IPG PHOTONICS

LASER ASSISTED COLD SPRAY

Nano AI SUPERALLOYS

Outline

- IPG Systems Development Group
- Laser Assisted Cold Spray (LACS) Process
- LACS Results
- IPG LACS Next-Gen System Capabilities

IPG is in the systems business, supplying complete laser material processing solutions.

Laser Sources

Beam Delivery

Integrated Systems

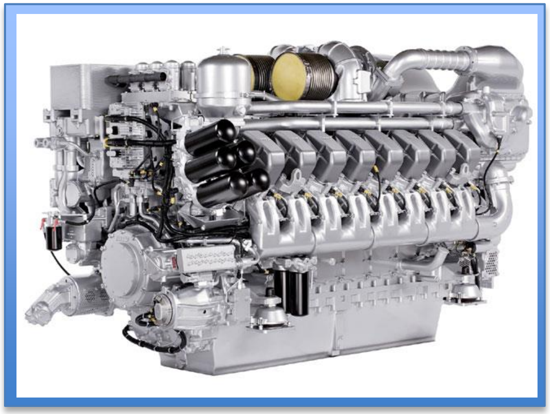
Laser Assisted Cold Spray (LACS)

IPG Photonics, the world's leading provider of fiber lasers, is developing a alternative solution for applying metal coatings to mechanical parts.

Laser Assisted Cold Spray (LACS) produces coatings having high adhesion and low porosity, without subjecting the part to high temperatures.

Using Nitrogen instead of Helium, LACS is a highly cost-effective and efficient process.

LACS Wear-Resistant and Corrosion-Resistant Coatings

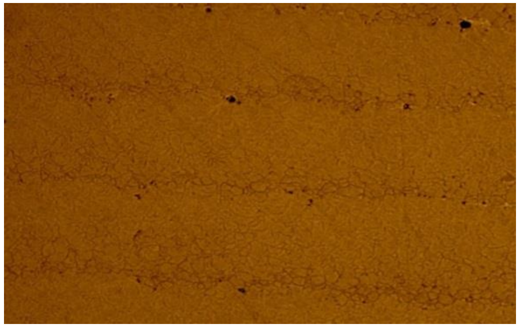


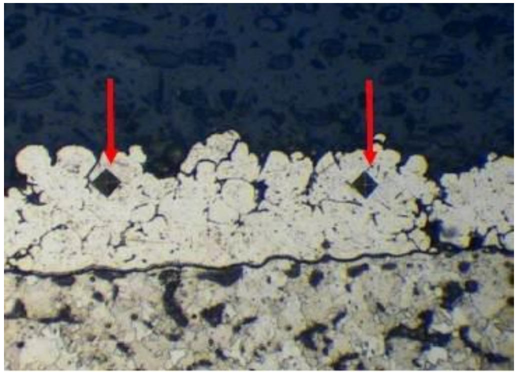
Moving equipment parts are subject to wear.

Repairs typically involve replacement, but newly manufactured parts are not always available.

LACS allows re-coating and re-building of parts with fast response and reduced costs.

Typical Coated Material Requirements





- Strong Adhesion
- High Tensile Strength
- Low Porosity
- Deposition Uniformity
- High Wear Resistance
- High Deposition Rate
- High Deposition Efficiency
- No Part Damage

LACS coatings can be machined like original metal.

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Laser Assisted Cold Spray - Process

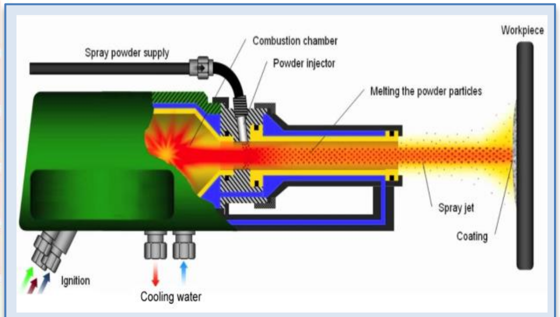
- Thermal Processing
- Molten Deposition
- High Velocity

- Thermomechanical
- Solid State Deposition
- Supersonic Velocity

- Mechanical Processing
- Solid State Deposition
- Supersonic Velocity

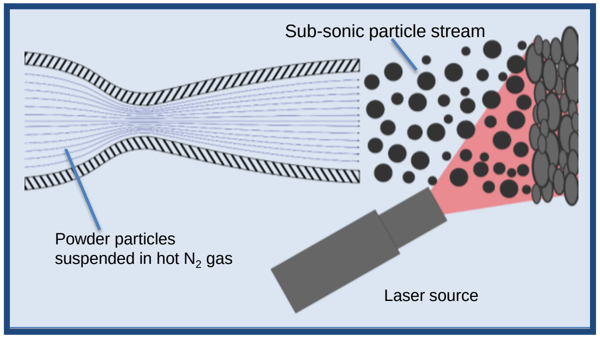
Melting — **Near Melting** — **Far Below Melting**

Thermal Spray



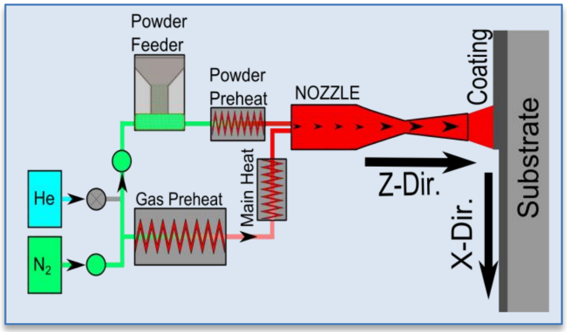
- Strong Adhesion
- High Porosity
- High Tensile Stress
- Oxidation & Heating

Laser Assisted Cold Spray



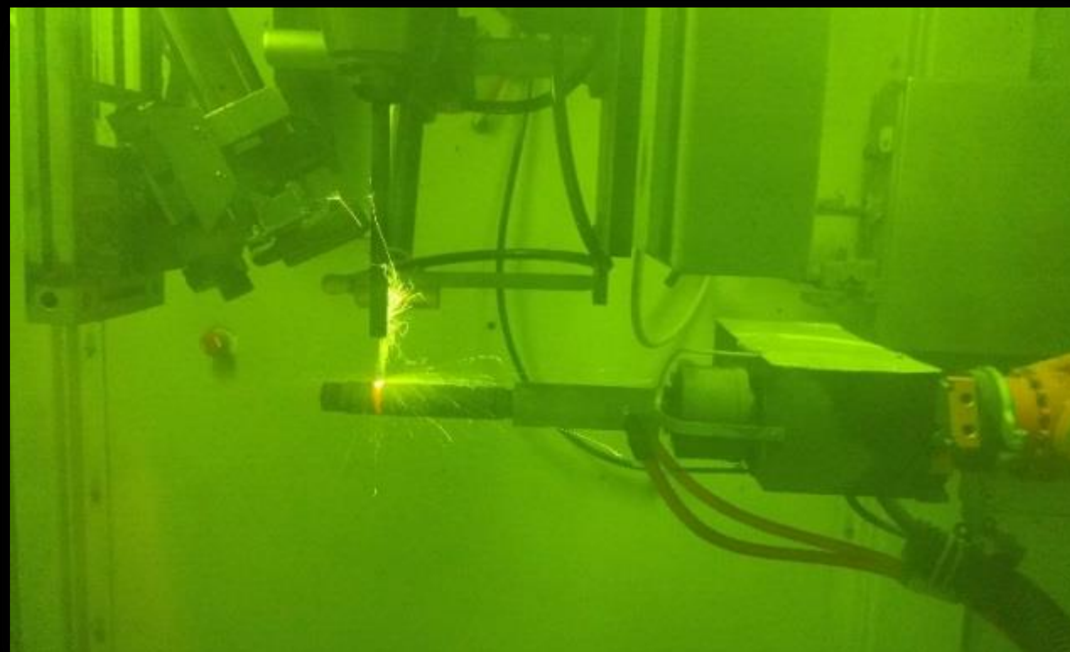
- Strong Adhesion
- Low Porosity
- Controlled Heat
- Economic N_2 Process

Cold Spray

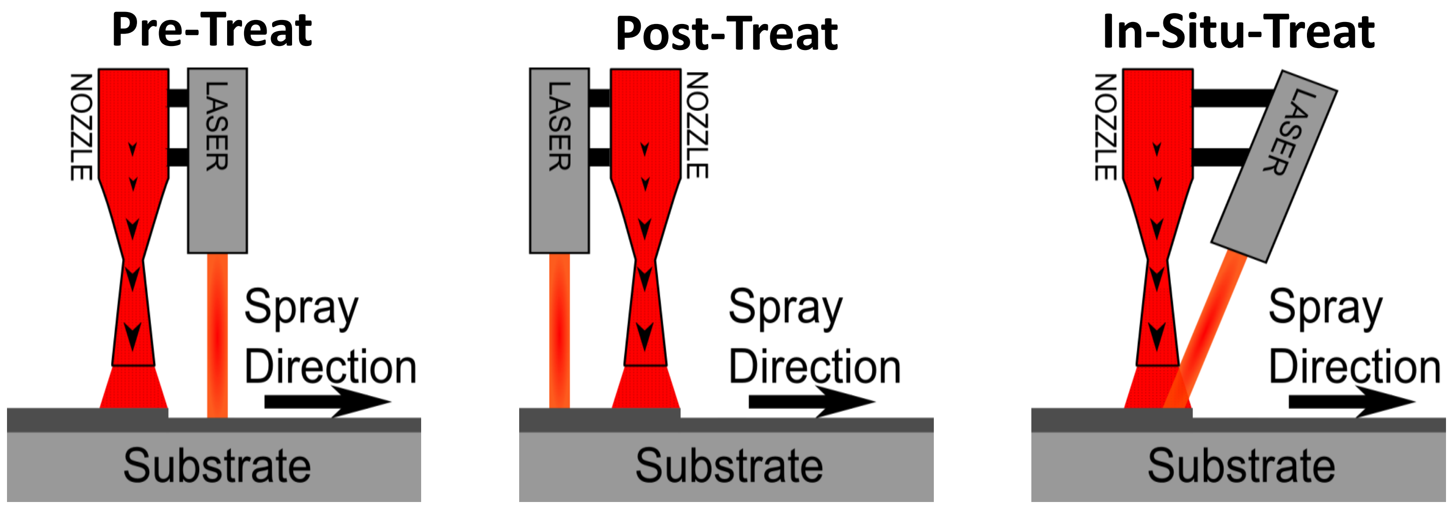


- Strong Adhesion
- Very Dense
- Compressive Stress
- Expensive He Process

LACS Deposition of CP Ti on a Steel Shaft



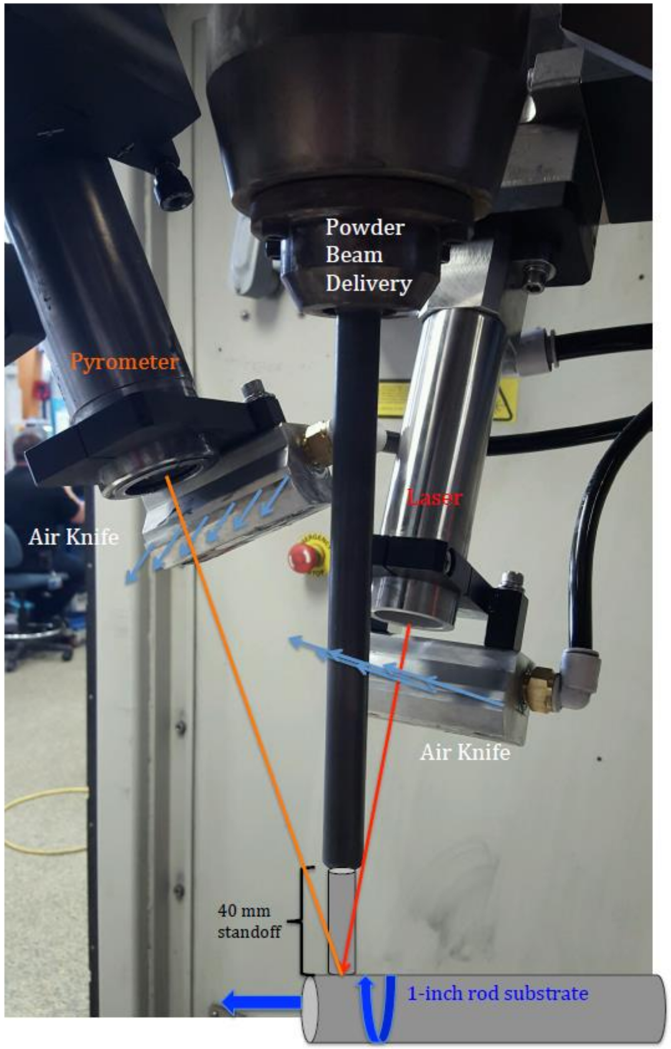
LACS Process Advantages



- Capable of spraying a wider variety of materials
- Use N_2 vs He with similar results, reducing operating costs
- The required minimum particle diameter for deposition is adjustable
- Surface Treatments:
  - Substrate preparation (surface ablation/cleaning/roughening)
  - Surface finish (post heating, shot peening, etc)
  - Heat treat on demand

Results – DOE

Feature	Parameter
Powder	Ti, Fe, Al, Ni, Cu, WC, Ta, Nb, Mo
Substrate Material	Fe (steel, cast iron, SS), Al, Cu
Powder Particles Size	5-150 µm
Powder Feed Rate	variable
Coating Thickness	50µm - 20 mm
Laser Power	10 kW (IPG YLS 10000)
Spot Size	6.0-8.00 mm, variable
Laser position/angle	Off axis, variable
Spray spot size	~10.0 mm
Nozzle Material	WC
Nozzle diameter	5.0 mm
Nozzle Standoff Distance	39.0 mm
Laser Set temp	variable
Raster Speed	variable
Speed of the gun	N/A
Nozzle Standoff Distance	39.0 mm
Gas	Air, He, N_2, mix
Gas Pressure	30 bar (nozzle design)
Gas Temperature	450 - 650°C
Part Geometry	Cylindrical, Flat



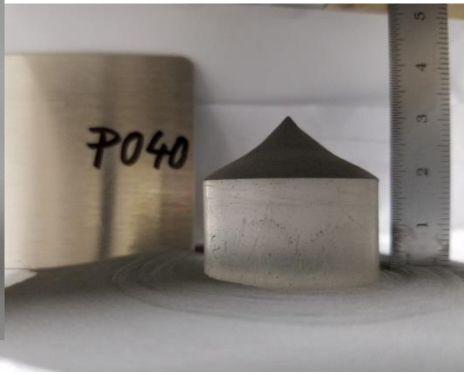
Results – Powder Characterization

Powder	Substrate
Ti-based	Steel
WC-Co/Ni	Cast iron, steel
Ni-based	Cu-based
Al-based	Al-based
HP Cu	
Stainless Steel	
Ta, Nb, Mo, W-Ta	Steel

<u>Powder Properties Assessed</u>

- Particle Size distribution
- Morphology
- Flowability
- Internal Porosity
- Apparent density
- Electrical conductivity
- Elemental Analysis
- Nanoindentation

Hall Flowmeter



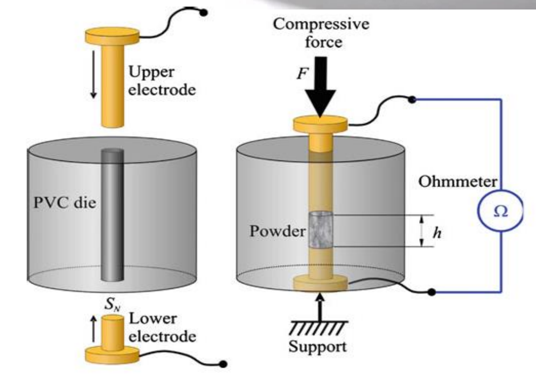
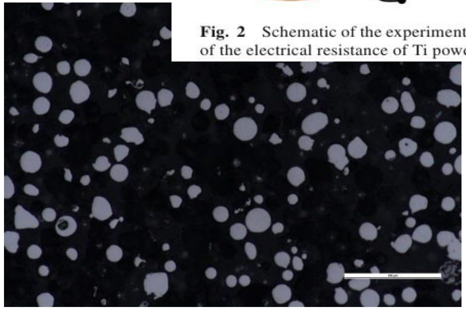
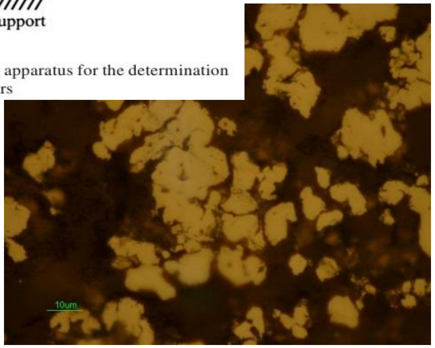


Fig. 2 Schematic of the experimental apparatus for the determination of the electrical resistance of Ti powders

Montes et.al. 2011





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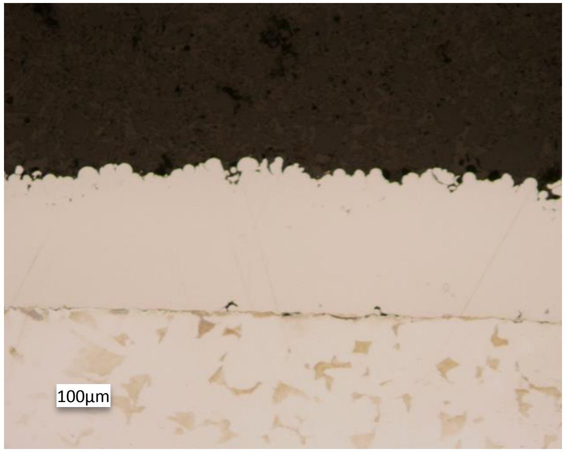
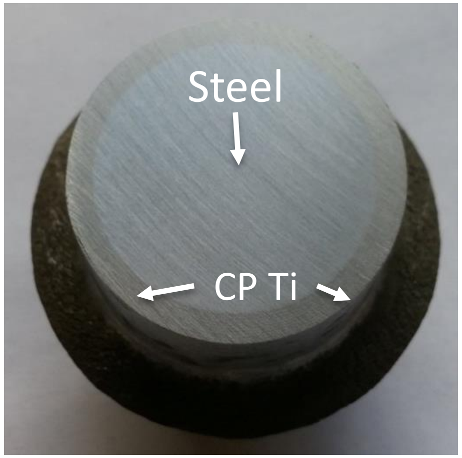
Results – CASE#1 - CP Ti on Steel

CP Ti G2 on Low Carbon Steel



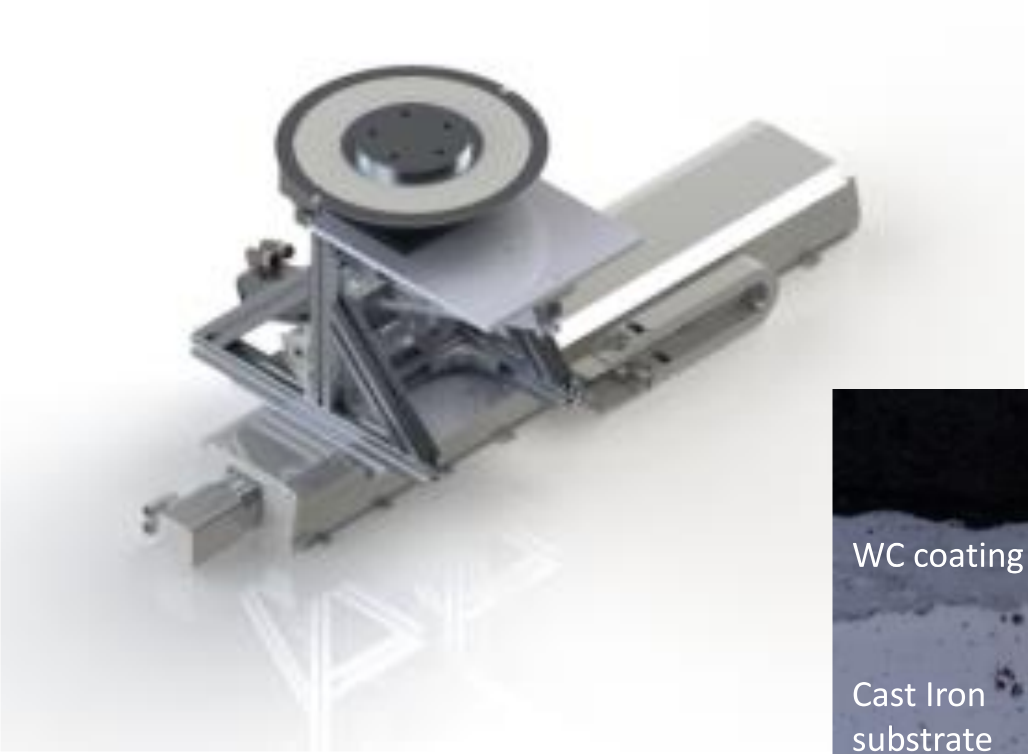


System	Vacuum Arc Spray	IPG-LACS	CGT 4000 (He)
Demo Material	CP Ti	CP Ti	CP Ti
Porosity	<1%	<0.8%	0.42%
Bond Strength	7.3 ksi	10 ksi*	3.8 ksi
Spray Cost ($/kg CP Ti)	197	199	322
Deposition Rate	3-5.4 kg/hr	5 kg/hr	14 kg/hr
Deposition Efficiency	High	88%	85-100%
Source	Steffens (1985)	IPG	IPG/Hussain (2011)

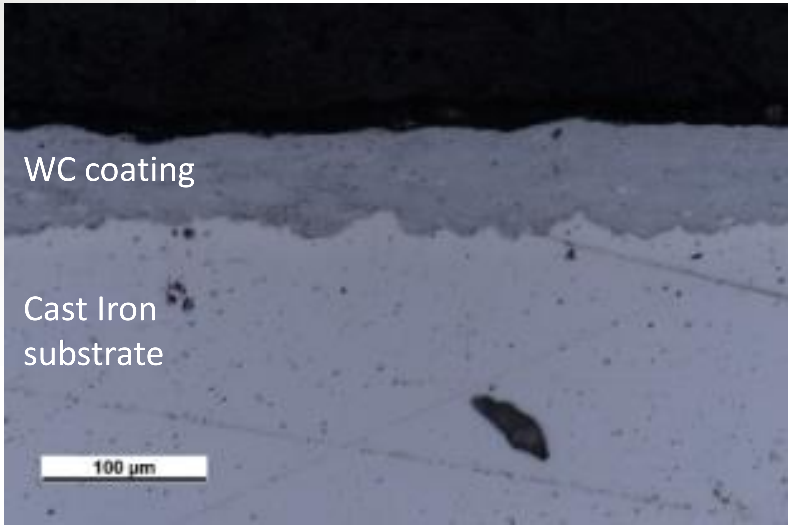
*Glue coating failure

Results – CASE#2 – WC on Cast Iron

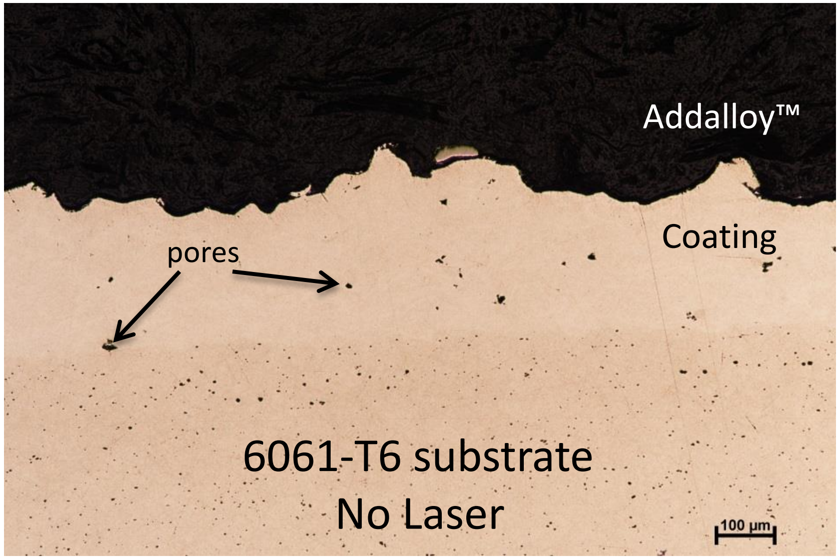
- Tungsten Carbide on Cast Iron Brake Rotors
  Goal: Increase rotor life from 60K to 120K km

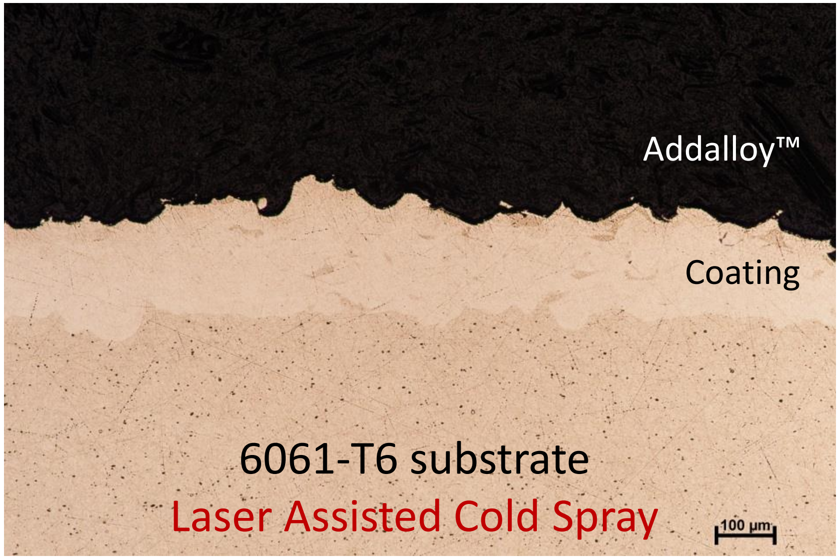


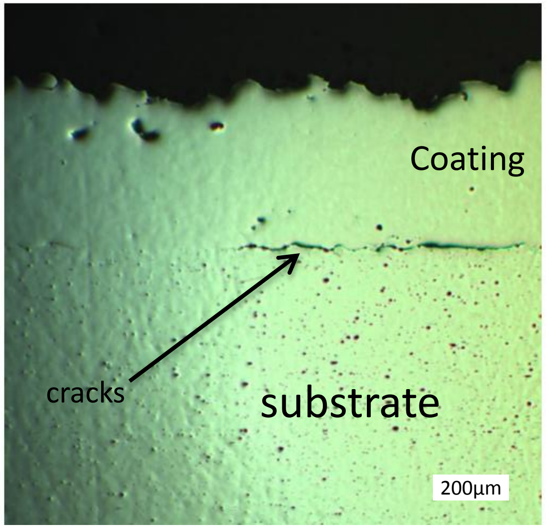
$R_a << 10$

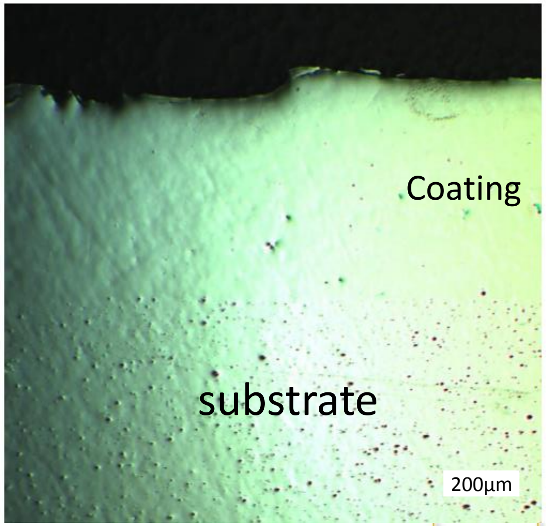


Results – CASE#3 – Addalloy^{TM} on Al

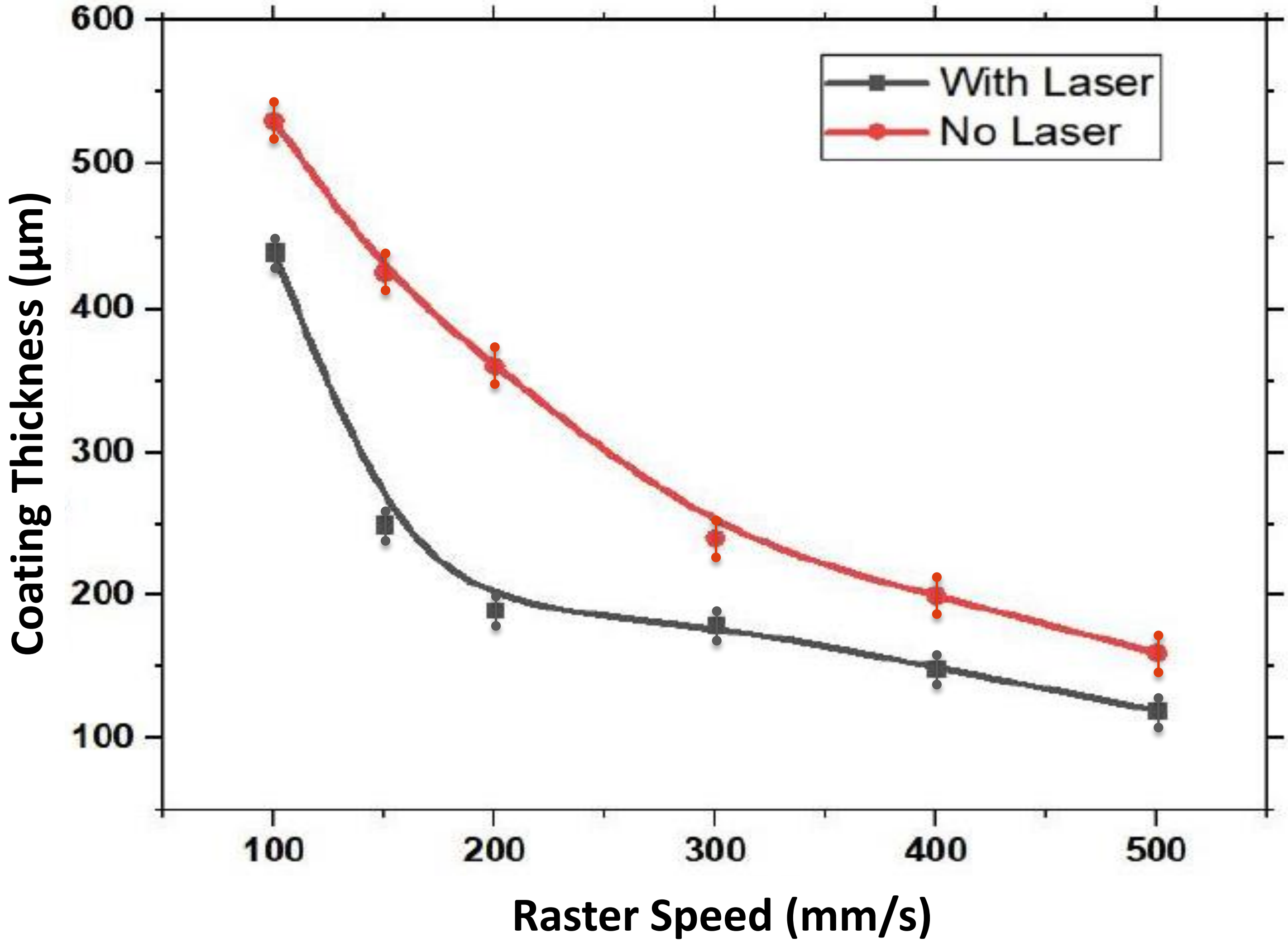








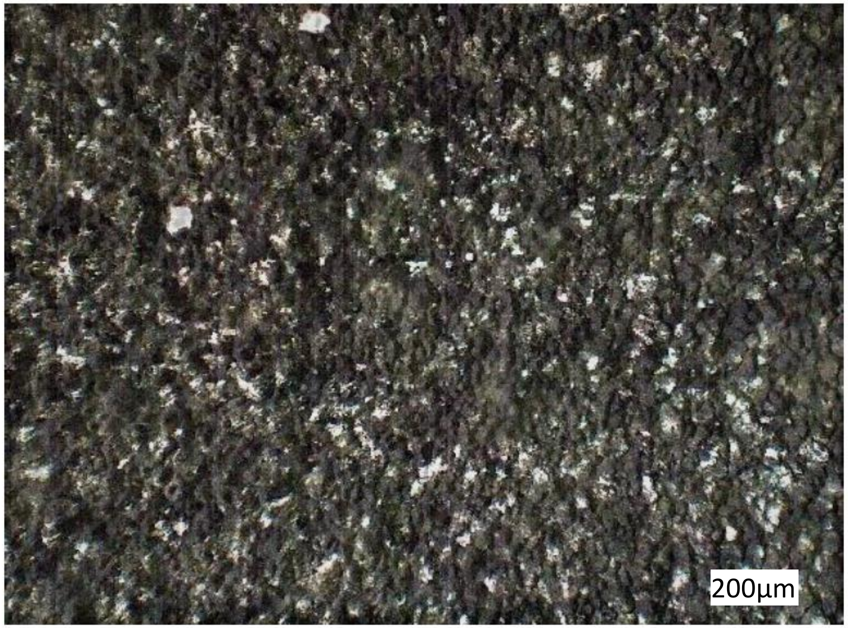
Results – CASE#3 – Addalloy™ on Al



Results – CASE#3 – Addalloy^{TM} on Al

Laser Assisted Cold Spray

Cold Spray



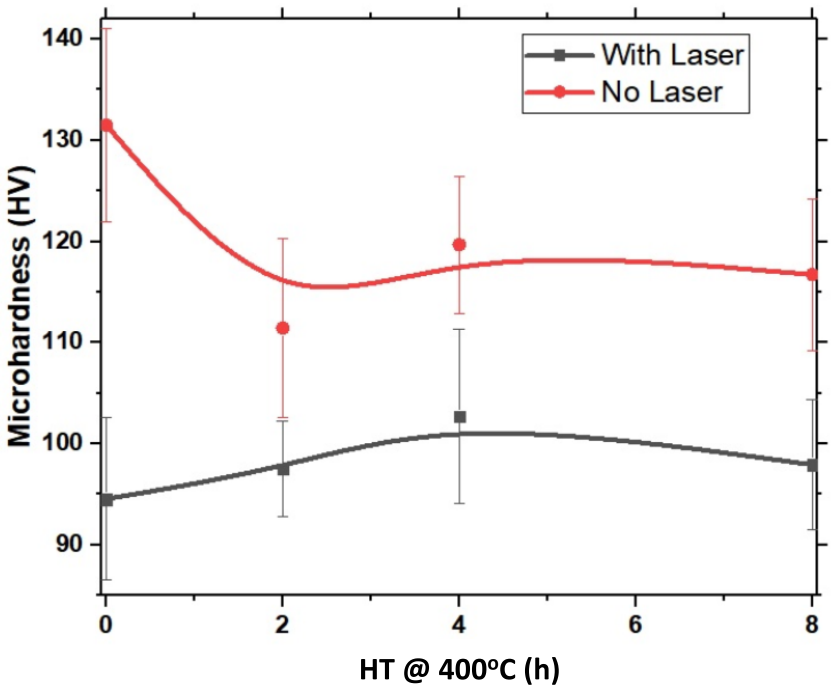
	With Laser (µm)	No Laser(µm)
Roughness average (Ra):	13.2	17.9

<u>Combination of optical images</u>

- Cross section view (magnitude of wave)
- Plane view at multiple heights (3D view of roughness)
- Plot image intensities across surface

Results – CASE#3 – Addalloy™ on Al

- **No laser**
  - Powder strength + strain hardening
  - After HT @ 400°C: strain hardening↓, precipitation hardening ↑
- **With Laser**
  - Full annealing of coating (no strain hardening)

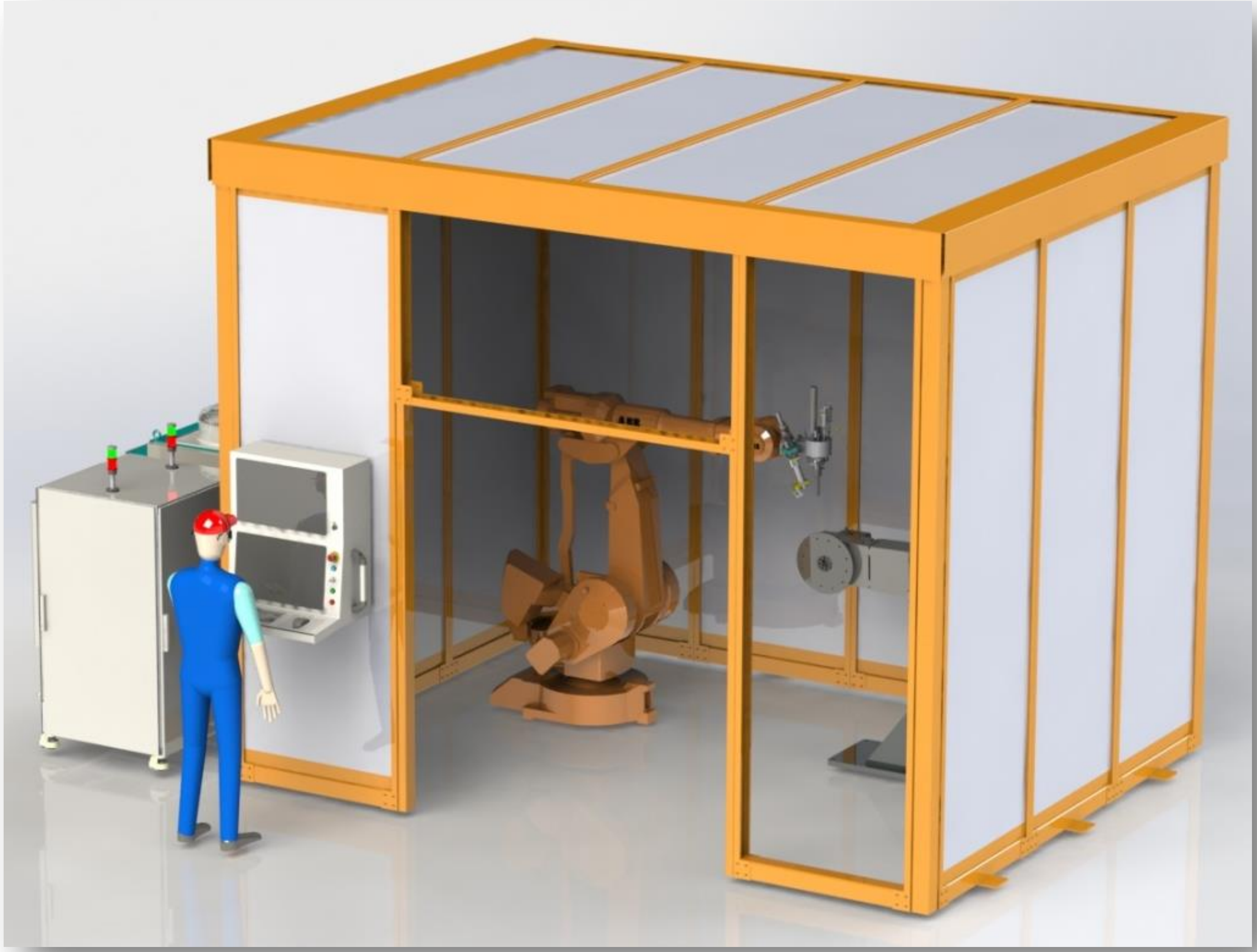


Strategy

1. Laser ON for first layer (increase bonding)
2. Laser OFF during coating (max strength)
3. Laser ON for last layer (smooth surface)

	Microhardness of Substrate (HV)
With Laser	68
No Laser	109

IPG LACS Next Gen



Summary of LACS Benefits

- Fast deposition rate reduces cycle time
- Nitrogen process gas is much cheaper than Helium
- Lower gas temperatures reduce energy use
- High deposition efficiency reduces material waste
- IPG’s unprecedented laser wall-plug efficiency (>40%) reduces operating costs (up to 100kW+)

Thank You

IPG Photonics Corporation

(NASDAQ: IPGP)