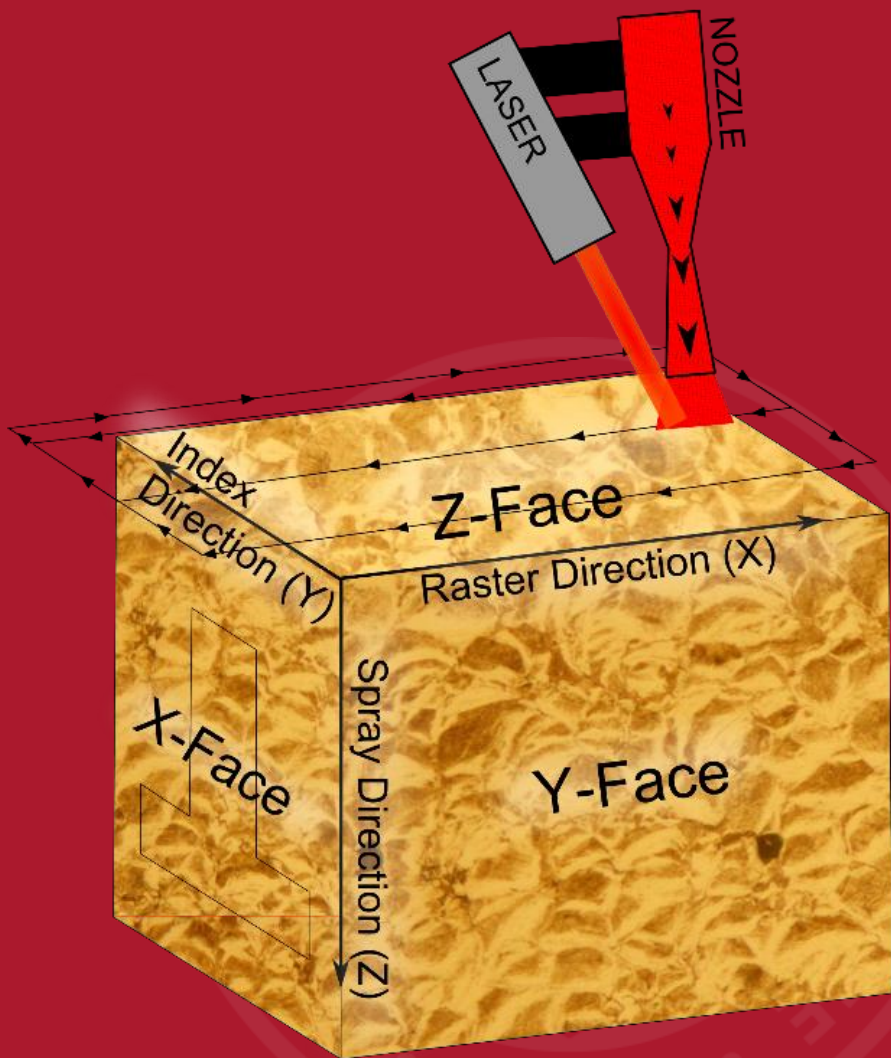
Laser Assisted Cold Spray of Titanium

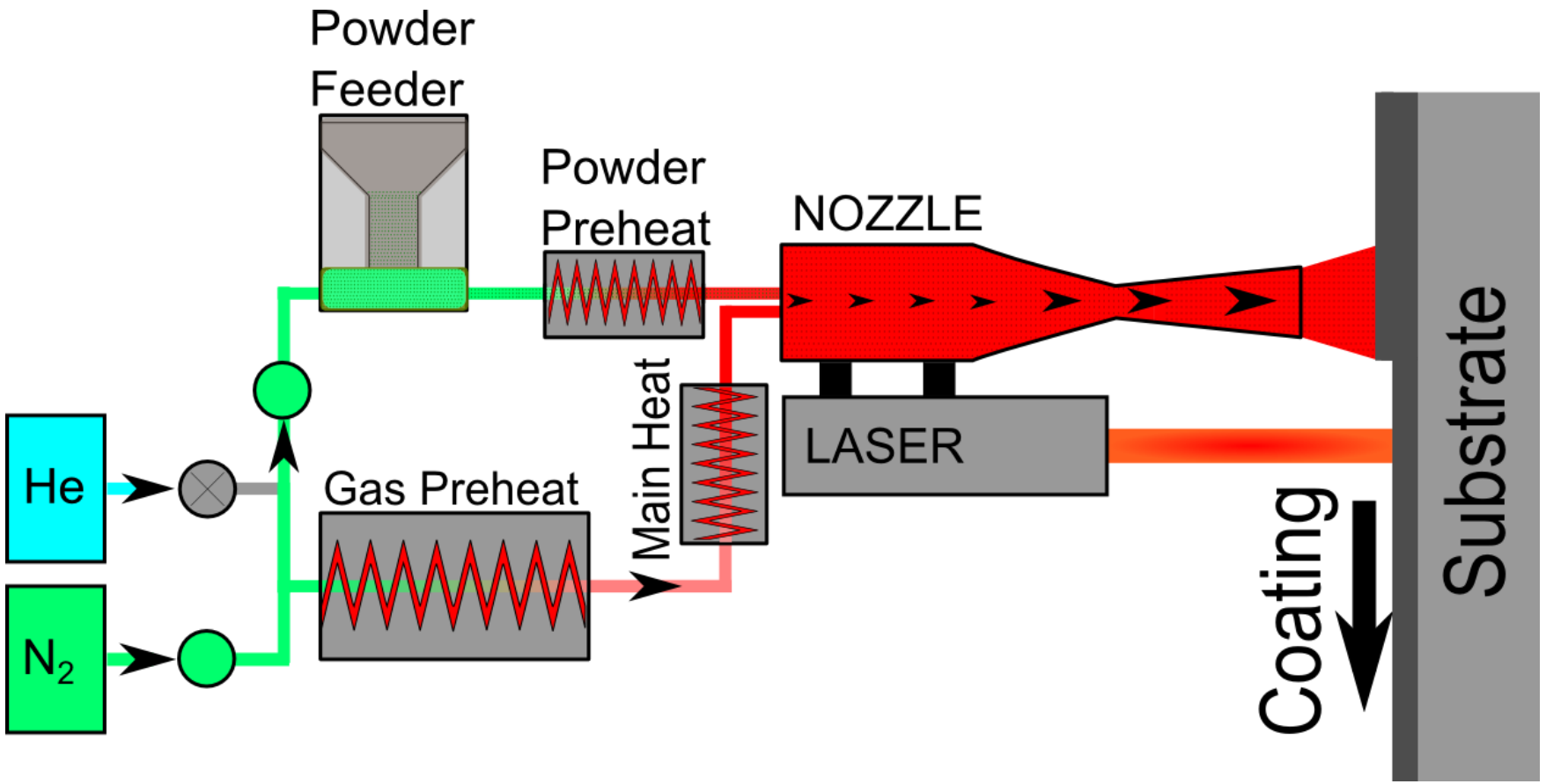
A. Birt, V. Champagne, R. Sisson, D. Apelian, J. Dallaraosa

6/24/2015

- Laser Assisted Cold Spray
- Titanium
- Experimental LACS
- Conclusions



Laser Assisted Cold Spray Setup



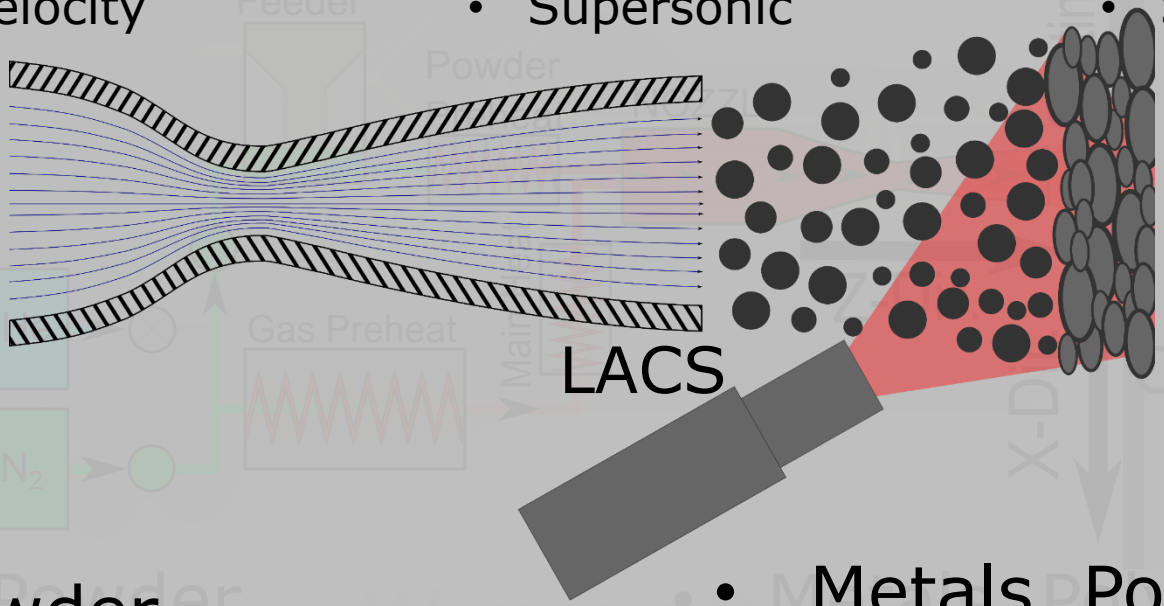
Process Context of LACS

- Thermal Processing
- Melting
- High Velocity

- Thermomechanical Processing
- Solid State
- Supersonic

- Mechanical Processing
- Solid State
- Supersonic

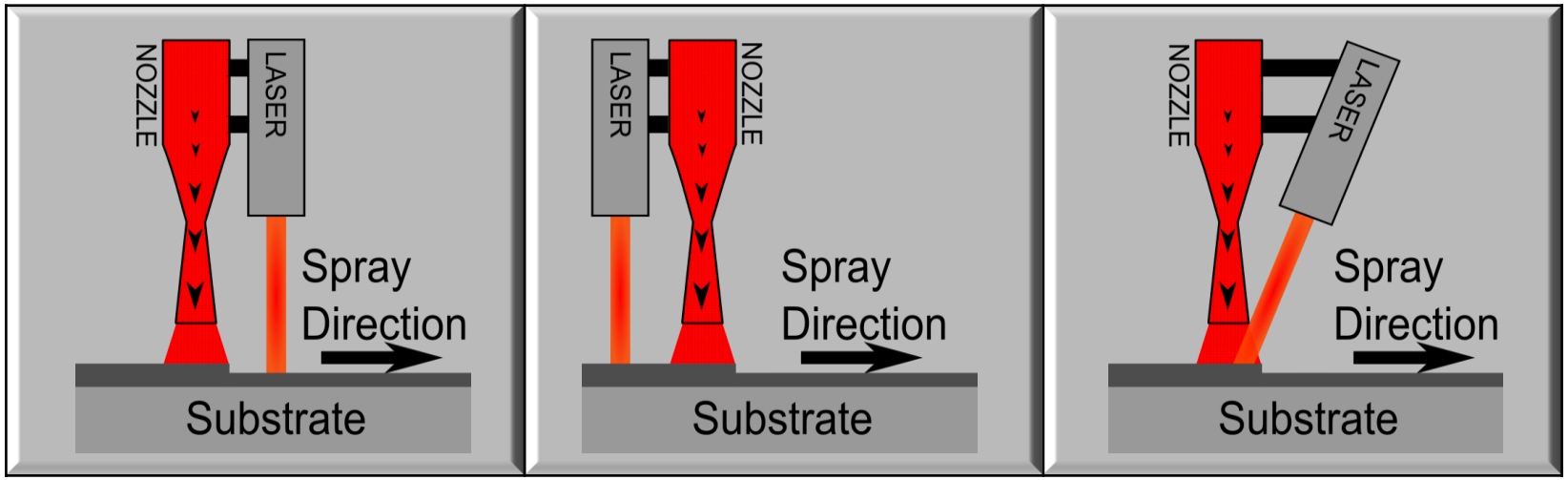
Laser-Assisted Cold Spray



- Powder
- Solid state
- Compressive residuals

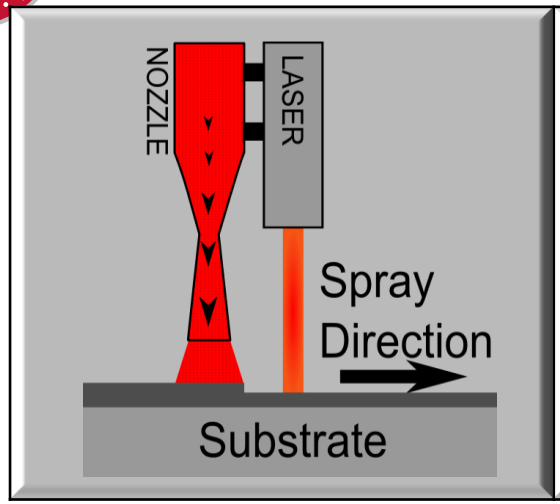
- Metals, Polymers, MMC
- Limited oxidation
- Thermal and Kinetic Energy Mode Control

Process Capabilities of LACS

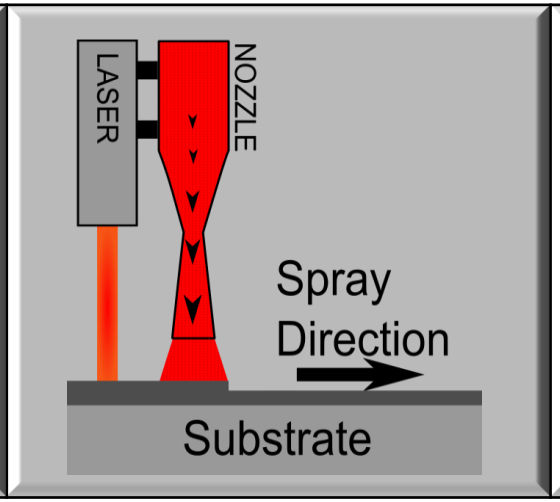


Pre-Treat	Post-Treat	In-Situ Treat
•**Anneal** substrate/deposit •**Soften** substrate/deposit •**Ablate** substrate/deposit	•**Anneal** substrate/deposit •**Ablate** substrate/deposit	•**Anneal** substrate/deposit •**Ablate** substrate/deposit •**Soften** impacting particles

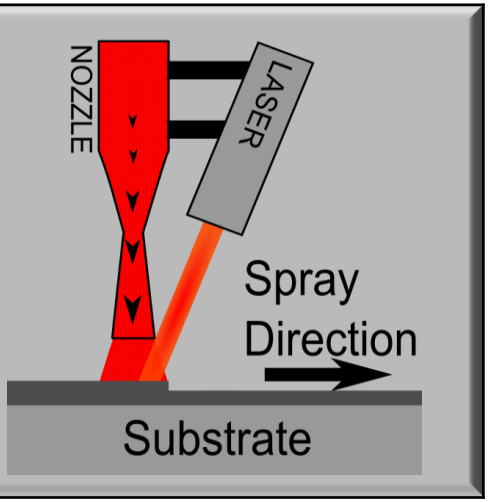
Process Effects of LACS



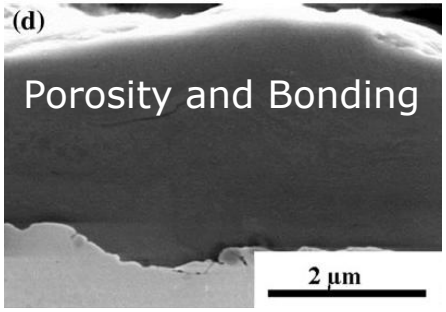
Pre-Treat



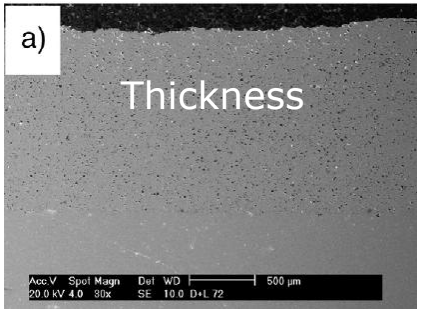
Post-Treat



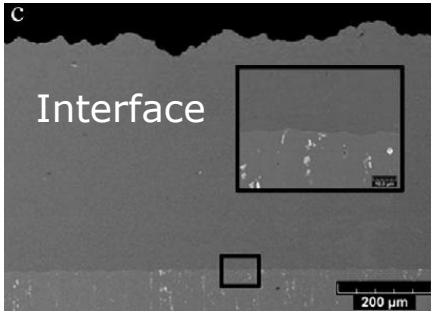
In-Situ Treat



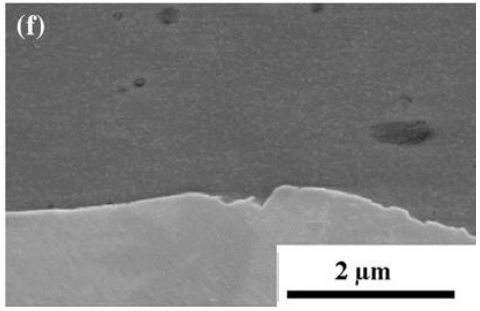
Al-12%Si



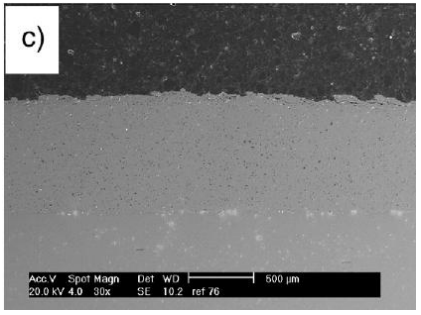
$Cu+Al_2O_3$



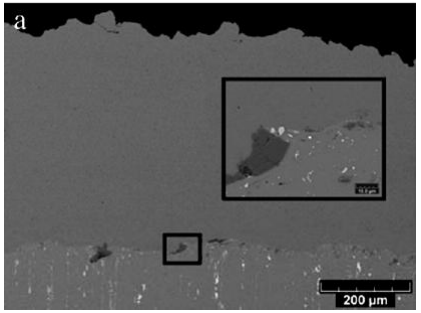
Al 6061



E. Olakanmi et. al



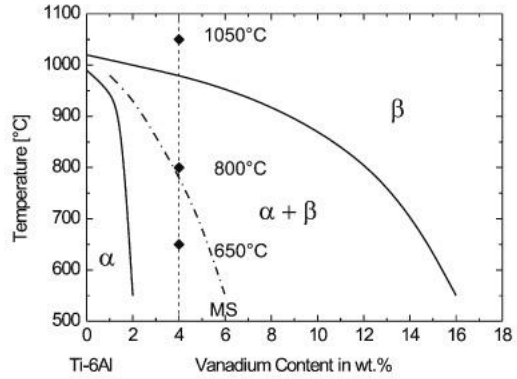
M. Kulmala et. al



Y. Danlos et. al

- Laser Assisted Cold Spray
- Titanium
- Experimental LACS
- Conclusions

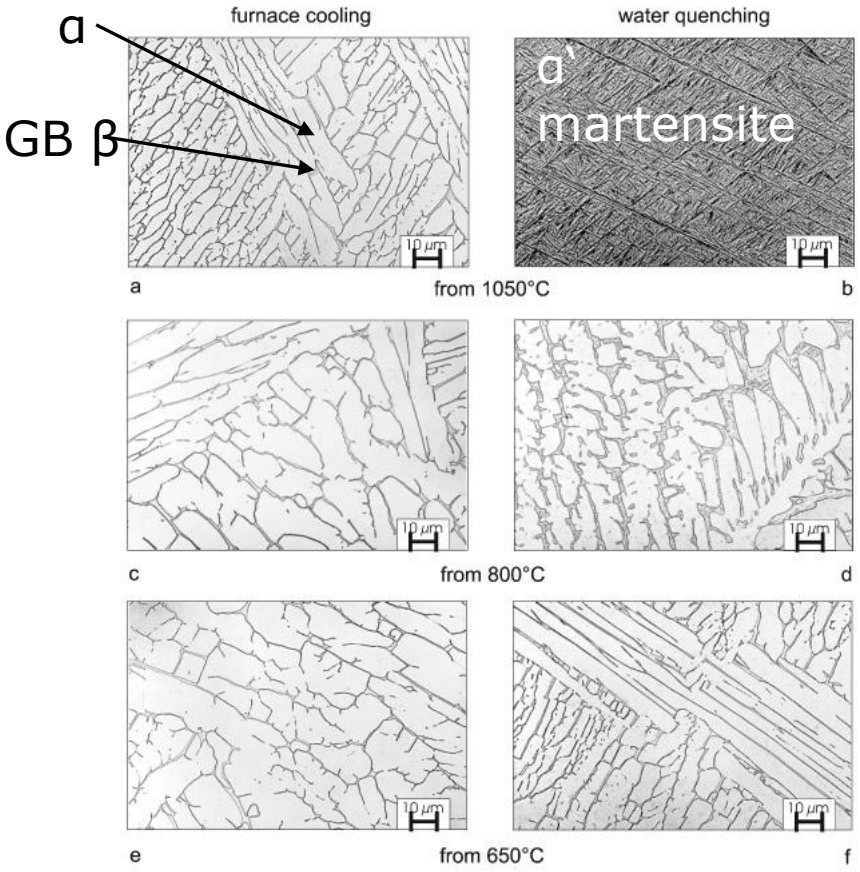
Material Selection: Ti-6Al-4V



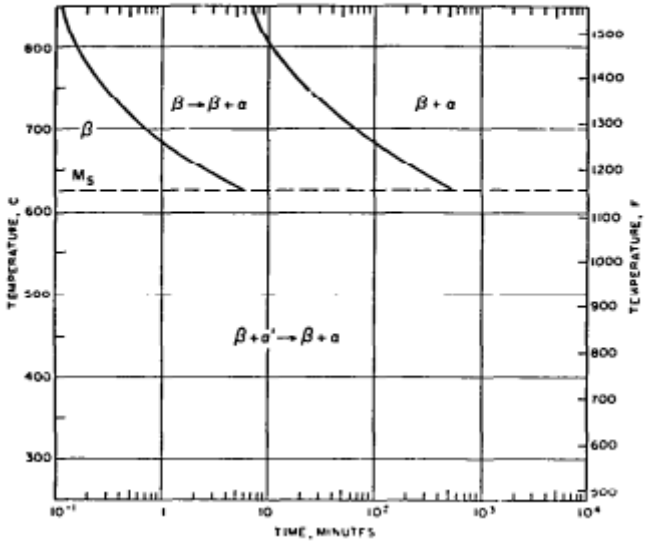
$$\textit{Cold Spray Cooling}$$

$$\frac{dT}{dt} = \frac{6h}{\rho * C_p * D} * (T_s - T_\infty)$$

$$\frac{dT}{dt} = 2 * 10^5 \ {}^{K}/_{s}$$

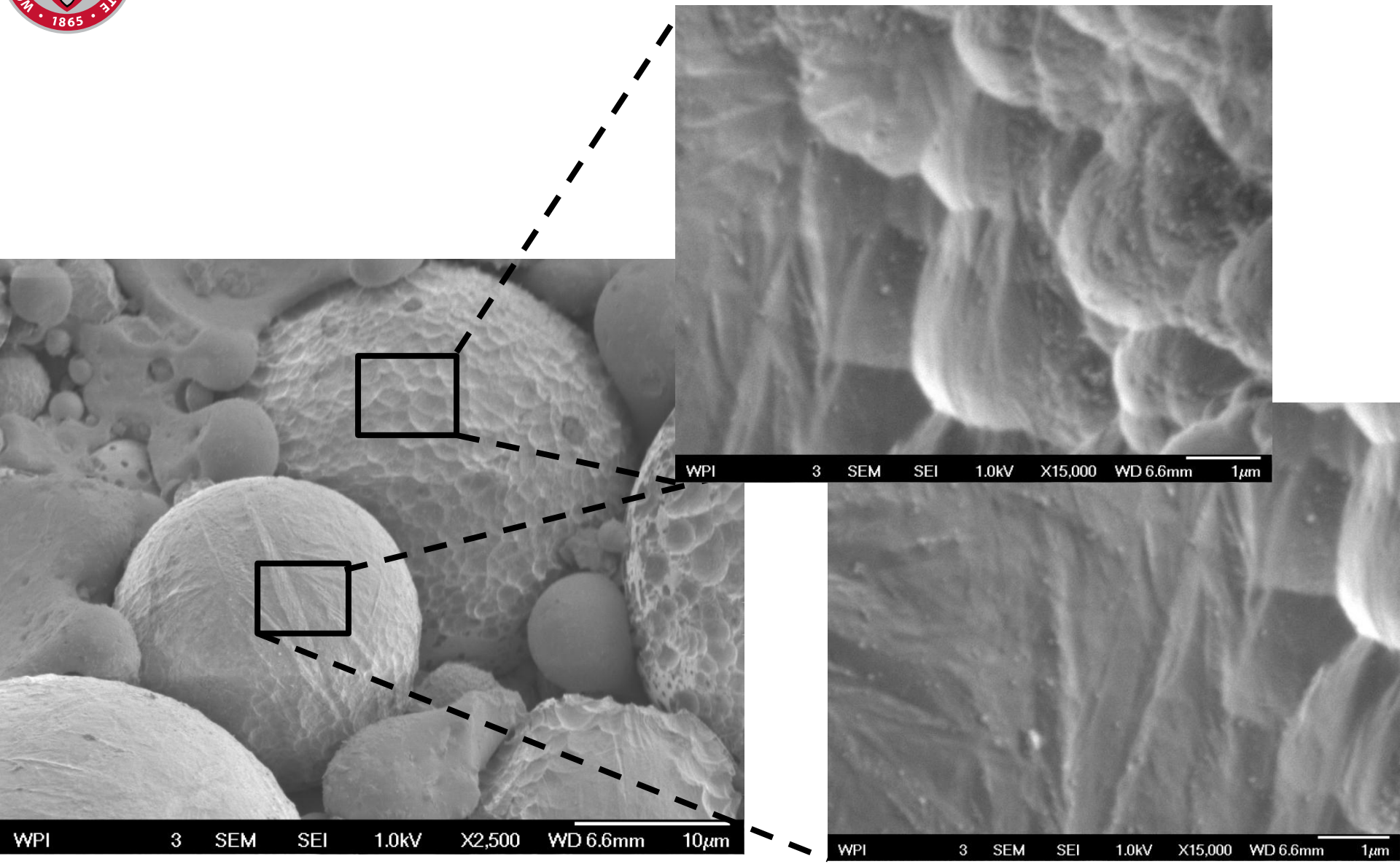


Ti-Al-V Alloys
Composition: Ti-6.0% Al - 4.0% V
Solution annealed at 1020°C (1868°F), and quenched directly to reaction temperatures

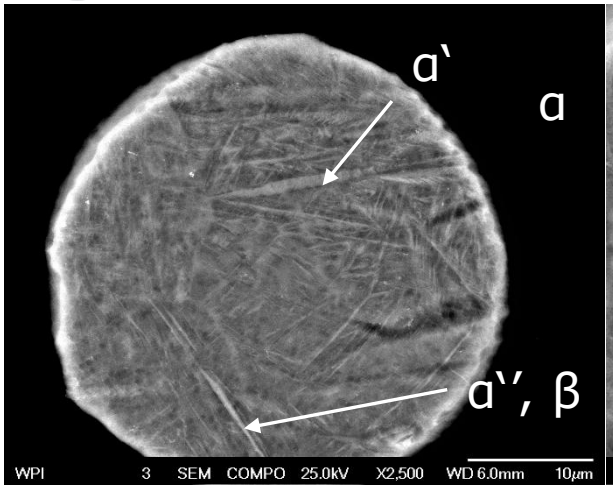


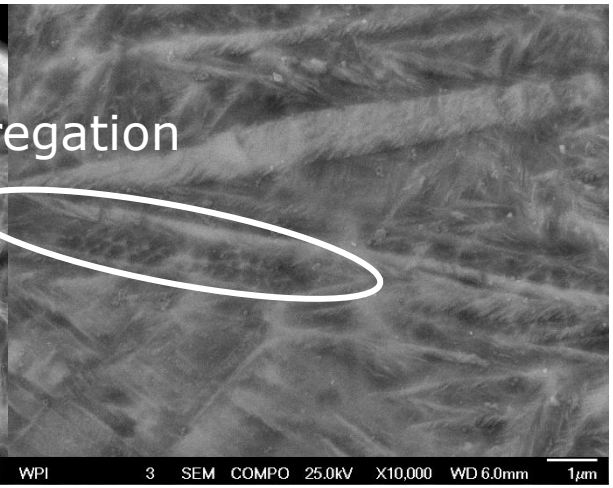
-Vander Voort Atlas of Time-Temperature Diagrams for Nonferrous Alloys
-ASM Atlas of Microstructures

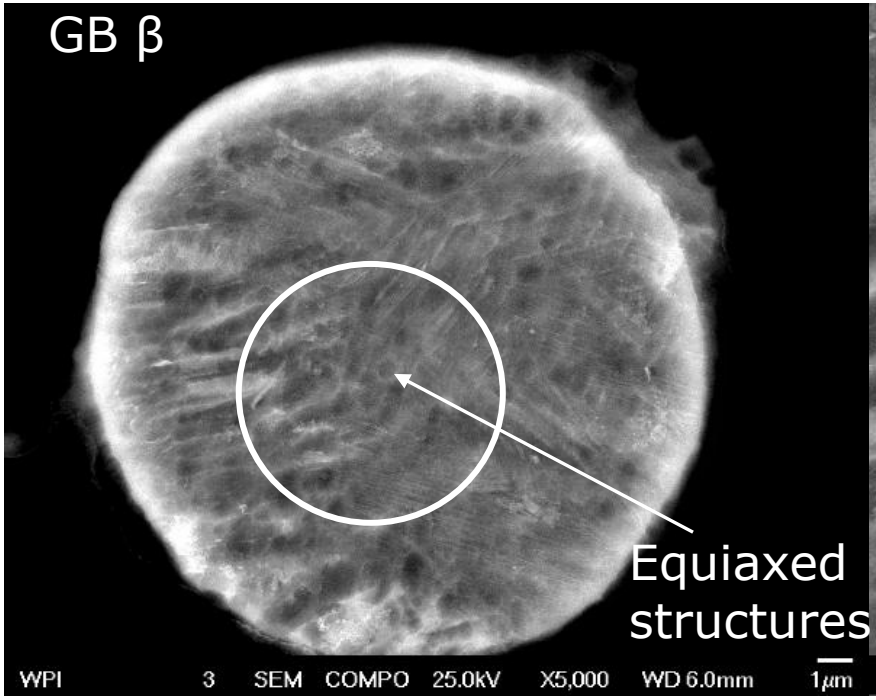
Ti-6Al-4V Plasma Atomized Powder

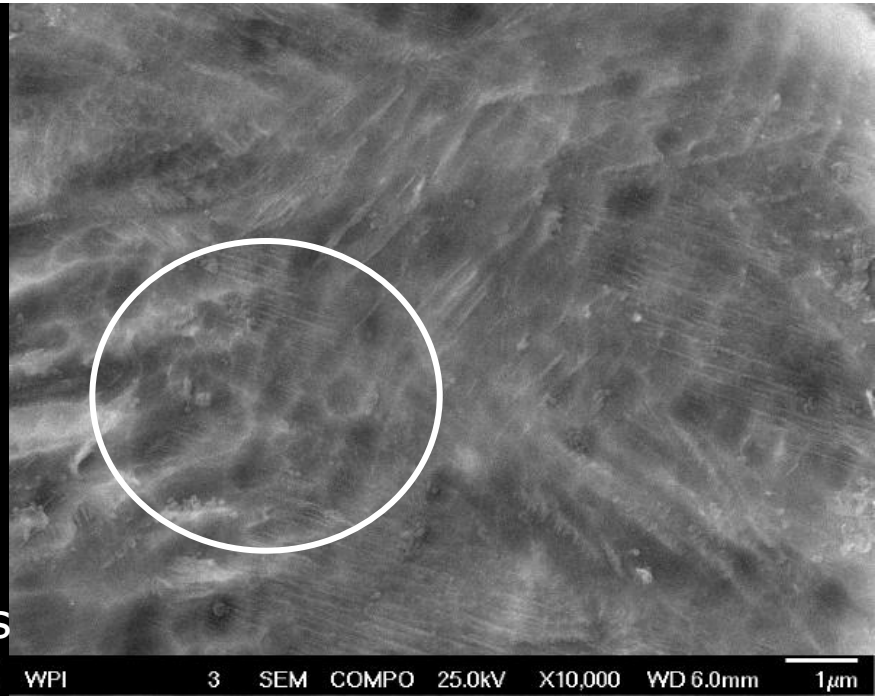


Ti-6Al-4V Plasma Atomized Powder

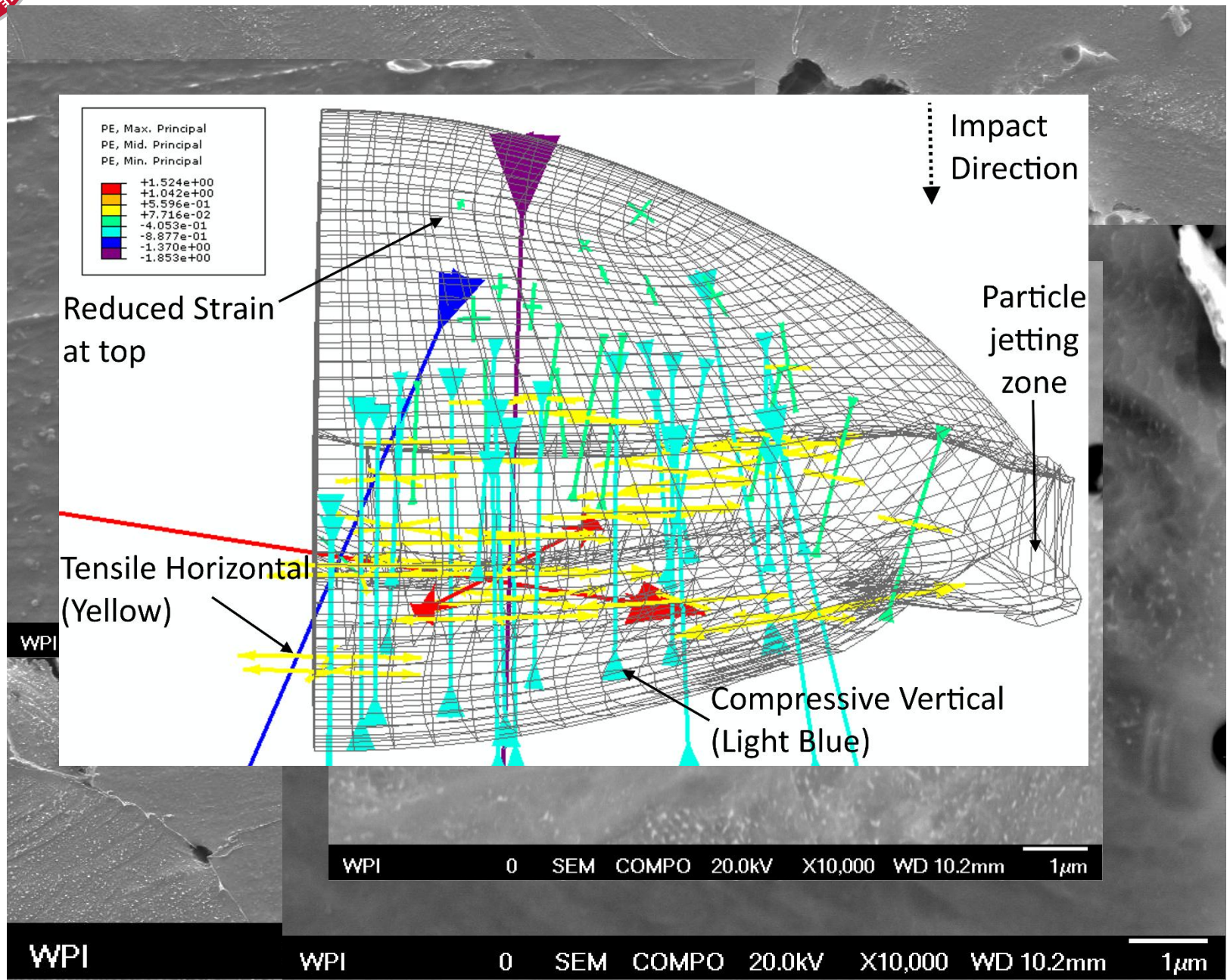






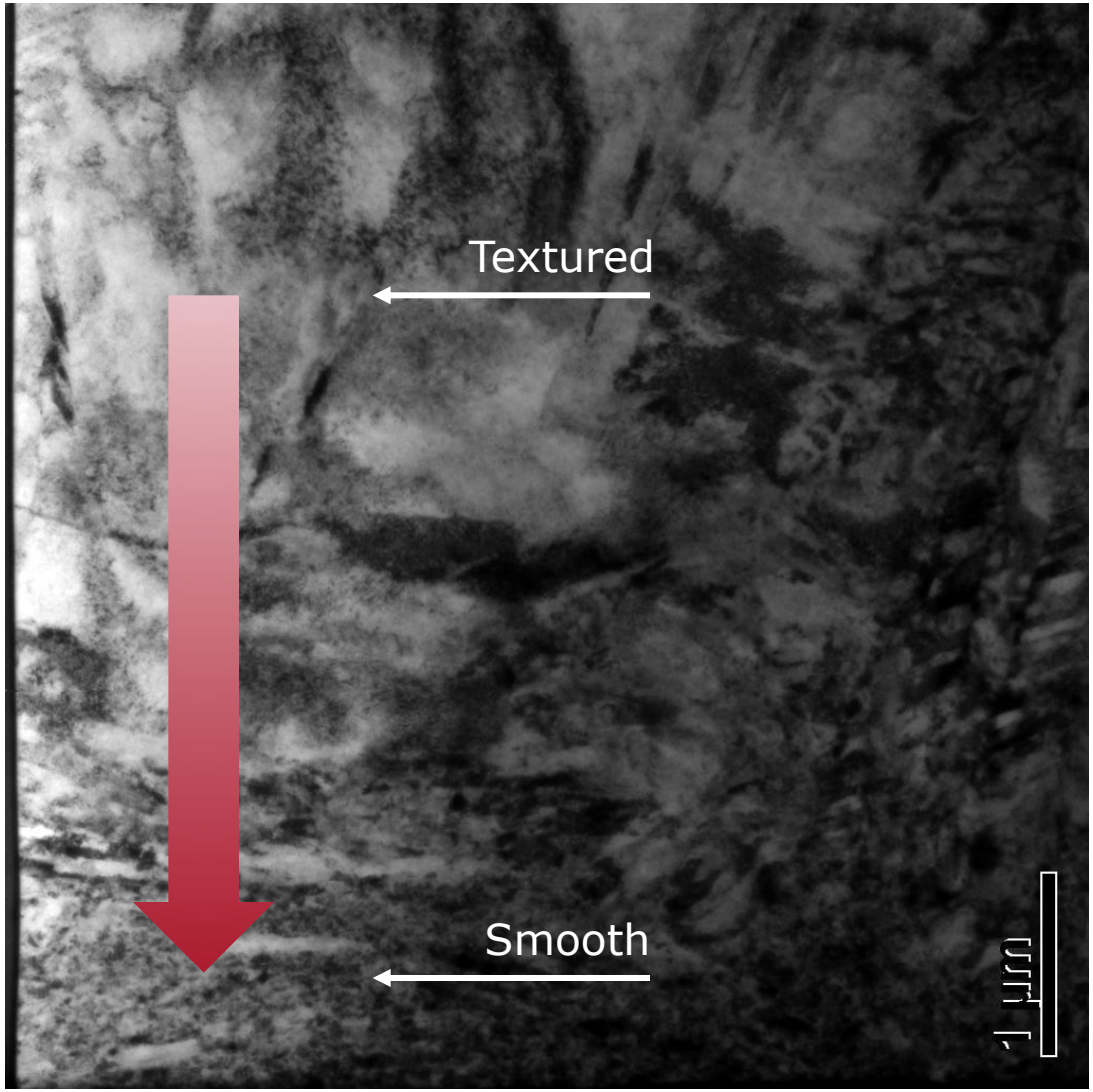


Cold Sprayed Ti-6Al-4V: SEM

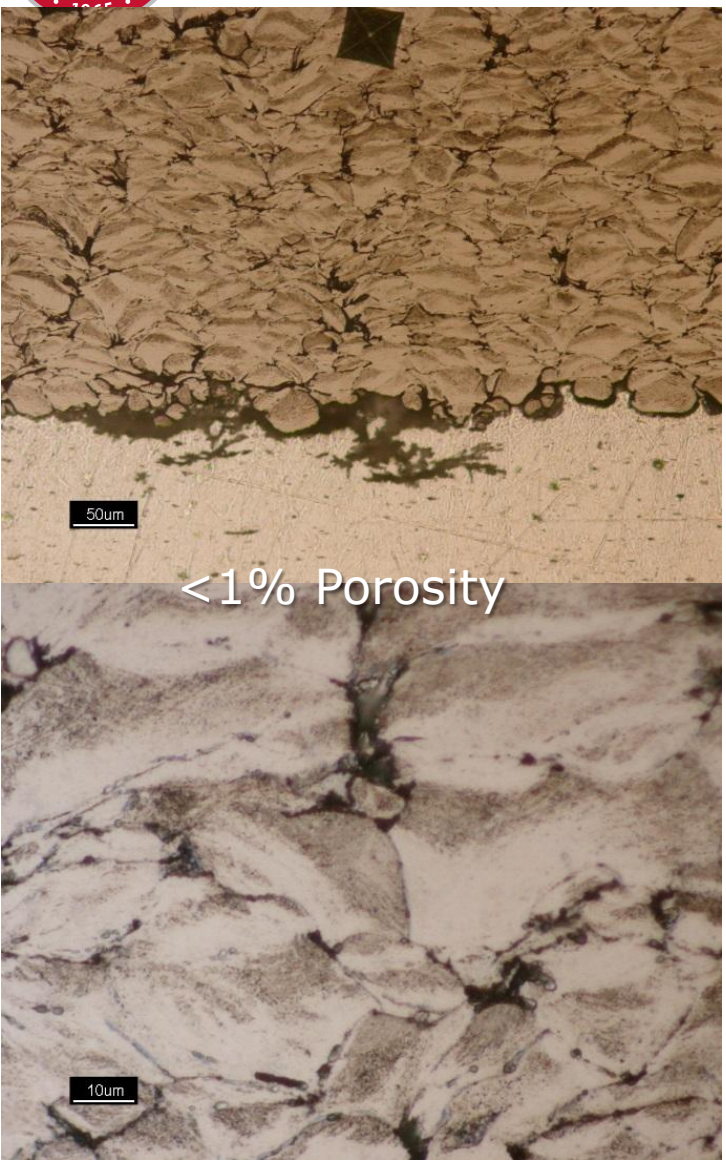


Cold Sprayed Ti-6Al-4V: TEM

Spray Direction

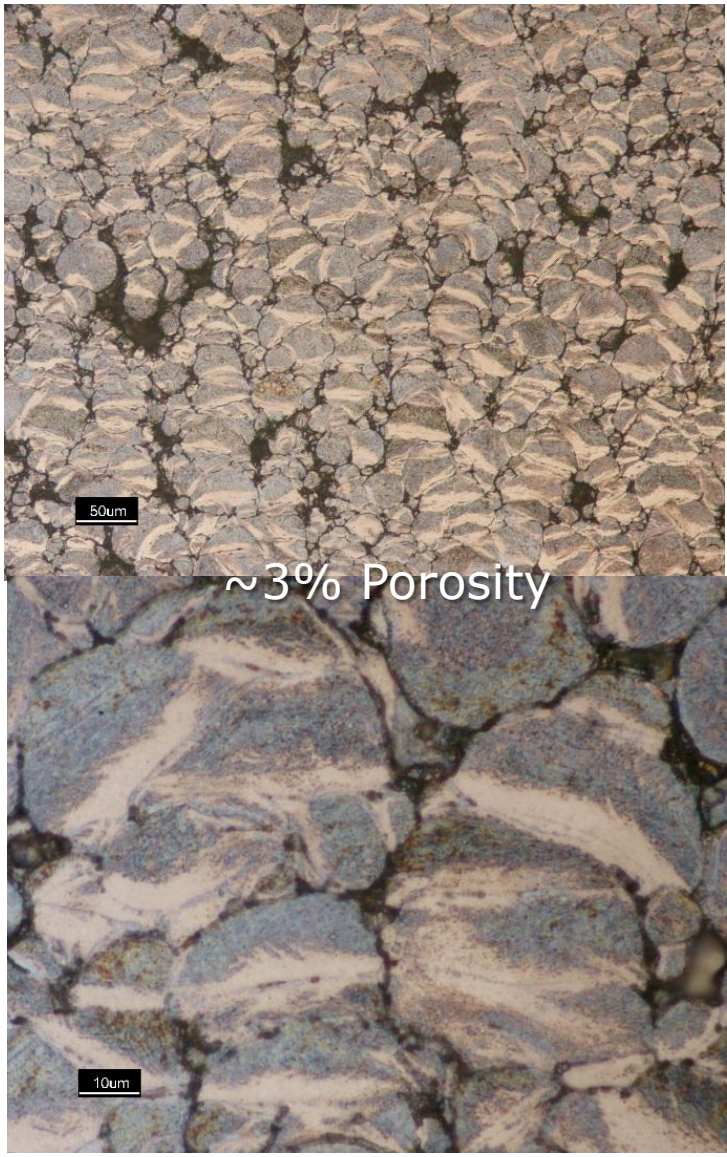


Cold Sprayed Ti-6Al-4V: Microstructure



70% He/30% N_2, 790 °C, 36 bar, 1 RPM

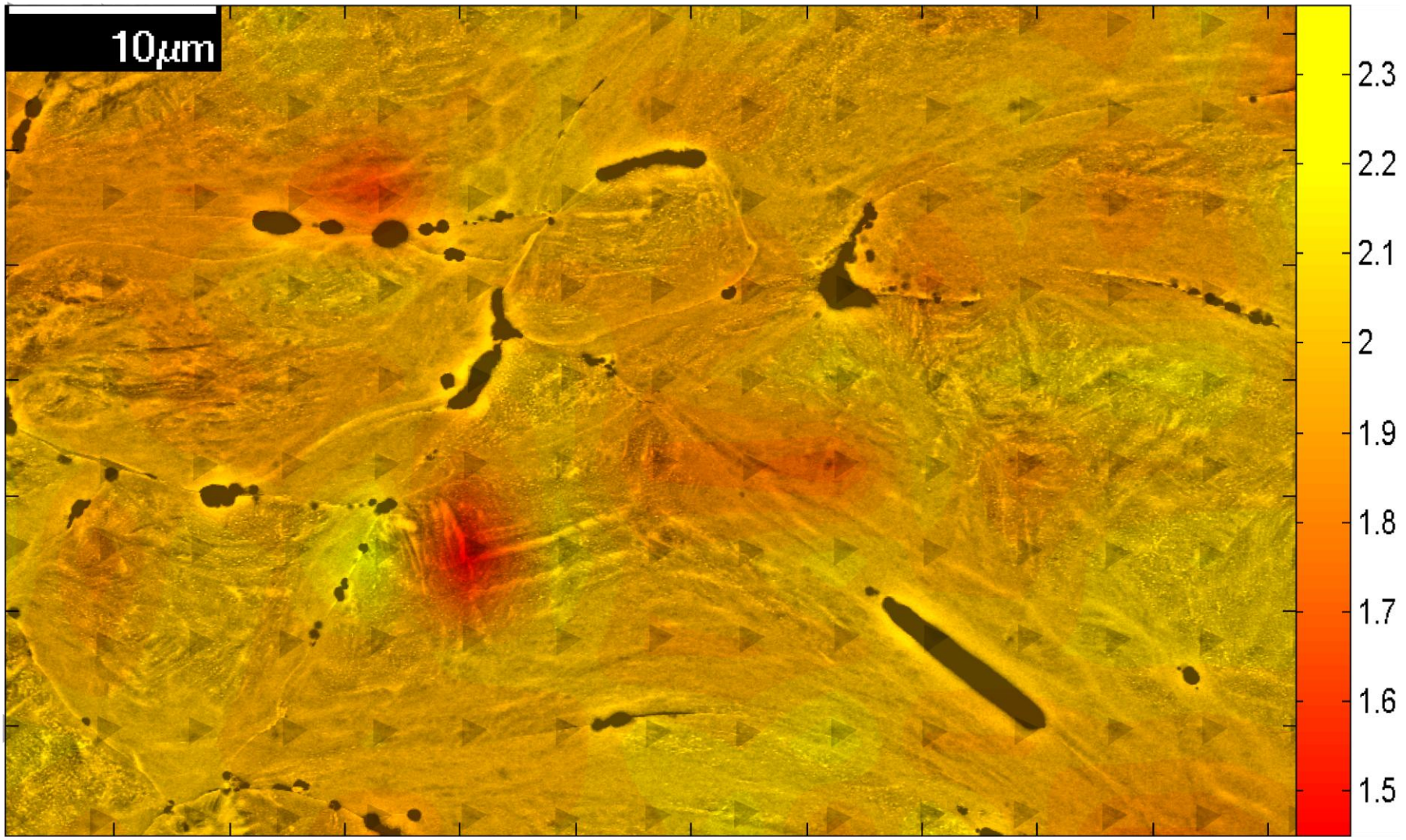
- Velocity of He **1.7x** more than N_2
- Negligible Temperature Difference
- Cost of He **30-80x** more expensive than N_2
- Blue = broken α'
- Brown = more worked α'
- Light = highly worked α'



100% N_2, 750 ° C, 30 bar, 2.5 RPM

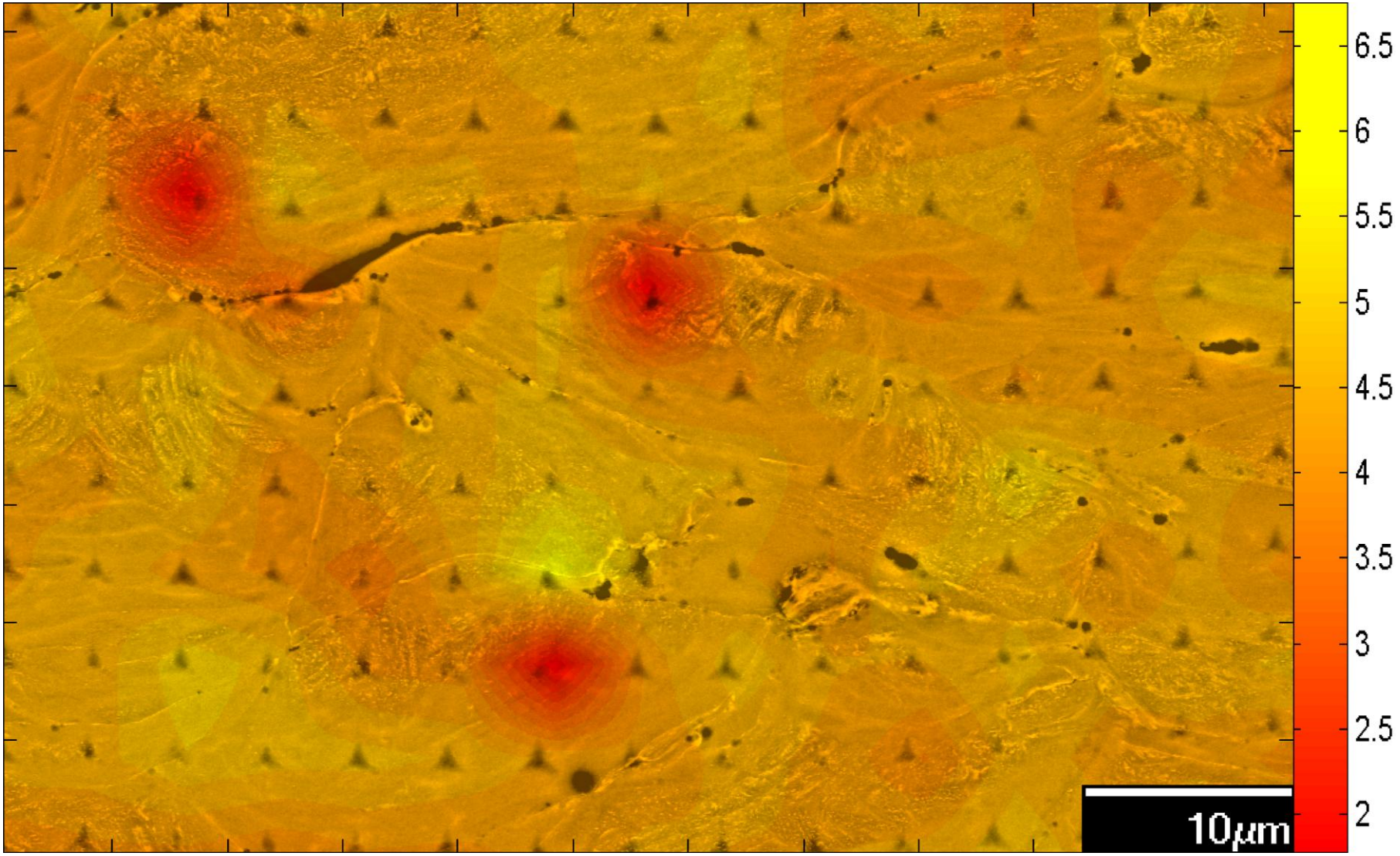
Nitrogen Sprayed Hardness Map

10 % Porosity



He/N_2 Sprayed Hardness Map

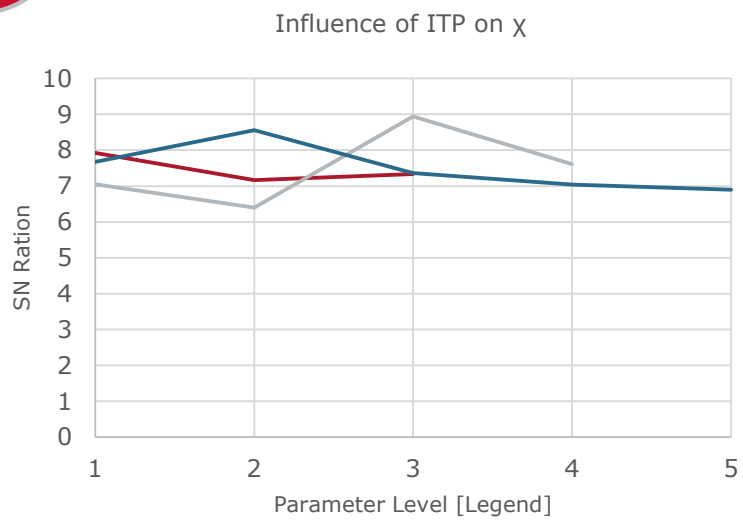
<2 % Porosity

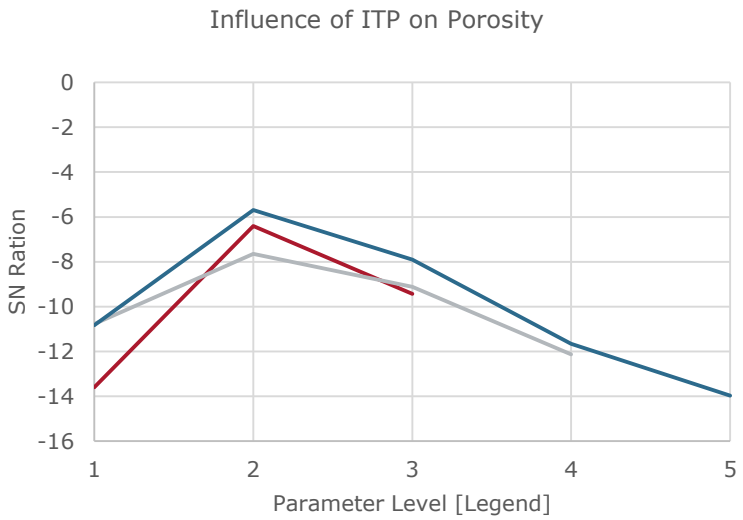


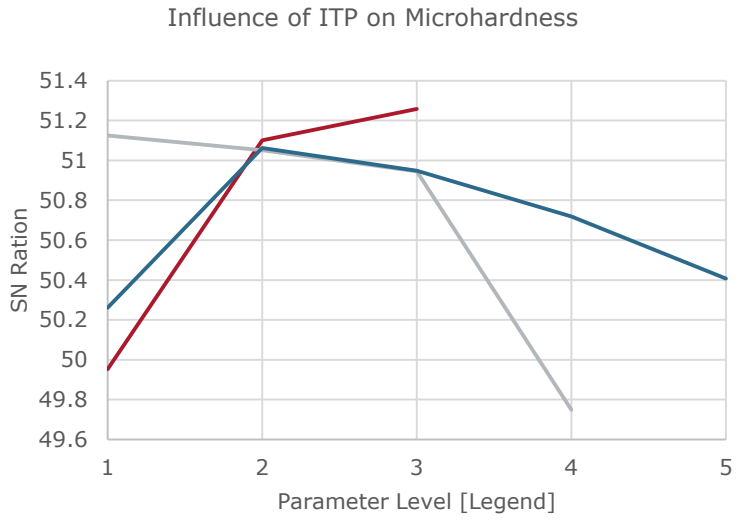
LACS Experimental Approach

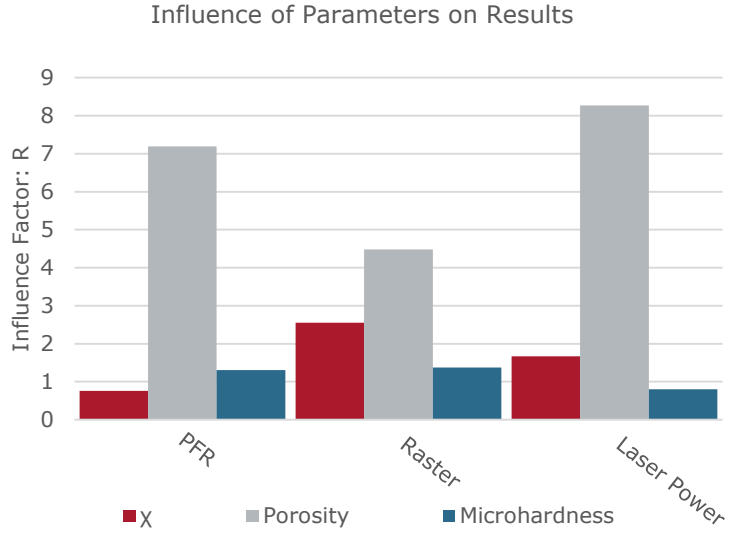
Result	Peak	Conversion	Sample Number
Porosity (%AF)	0.991	$\frac{Min.Porosity}{Porosity}$	6
Microhardness (Hv)	398	$\frac{Hardness}{Max\ Hardness}$	24

LACS Response: S/N Results



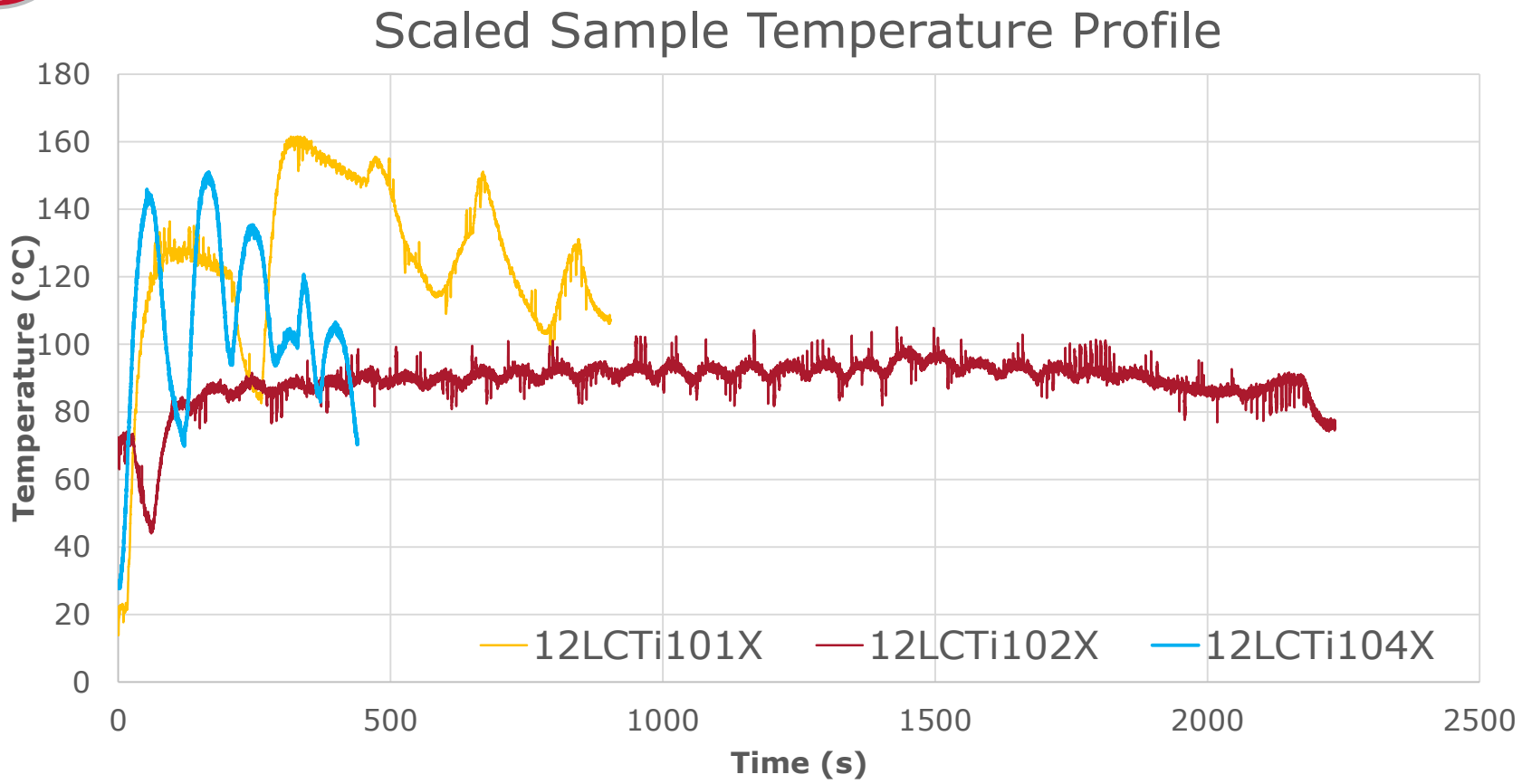






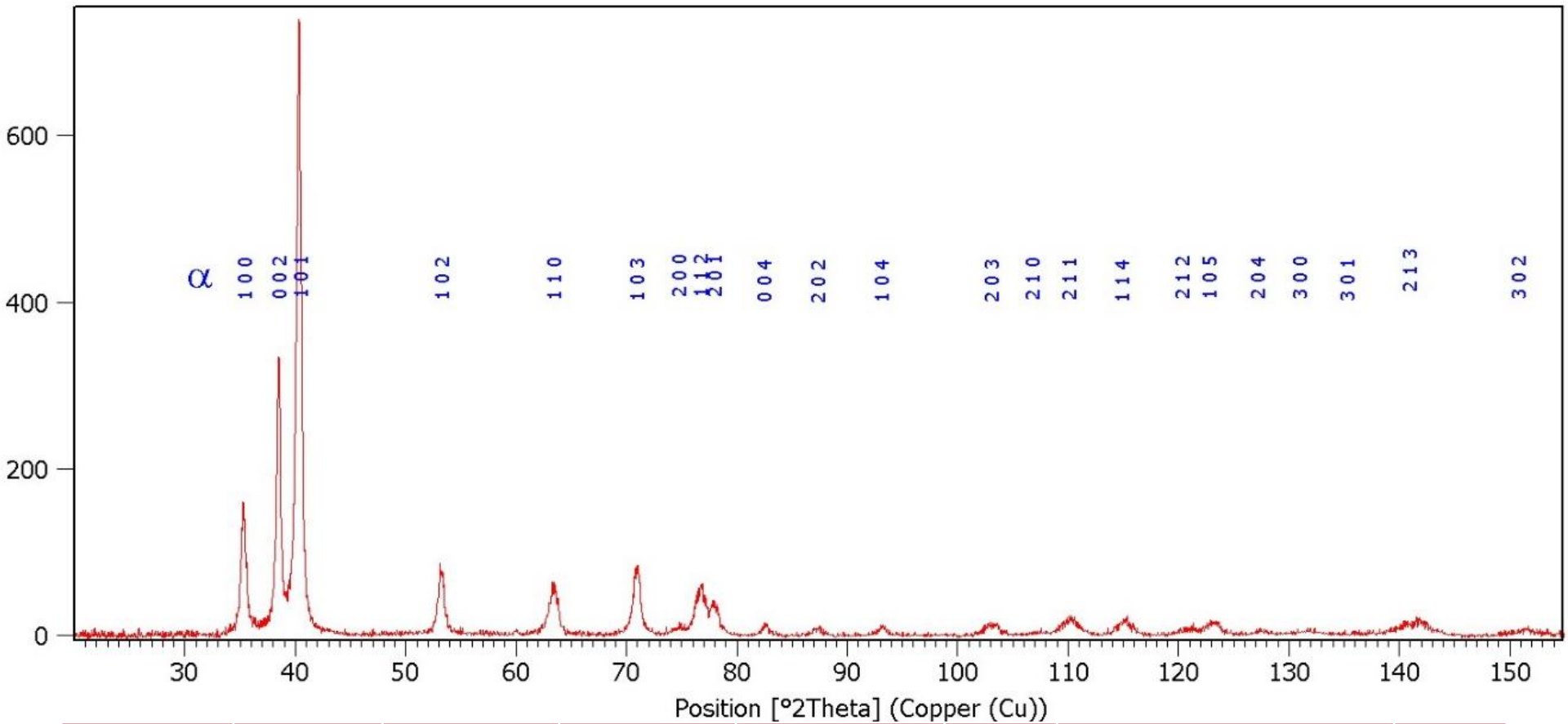
PFR [1, 3, 5 RPM] — Raster [50, 100, 200, 400 mm/s] — Laser Power [50, 100, 300, 600, 1000 W]

Scaling Up Sample Size



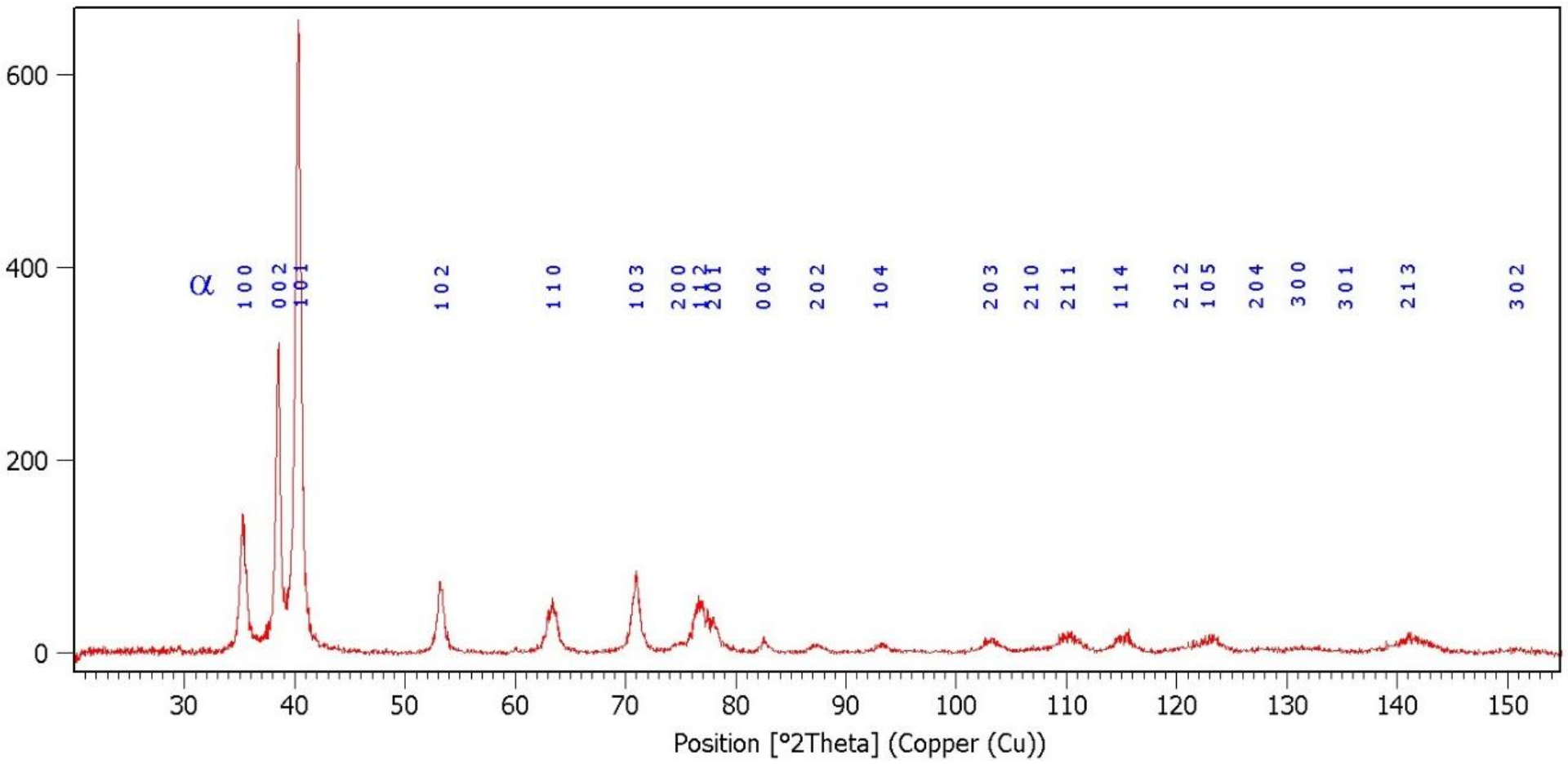
SAMPLE	PFR (RPM)	RASTER (MM/S)	POWER (W)	POROSITY (%AF)	CV	MICROHARDNESS (HV,200 GF,10S)	CV
101	5	50	300	4.62	0.38	387	0.05
102	1	400	300	0.81	0.17	313.6	0.26
103	1	50	600	10.92	0.13	461	0.57
104	5	400	1000	2.21	0.29	330.8	0.07

LACS Scaled Sample 101



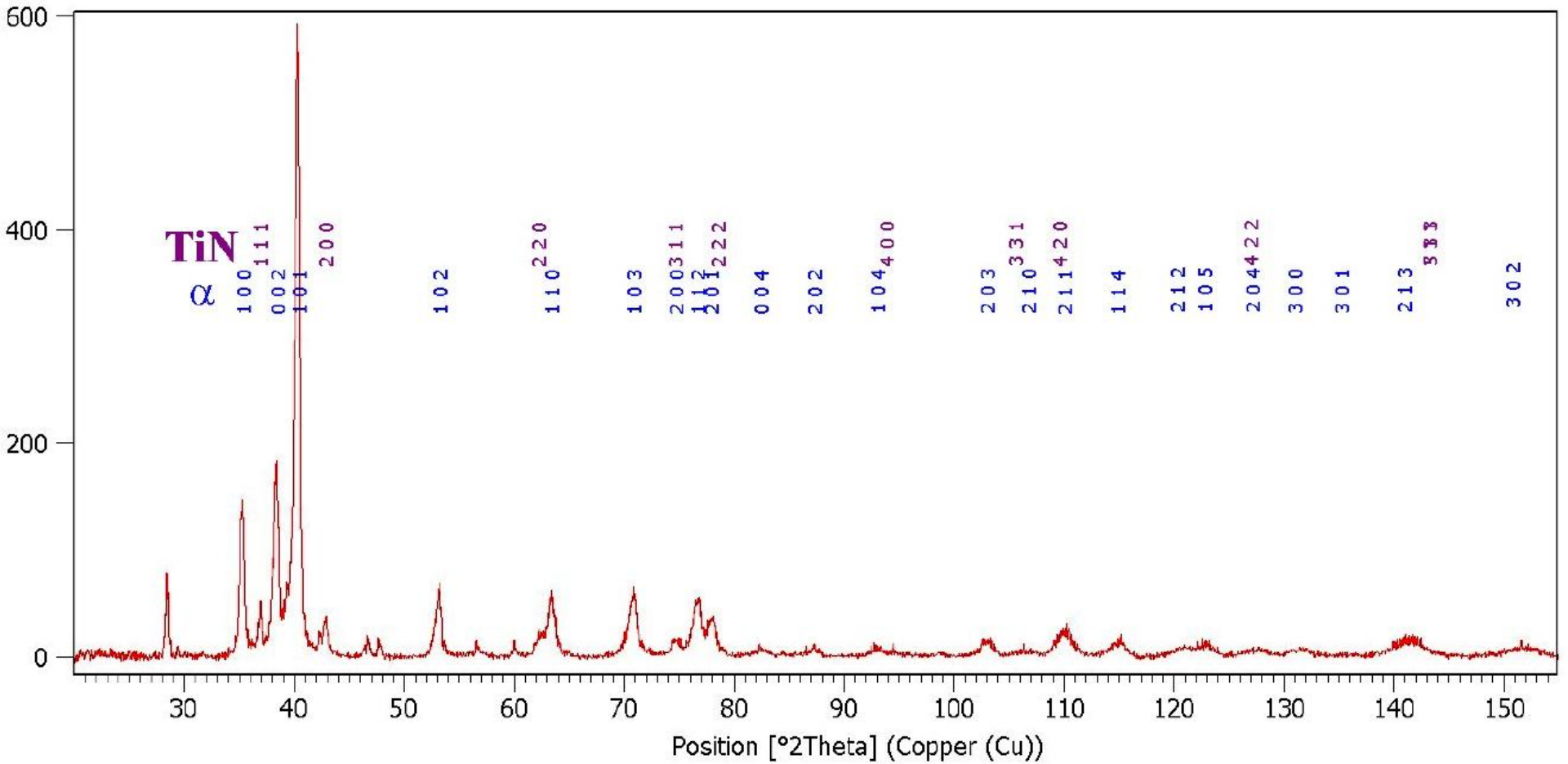
SAMPLE	PFR (RPM)	RASTER (MM/S)	POWER (W)	POROSITY (%AF)	CV	MICROHARDNESS (HV,200 GF,10S)	CV
101	5	50	300	4.62	0.38	387	0.05

LACS Scaled Sample 102



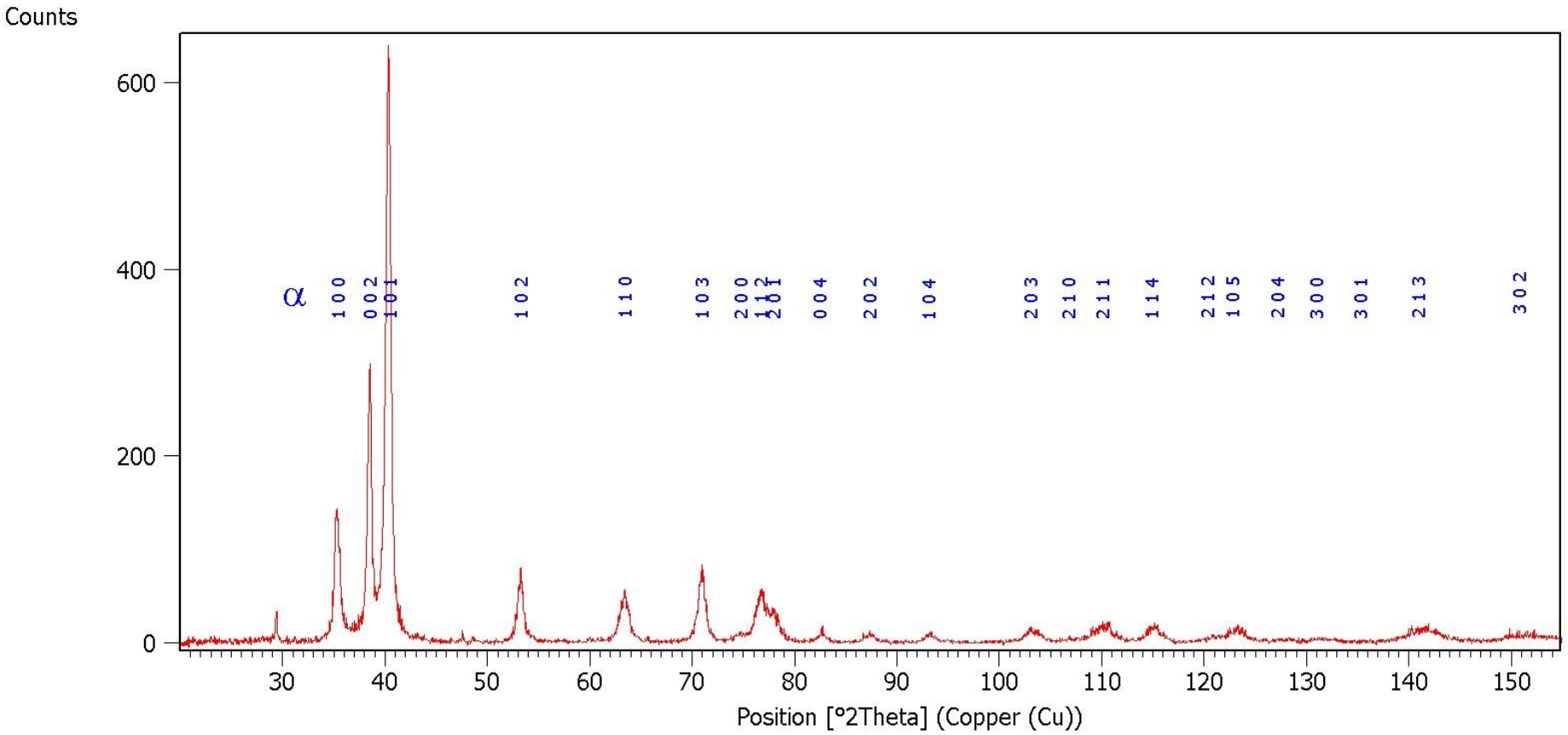
SAMPLE	PFR (RPM)	RASTER (MM/S)	POWER (W)	POROSITY (%AF)	CV	MICROHARDNESS (HV,200 GF,10S)	CV
102	1	400	300	0.81	0.17	313.6	0.26

LACS Scaled Sample 103



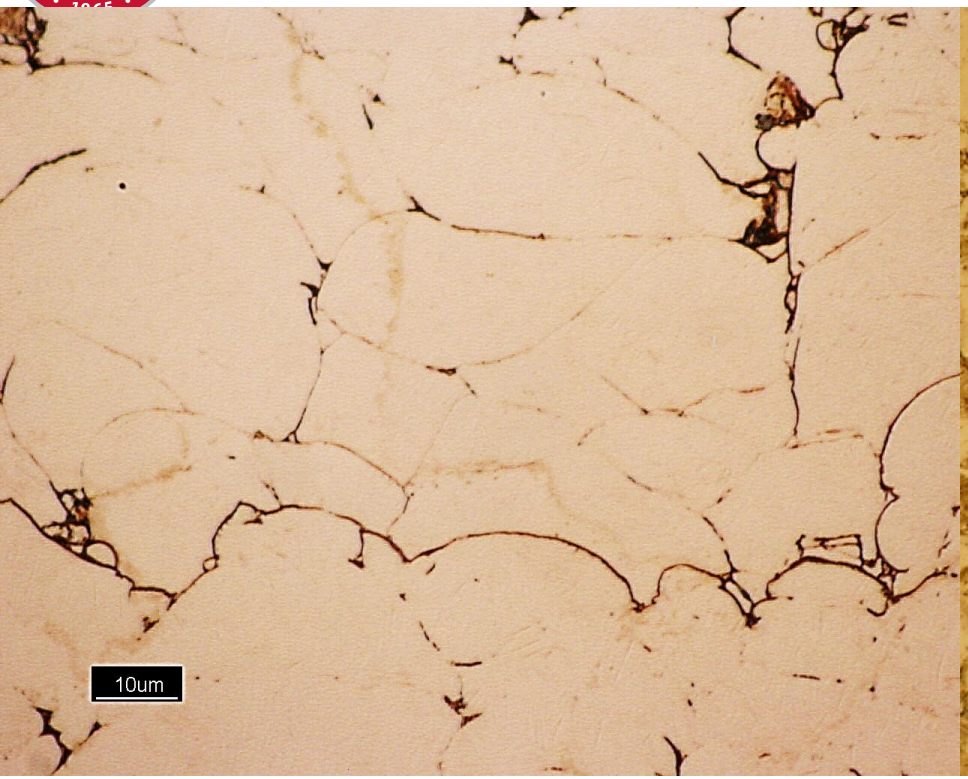
SAMPLE	PFR (RPM)	RASTER (MM/S)	POWER (W)	POROSITY (%AF)	CV	MICROHARDNESS (HV,200 GF,10S)	CV
103	1	50	600	10.92	0.13	461	0.57

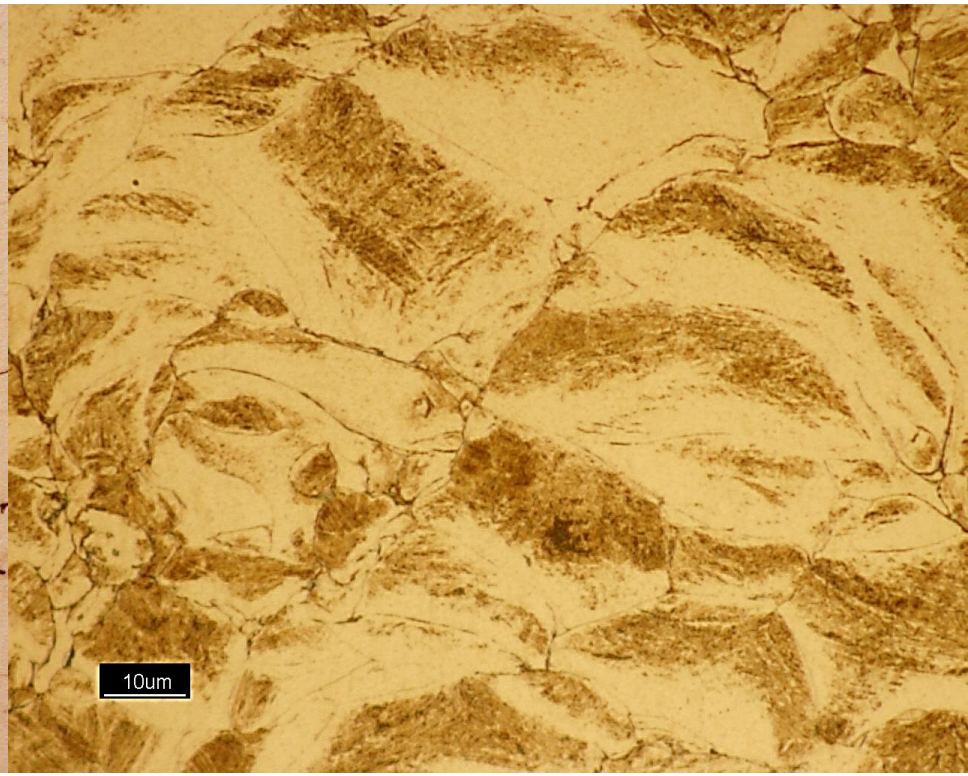
LACS Scaled Sample 104



SAMPLE	PFR (RPM)	RASTER (MM/S)	POWER (W)	POROSITY (%AF)	CV	MICROHARDNESS (HV,200 GF,10S)	CV
104	5	400	1000	2.21	0.29	330.8	0.07

Alternative Methods to Lasing

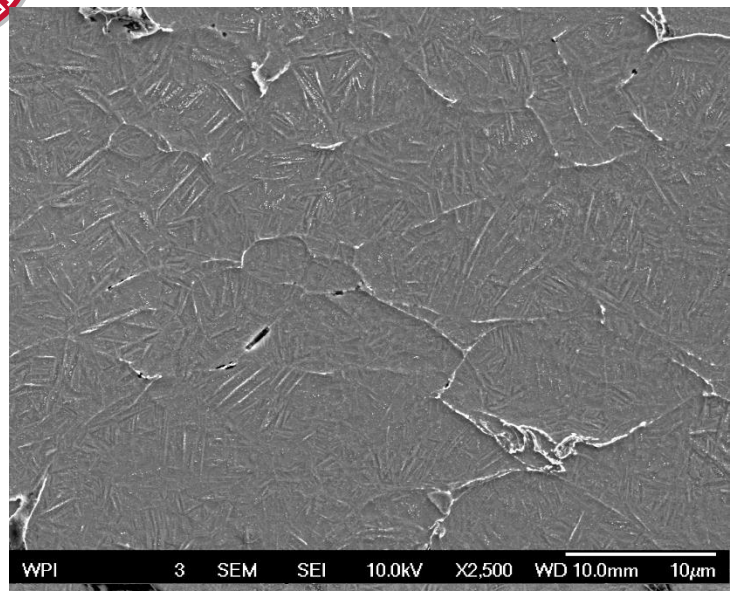


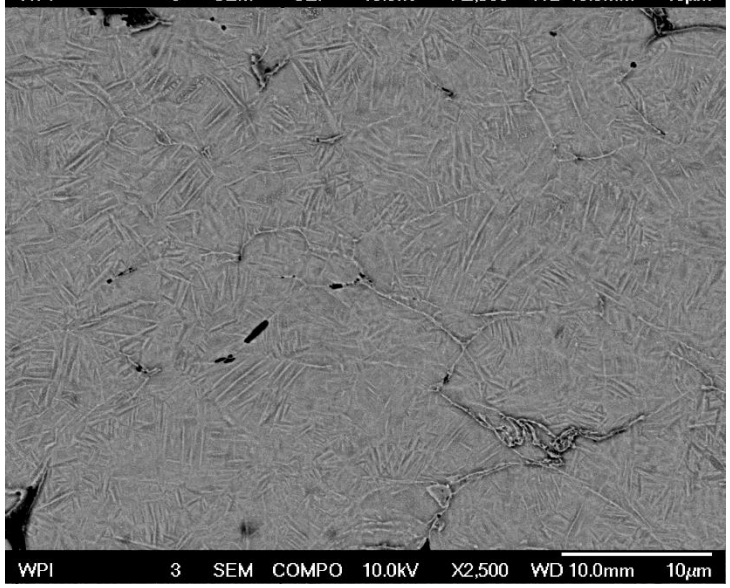


- 12LCTi108X
- PFR = 1 RPM
- Raster = 400 mm/s
- **Power = 600 W**
- Laser Position: B/W
- Coating Thick: ~ 1 mm
- Porosity: 3.05%

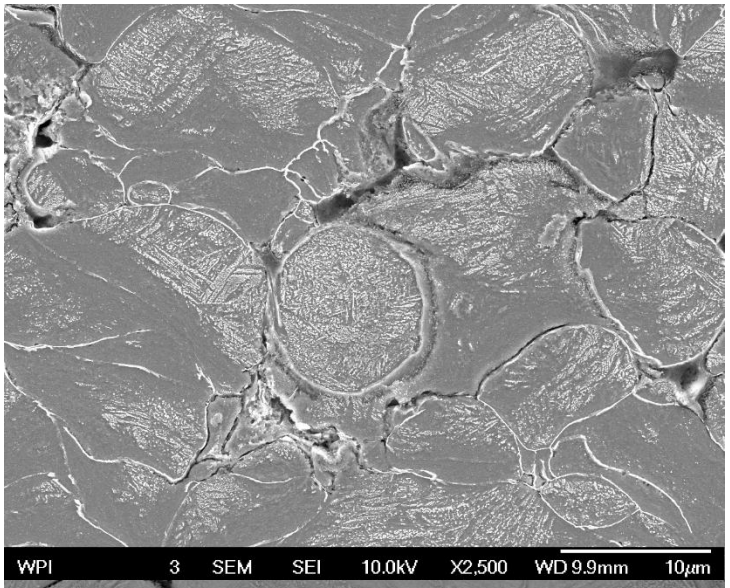
- 12LCTi109X
- PFR = 1 RPM
- Raster = 400 mm/s
- **Power = 300 W**
- Laser Position: B/W
- Coating Thick: 3 mm
- Porosity: 0.86%

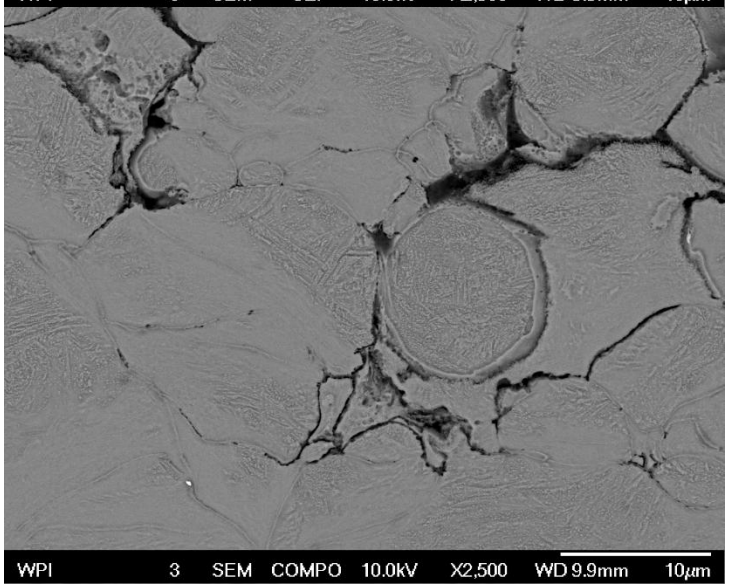
Alternative Methods to Lasing





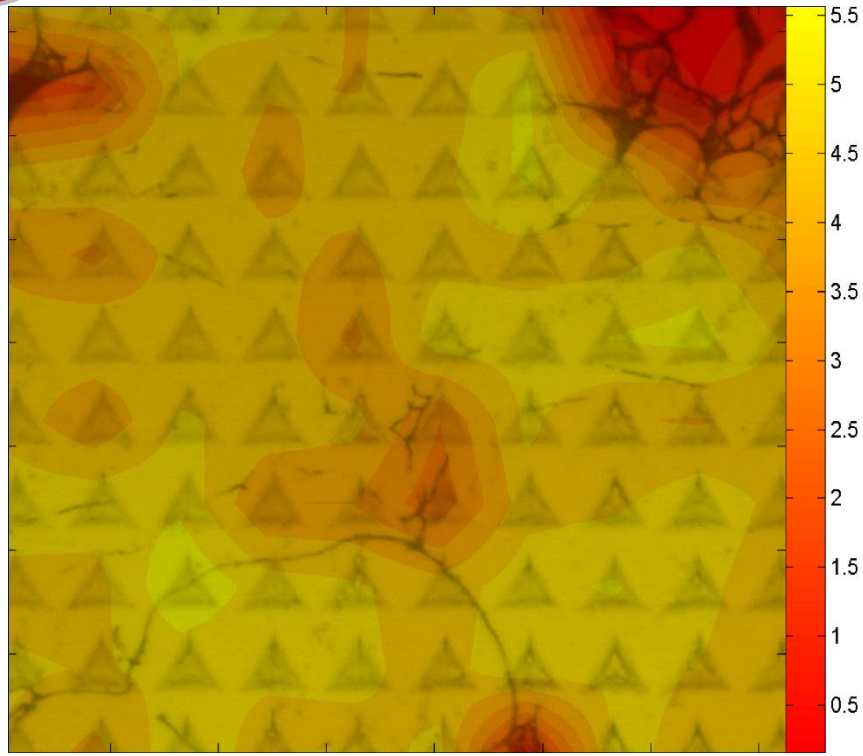
12LCTi108X



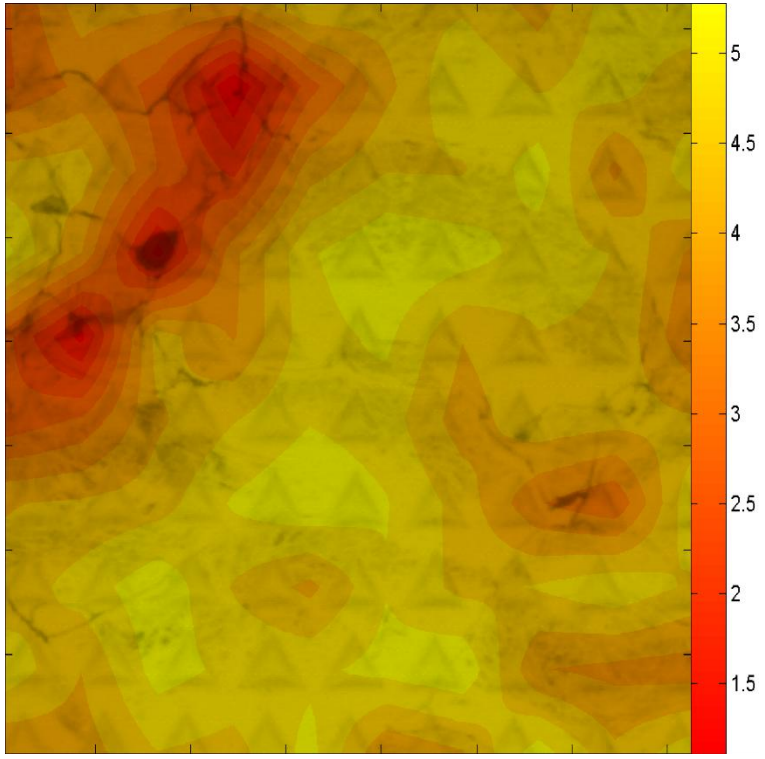


12LCTi109X

Alternative Methods to Lasing



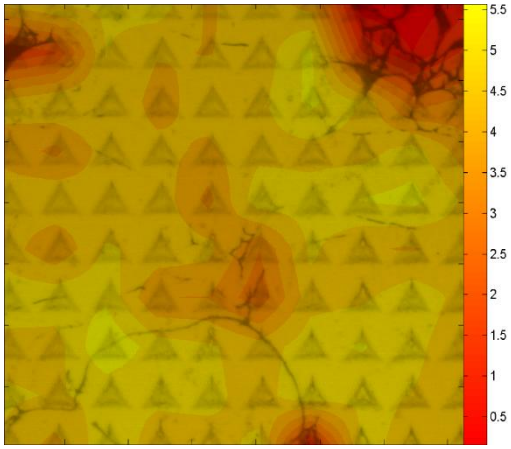
- 12LCTi108X
- PFR = 1 RPM
- Raster = 400 mm/s
- **Power = 600 W**
- Laser Position: B/W
- Coating Thick: ~ 1 mm
- Porosity: 3.05%



Hardness (GPa)

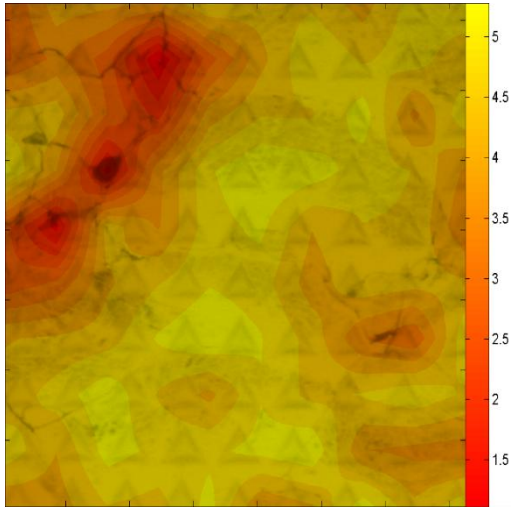
- 12LCTi109X
- PFR = 1 RPM
- Raster = 400 mm/s
- **Power = 300 W**
- Laser Position: B/W
- Coating Thick: 3 mm
- Porosity: 0.86%

Ti-6Al-4V Comparison



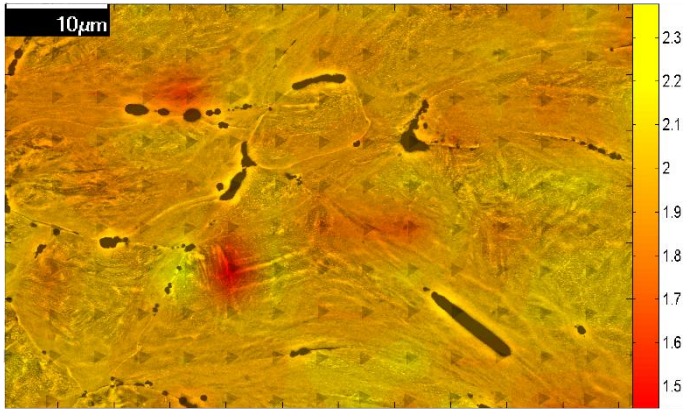
Laser in B/W at 600W

- Porosity: 3.05%
- Average Nanohardness: 4.63 GPa



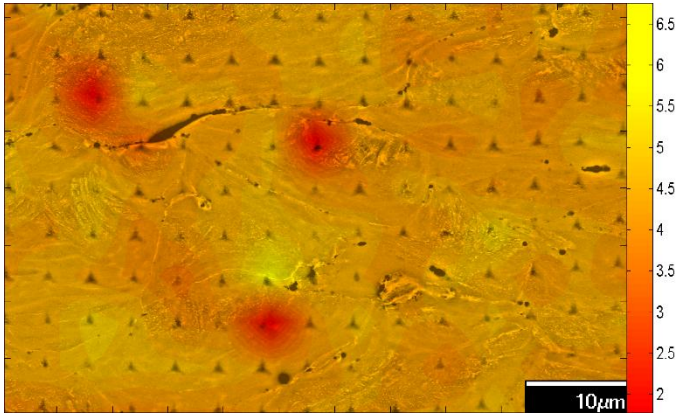
Laser in B/W at 300W

- Porosity: 0.86%
- Average Nanohardness: 4.47 GPa



Cold Spray Pure Nitrogen

- Porosity: 10% (as low as 3% for some samples)
- Average Nanohardness: 2.1 GPa

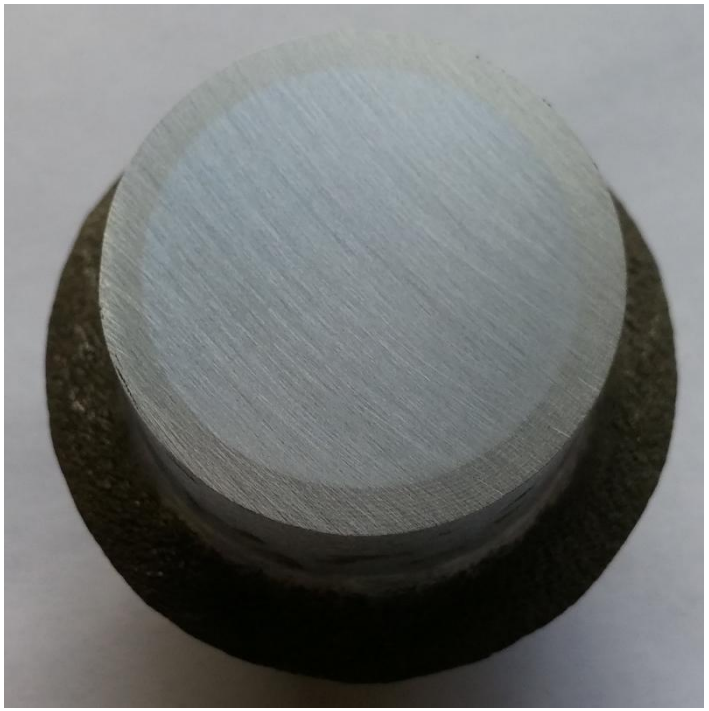


Cold Spray Helium + Nitrogen

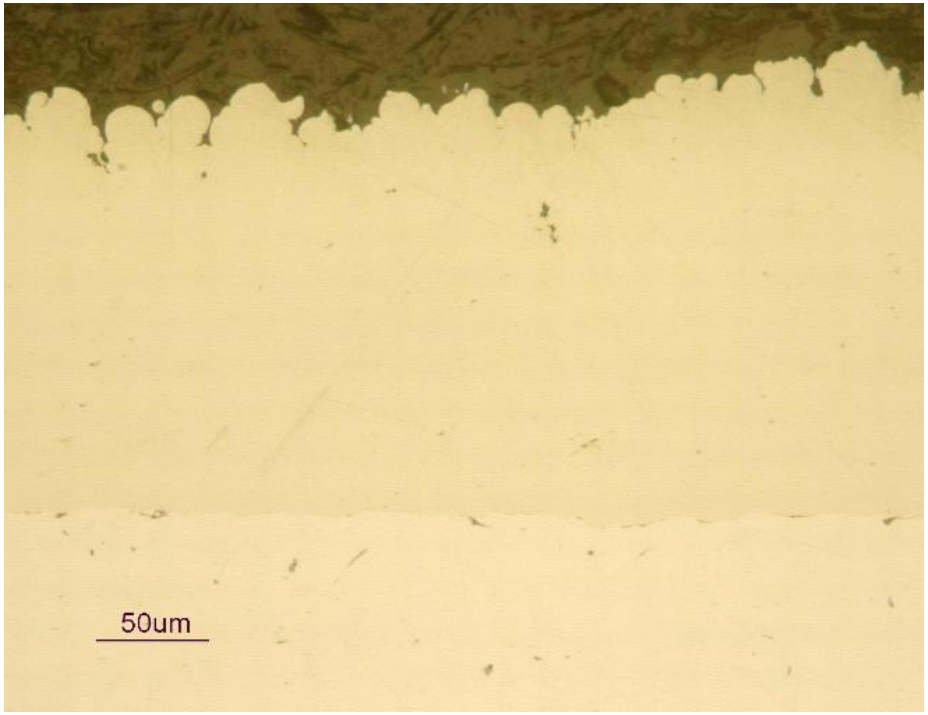
- Porosity: <2% (as low as 1% for some samples)
- Average Nanohardness: 5.07 GPa

LACS of Grade 1 CP Ti

CP Titanium on Steel



CP Titanium



Property	LACS (Nitrogen)	Cold Spray (Helium)
Thickness	>2 mm	-
Porosity	<0.5%	0.1-11%
Bond Strength	>10000 psi	>10000 psi
Hardness	189 Vickers, 91 Rb	150-320 Vickers
Deposition Efficiency	88%	80-95%
Deposition Rate	84.8 g/min	-
Process Gas	Nitrogen	Helium

CS Data from T. Hussain 2013

- Laser Assisted Cold Spray
- Titanium
- Experimental LACS
- Conclusions

Conclusions

1. Framework and Baseline
2. Microstructural Control
3. LACS Nitrogen versus CS He Property Match
4. Different Materials
5. Novel Materials

U.S. Army Research Laboratory
Contract #: W911NF-10-2-0098