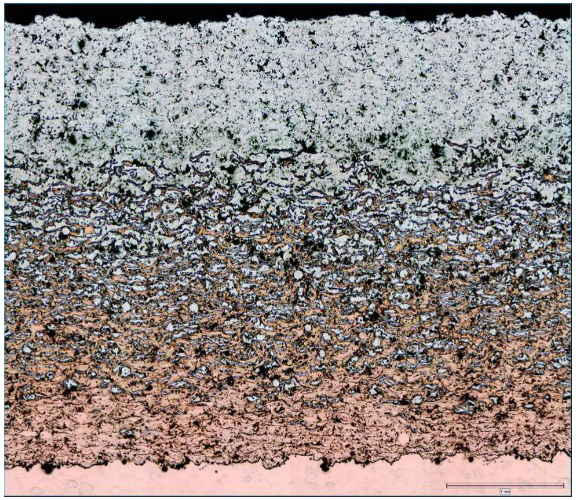
Motivation

- ***Additive Manufacturing (AM) processes are being considered, and ultimately adopted, for an ever-increasing range of applications.***
- ***Sandia capabilities include:***
  - Laser Engineered Net Shaping™ (LENS®);
  - Thermal Spray Research Laboratory (TSRL).

1.0 mm

LENS® 304L Stainless Steel (EBSD image)



1.0 mm

Thermally Sprayed Cu + Al Graded Coating

Project Objectives

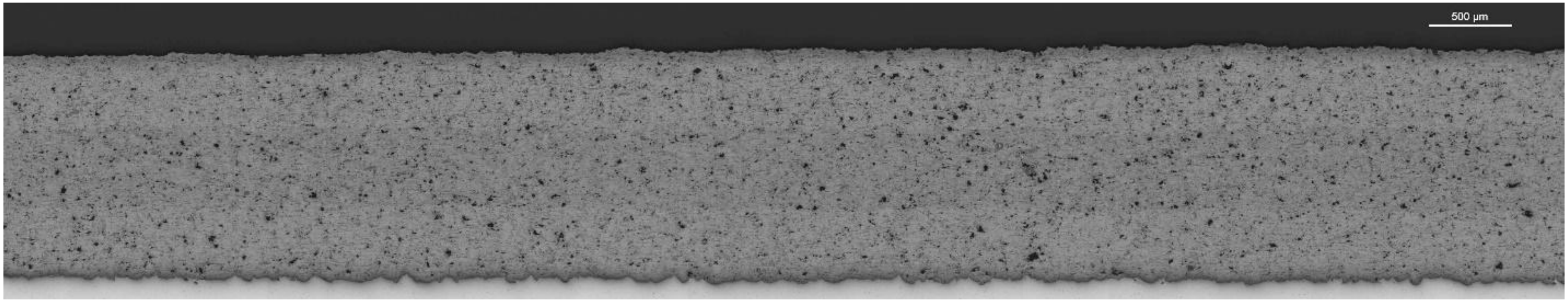
- ***Characterize the high-strain-rate behavior of thermally sprayed tantalum (Ta) deposits with focus on stochastic effects arising from random, spatially dependent microstructural variations in:***
  - material texture, composition & contaminant content (*e.g.*, oxides, nitrides, other impurities);
  - grain/splat & pore morphology (*e.g.*, size, shape, orientation, boundary properties);
  - microfracture & defect morphology.

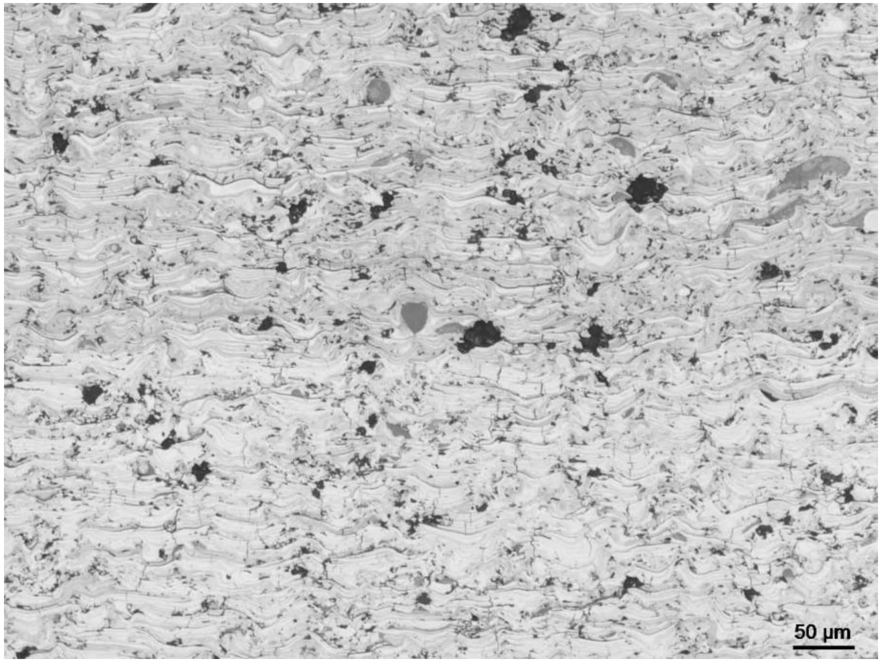
Tantalum Sample Preparation

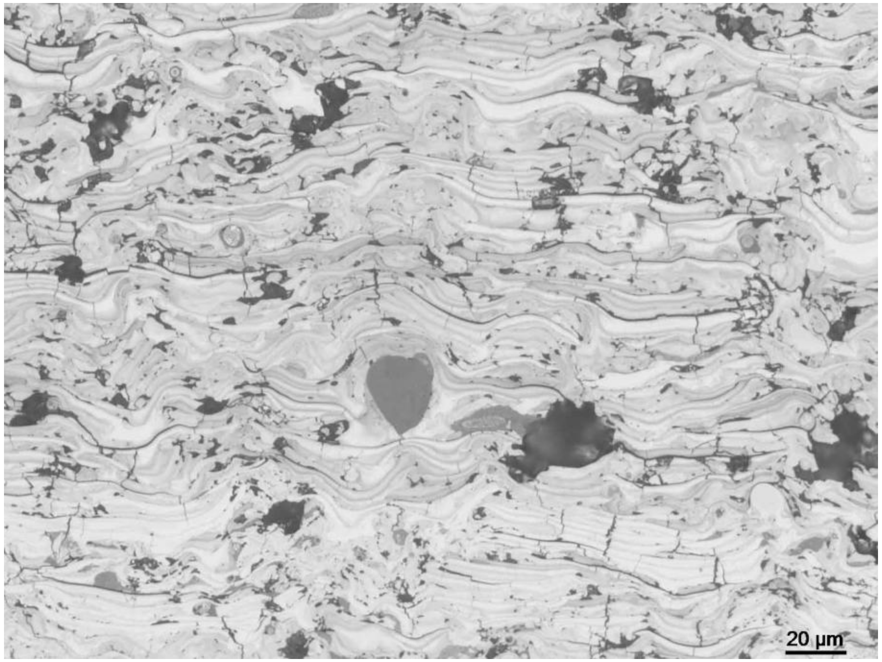
- ***Air Plasma Spray (APS) Process***
  - spherical, high-purity tantalum powder feedstock;
  - fluidized bed powder feeder (Oerlikon Metco);
  - APS torch (Praxair) with internal powder injection for generation of molten Ta droplets;
  - 6-axis robot (ABB) for control of torch traverse speed (150 mm/s) & standoff distance (127 mm);
  - deposition on grit-blasted 6061-T6 aluminum plate (12.7-mm thk).

- ***Machining***
  - round coupons extracted from sprayed plates using electrical discharge machining (EDM);
  - smaller samples for transmitted wave (*i.e.*, forward ballistic) impact experiments separated from baseplate using EDM;
  - free surfaces polished flat prior to shot assembly.

Optical Metallography of Ta Film







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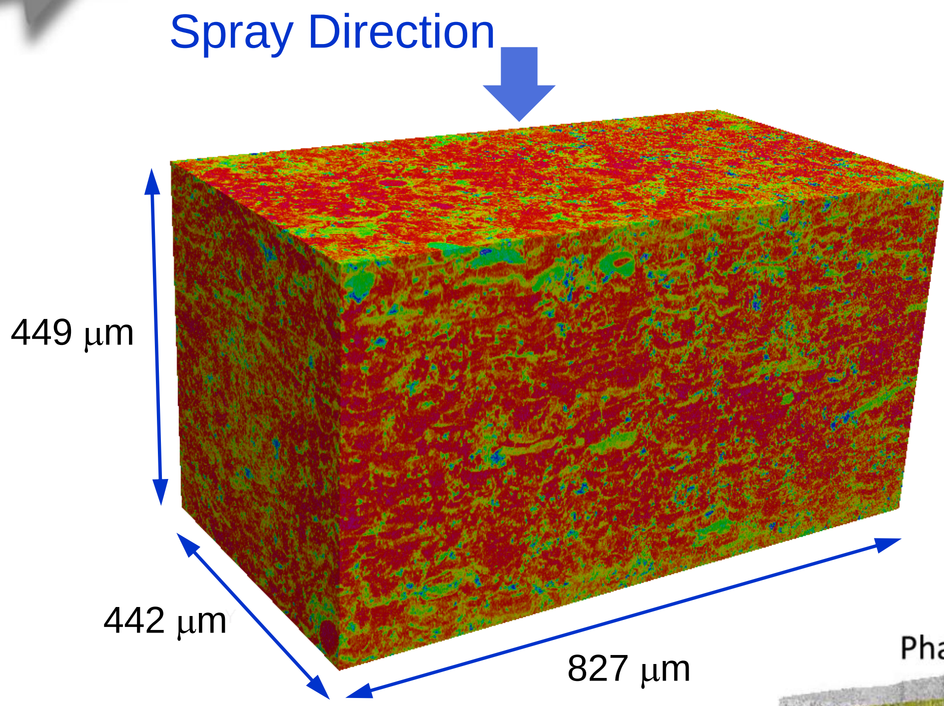
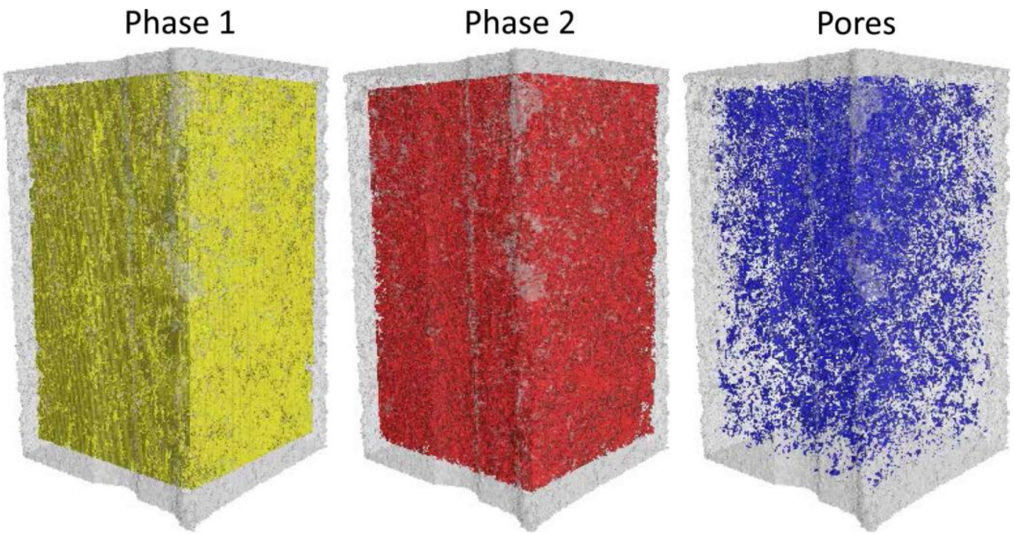
X-ray Tomography of Ta Film



3D density map from x-ray tomography (Advanced Photon Source, ANL) at ~0.8-μm resolution performed on rectangular specimens cut from a second batch of material produced with the same spray conditions. A subset of the data is shown for clarity.

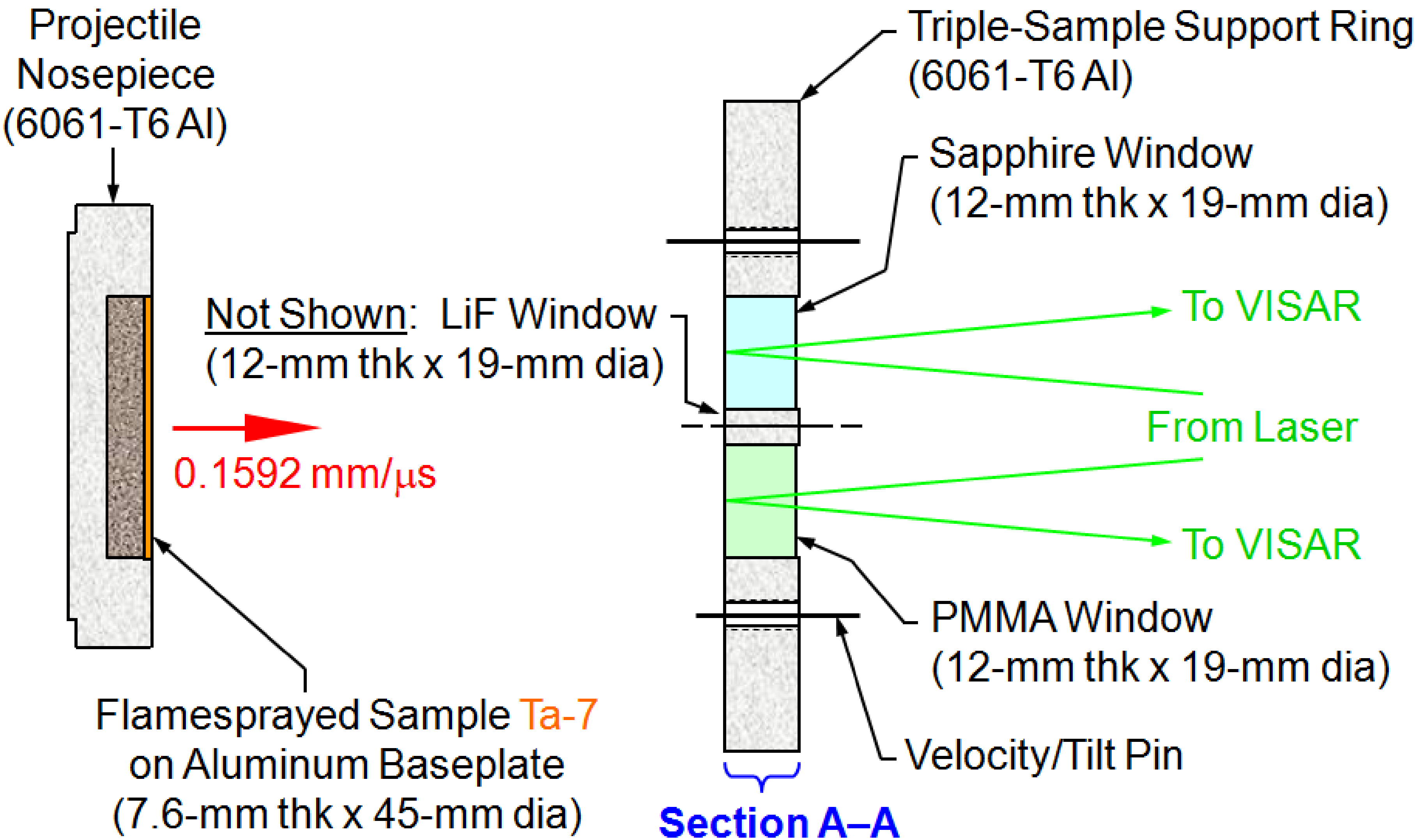


Ta (1) & Ta oxide (2) phases are distinguished from pores.

Dynamic Database Generation

- ***Conduct gas-gun experiments to determine aggregate dynamic material properties from multiple thermal spray samples that constitute a statistical basis for stochastic modeling and simulation:***
  - ***reverse-ballistic*** impact tests → Hugoniot EOS data;
  - ***forward-ballistic*** tests on ***window-backed samples*** → dynamic yield strength (Hugoniot Elastic Limit), non-equilibrium effects, high-pressure yield strength;
  - ***forward-ballistic*** tests on ***unbacked samples*** → HEL and spall strength estimates.

Reverse-Ballistic Shot FSTa-1G17



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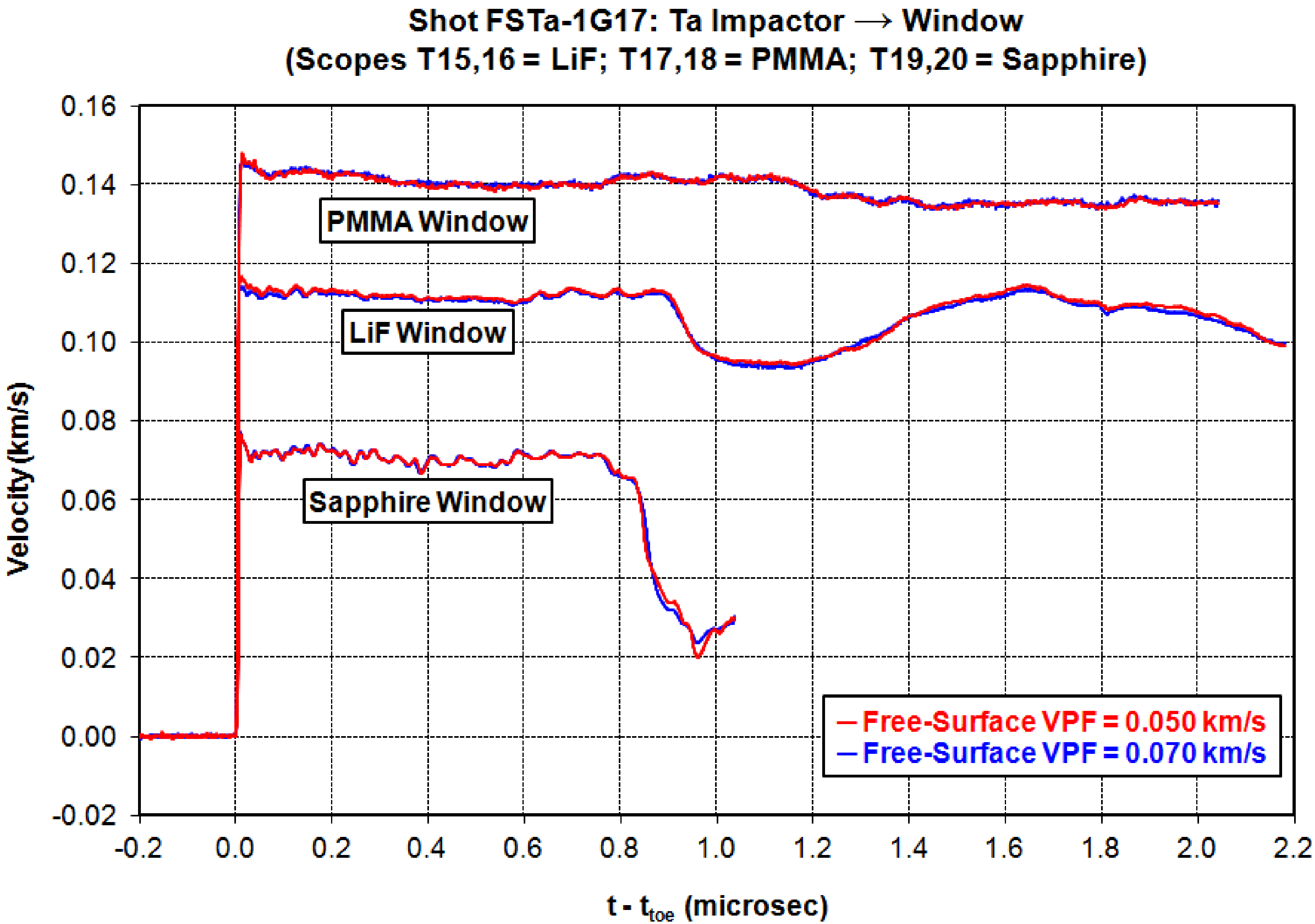
Impact Interface Motion



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Equation of State Data

Shot FSTa-1G17: Hugoniot Measurements

Impactor Sample No.	VISAR Window Material	Scope No.	Mean Plateau Velocity (km/s)	Hugoniot Particle Velocity (km/s)	Hugoniot Stress (GPa)
Ta-7*	PMMA	T17	0.1413	0.01795	0.471
		T18	0.1414	0.01776	0.472
	LiF	T15	0.1122	0.04696	1.570
		T16	0.1117	0.04752	1.562
	Sapphire	T19	0.07094	0.08826	3.186
		T20	0.07099	0.08821	3.189

*Measured impact velocity = 0.1592 km/s

$(\rho_{mean}/\rho_{Ta} = 13.331/16.656 = 0.800)$

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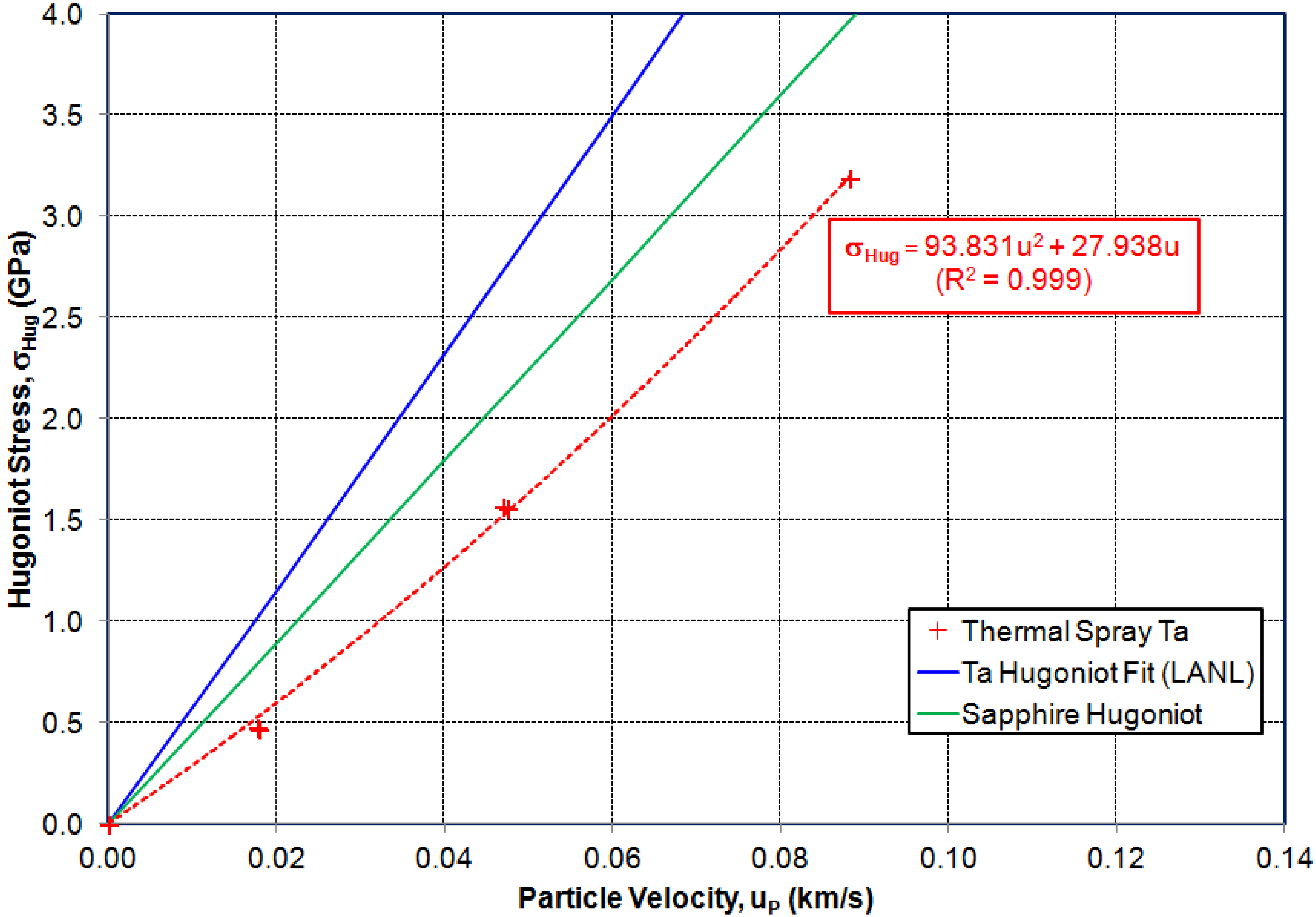
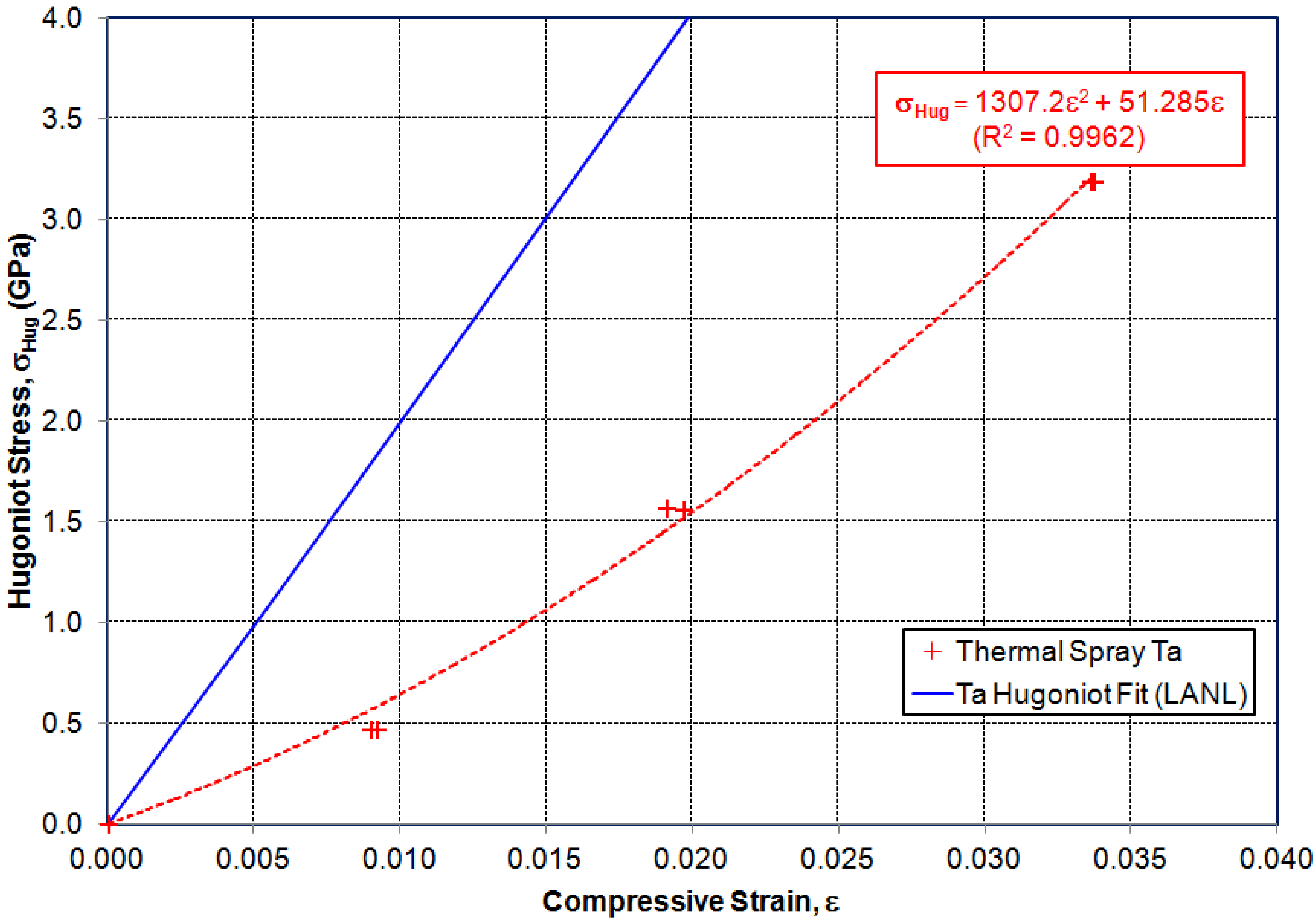
Equation of State Data



Equation of State Data



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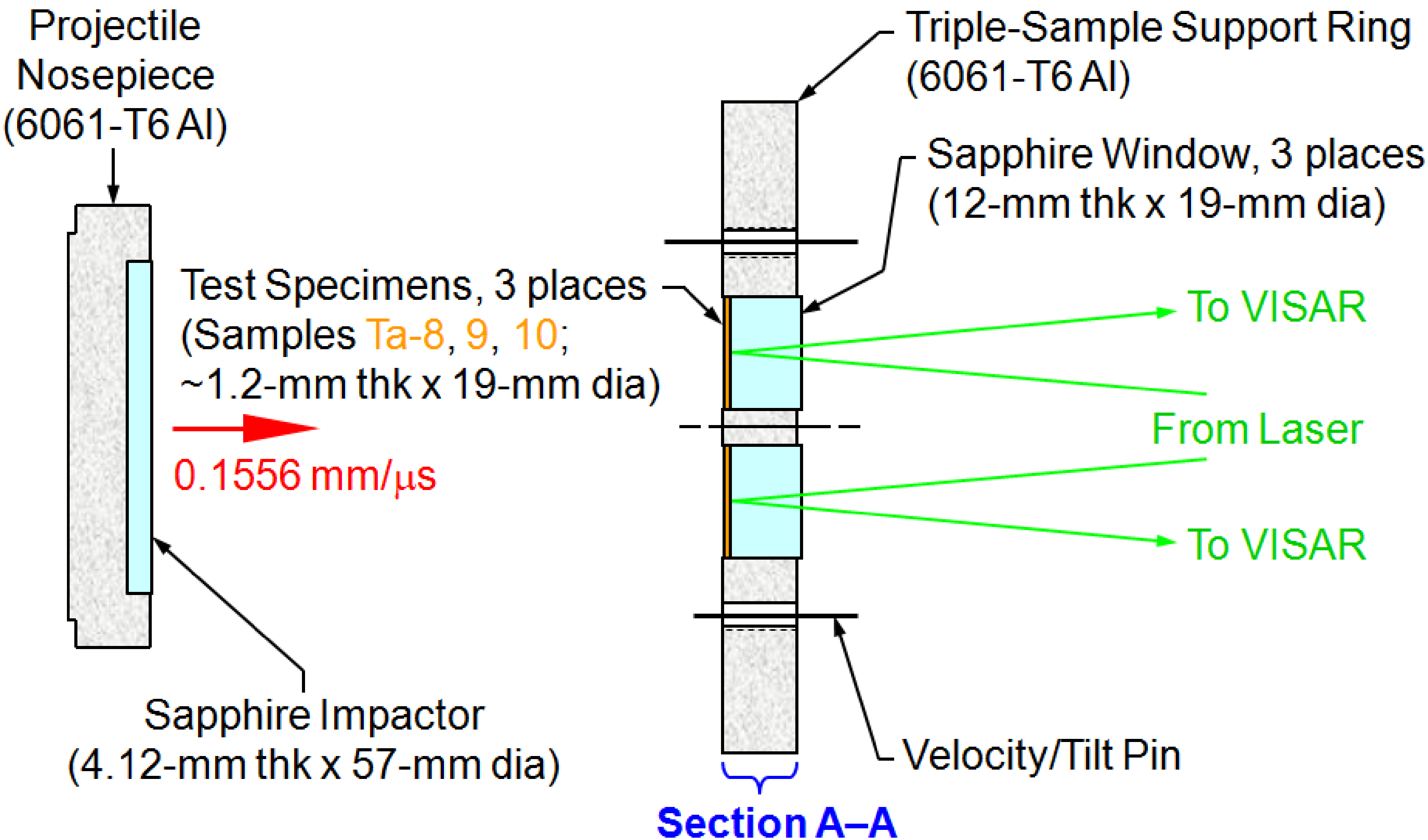
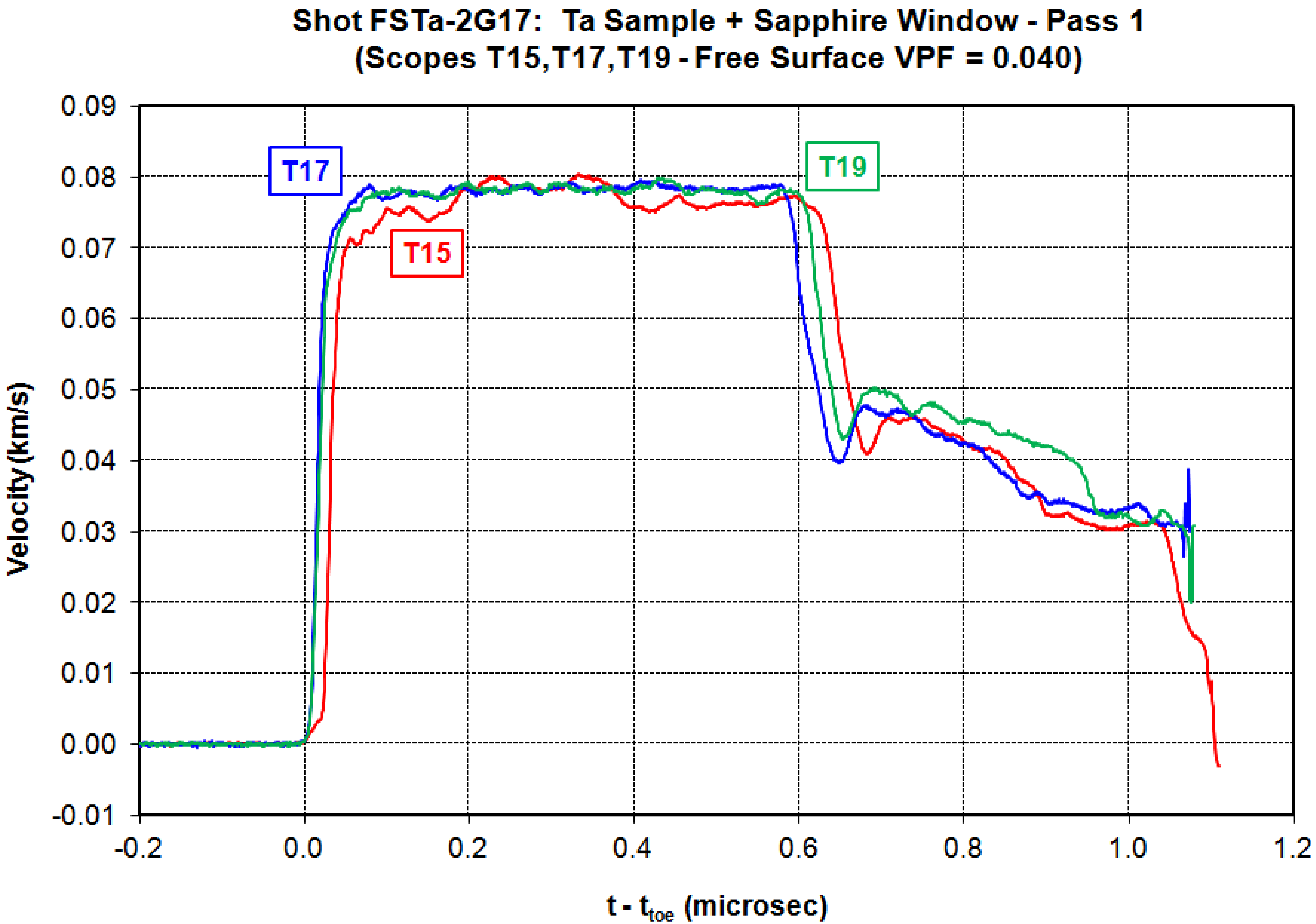
Forward-Ballistic Test (FSTa-2G17)



Sample/Window Motion



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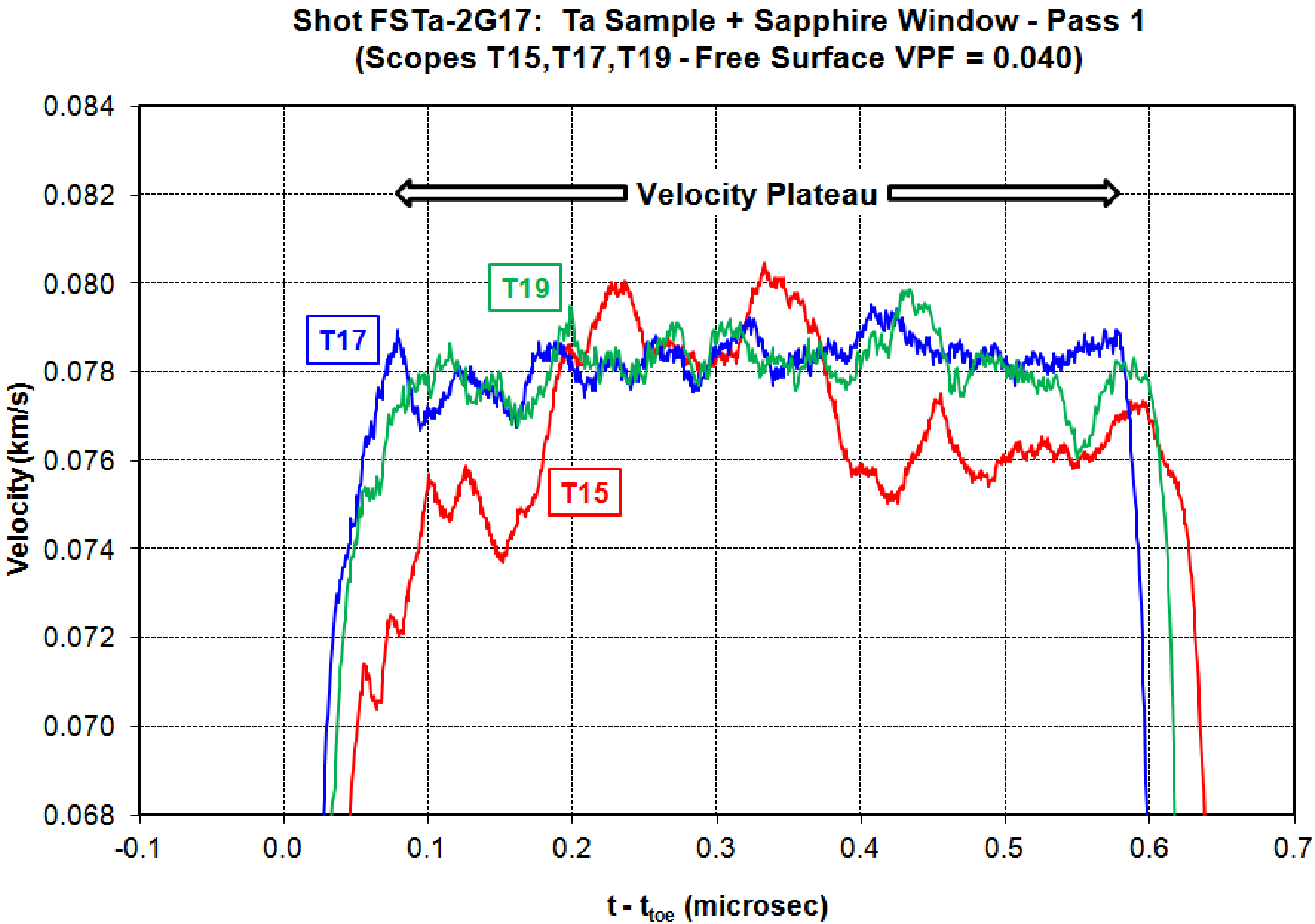
Sample/Window Motion



Sample/Window Motion

Shot FSTa-2G17: Plateau Velocity Measurements

Sample No.	Density* (g/cm^3)	Scope No.	Mean Plateau Velocity (km/s)	Standard Deviation (km/s)	Average Deviation (km/s)
Ta-8	13.209	T19	0.0781	0.0007	0.0005
		T20	0.0781	0.0006	0.0005
Ta-9	13.426	T17	0.0782	0.0005	0.0004
		T18	0.0784	0.0007	0.0005
Ta-10	13.357	T15	0.0767	0.0021	0.0017
		T16	0.0767	0.0017	0.0014

*Mean Density (3 samples) = 13.331 g/cm^3; St. Dev. = 0.111 g/cm^3

(ρ_{mean}/ρ_{Ta} = 13.331/16.656 = 0.800)

Summary

- ***Reverse-ballistic testing:***
  - Hugoniot EOS data for thermally sprayed tantalum samples exhibit ~40 -50% lower shock impedance than archival LANL results for conventionally wrought, full-density Ta;
  - fluctuations occur in the measured particle-velocity plateau amplitude for the Ta impactor/window interfaces (~1% for PMMA & LiF windows; ~2% for sapphire).
- ***Forward-ballistic testing:***
  - sample-dependent fluctuations (~0.6 – 3%) are detected in the measured particle velocity plateau at the interface between thermally sprayed tantalum samples and sapphire backing windows;
  - one of three thermally sprayed Ta samples showed evidence for a Hugoniot Elastic Limit (HEL) of ~0.18 GPa, compared to a value of ~0.77 GPa for conventionally wrought Ta;
  - unloading from the peak stress state appears to be hydrodynamic with no clear indication of retained high-pressure strength.

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