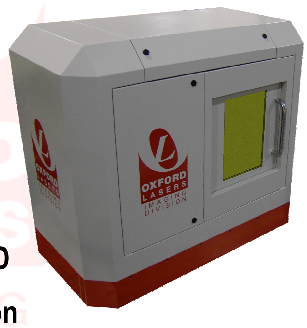
Visualising Particles in Extream Cold Gas Dynamic Spraying (CGDS)



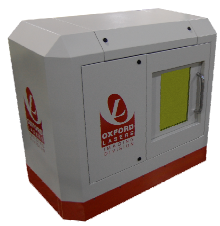
Dr Séamus D Murphy EngD

Manager of Imaging Division

Seamus.murphy@oxfordlasers.com

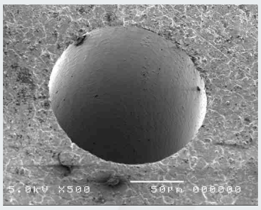
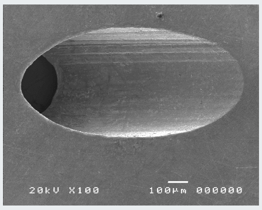
Oxford Lasers Ltd

- Over 37 years old
  - Industrial - Lasers Micromachining
    - Micro-machining system
    - Application Lab for sub-contract
    - manufacture
  - Imaging - High speed imaging / flow visualisation
    Particle sizing / Spray analysis
    - Standard & Custom system
    - Frequency range 1 Hz to 200,000 000 Hz

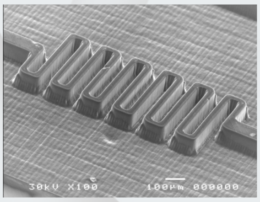
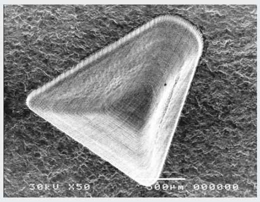


Micro-Machining - Ablation

Micro-Drilling

Micro-Milling

Outline

- Why do we use Lasers in high speed imaging
  - What are the important properties that we use ?
- Application Techniques
  - High Speed Imaging
    - Types of illumination
  - Image based Particle Sizing (PDIA)
    - Particle size and Particle velocity data
  - Flow Field Vector Analysis (PIV)
    - Flow velocity data
- Cold Gas Dynamic Spraying CGDS
  - Case 1 - System behaviour with changes in powder type, gas
  - Case 2 - Nozzle performance

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Why use a pulsed Laser ?

PULSE RATE: Capture Up to **50,000** images per second. High pulse rate allows detailed analysis of fast events.

IMAGE BLUR: The Laser provides down to a **5 nano second** exposure times, which eliminate blur - ***No Motion Blur***.

Conventional Illumination
"Standard Photographic light"
Blurred Image, only see the outline of the spray

Pulsed Light source
"Laser light 25 ns"
No Motion Blur, see liquid breakup, ligament formation & drops

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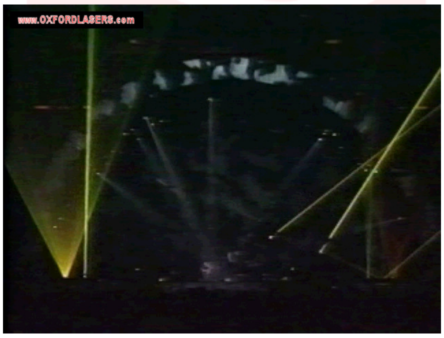
Why use a pulsed Laser ?

We can EASILY MANIPULATE THE OUTPUT:

Light from laser has "***Low divergence***" – Light does not spread and therefore allow various types of illumination.

High speed camera – as the operating frequency increases ↑ the amount of light required increases ↑ exponentially

Laser Light can be "***Focused***" to provide Intense lighting @ High frequency



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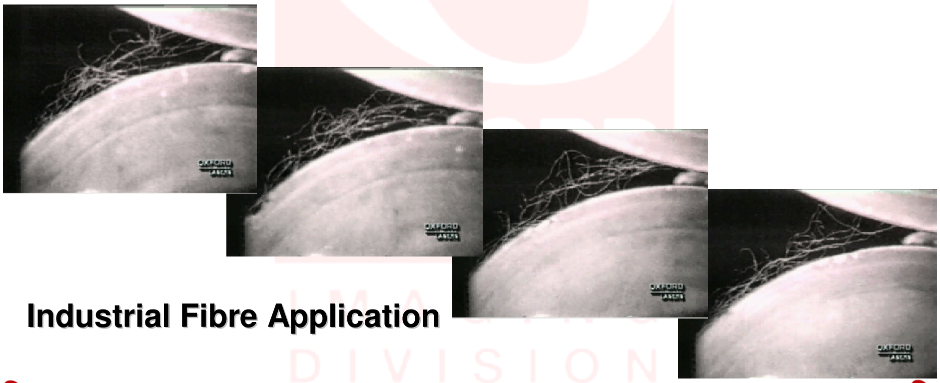
Why use a pulsed Laser ?

"High frame rate require high intensity lighting"

"COLD" LIGHT Source: Short pulse duration means No infrared radiation, no thermal effects, ideal for delicate measurements such as spray and droplet analysis.



Industrial Fibre Application

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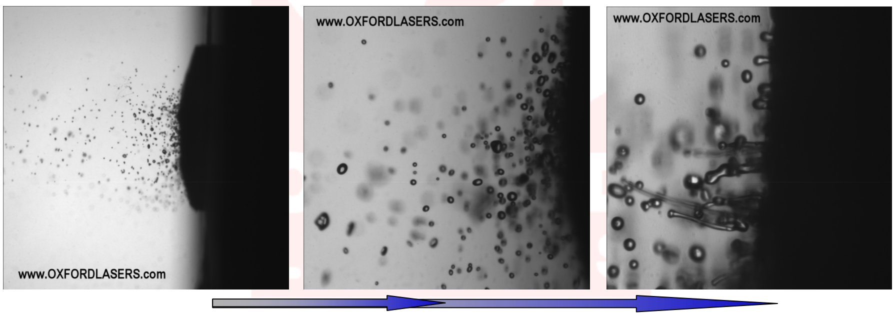
Why use a pulsed Laser ?

High speed – high magnification

"Low divergence light source provides High intensity lighting"

Example - Medical Coating process – define process conditions



Blur free high quality images	Blur free high quality images	Blur free high quality images
Field of view 3910 microns	Field of view 756 microns	Field of view 454 microns
"See over all spray "	*"See individual drops"*	*"See drop formation"*

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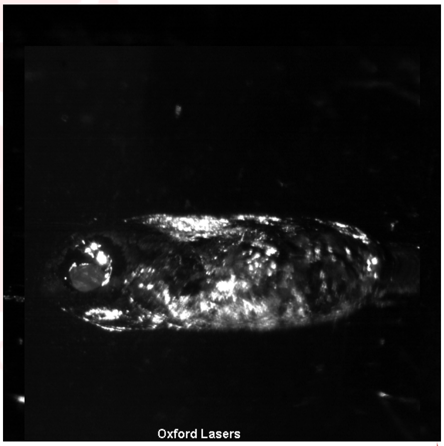
Why use a pulsed Laser ?

Monochromatic light

"Single wave length"



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Hardware Technology

- **Lasers Source**
  - Frequency Range 1 – 50,000Hz
  - Single pulse or Dual pulse arrangement
  - Pulse duration 1.5 nano seconds to 1000ns
  - Pulse energy 2 mille joule to 500 mille joule

- **Camera**
  - ***Low frequency Cameras***
    - Application to low speed / frequency events
    - Images resolution up to 16,000,000 pixels
    - Various modes image capture –
      - Single image or Dual images mode
      - Two images with very small time separation between images
      - Dual mode Equivalent frequency up to 80,000,000Hz
  - ***High Frequency cameras***
    - General high speed / frequency
    - Range from 60Hz to 1,200,000Hz

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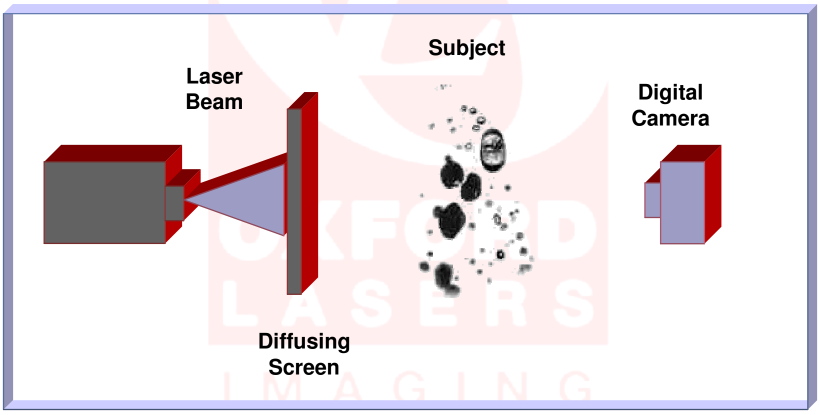
Lighting Techniques

Back illumination



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Lighting Techniques

Back illumination

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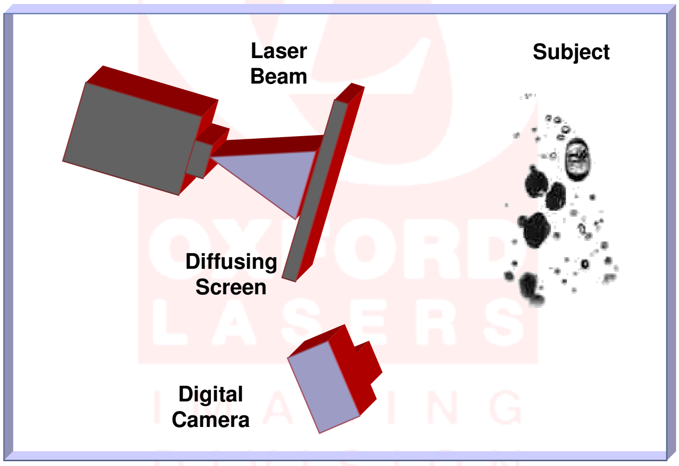
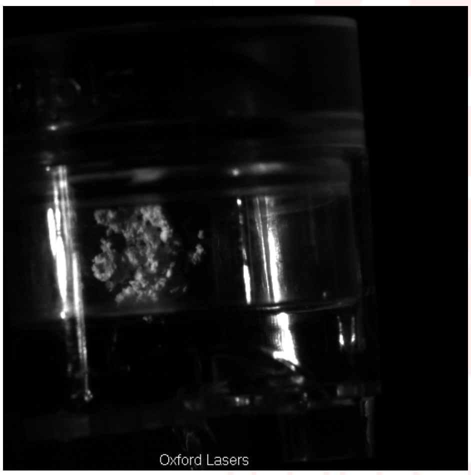
Lighting Techniques

Front illumination



Lighting Techniques

Front illumination



Study of powder Fluidization

Imaging @ 8000Hz

- **Powder “A”**
  - Combination of front and rear illumination
  - Image Fluidization of Powder as it is evacuated from the system
  - Powder –
    - No Large agglomerations of powder, small particle appear to break away from the bulk of the material in a even stream

Work completed at University of Bath
School of Pharmacy and Pharmacology

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Study of powder Fluidization

Imaging @ 8000Hz

- **Powder “B”**
  - Combination of front and rear illumination
  - Image Fluidization of Powder as it is evacuated from the system
  - Powder –
    - Large agglomerations of powder are drawn away from the bulk of the material

Work completed at University of Bath
School of Pharmacy and Pharmacology

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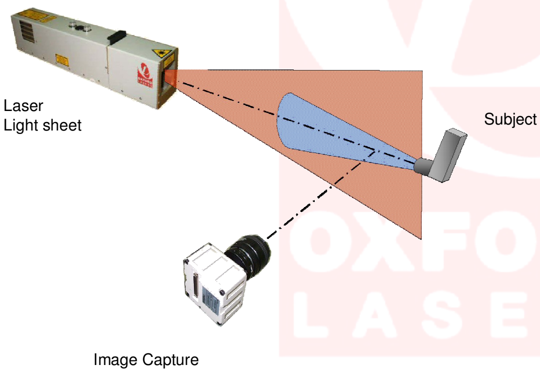
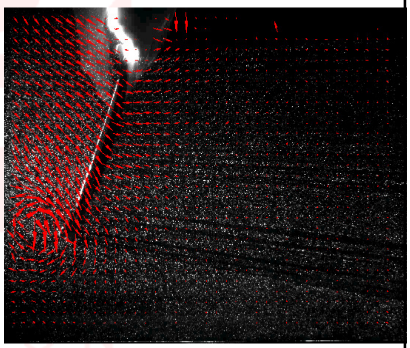
Lighting Techniques

Light Sheet





Cold Gas Dynamic Spraying (CGDS)

- Advanced coating technology for the production of metal based coating.
- Process involves the deposition of a metallic layers and structure from fine powders propelled using a high pressure gas jet
- Benefits over thermal spraying techniques
  - High strength coating – low porosity
  - High quality coating :- corrosion and oxidation resistance
  - Minimal impact on substrate – lower operating temperature – does not affect the material properties of the substrate.
  - Free form process – can be used to build up complex components

Cold Gas Dynamic Spraying (CGDS)

Industries

- Aerospace
- Oil & Gas
- Petrochemical
- Automotive
- Electronics
- Power Generation
- Medical

Application

- Corrosion mitigation
- Berings
- Thermal Management
  - Switch gears
  - Conductive tracks
- Oxidation mitigation
- Biocompatible coating
  - Medical device
  - implants

Cold Gas Dynamic Spraying Process (CGDS)

Basic Principal –

Provide particles with sufficient Kinetic and Thermal Energy so that when they impact the substrate they will form a bond.

Particle size range 10 microns to 50 microns

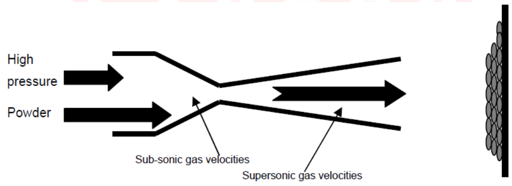
Particles accelerated to velocities between 500 – 1000m/s in a supersonic jet of compressed gas

Particles impacting the substrate will experience a plastic deformation that disrupts the surface film (such as oxides) and bonding occurs under high pressure.

Slow build up of material, typically **100 to 1000 um** thick

Deposition process –

For Thermal sprays the performance of the deposition process, is dependant on the velocity and temperature of the particles.



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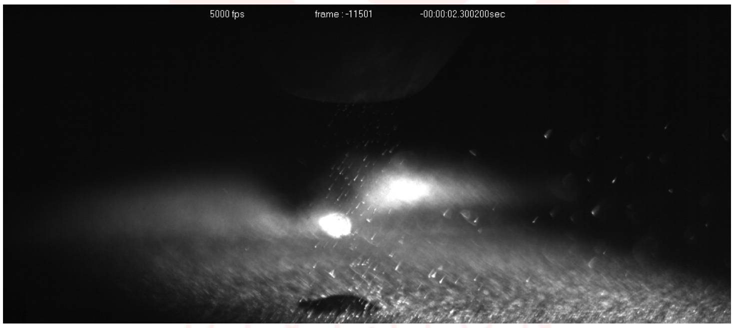
Cold Gas Dynamic Spraying Process (CGDS)

CGDS – Particle sprayed at lower temperature from **0 to 500 °C**

For thermal sprays gas temp range from 1000 °C to 15000 °C

So to achieve the plastic deformation necessary, much **higher velocity** are required to achieve a well bonded and cohesive coating.



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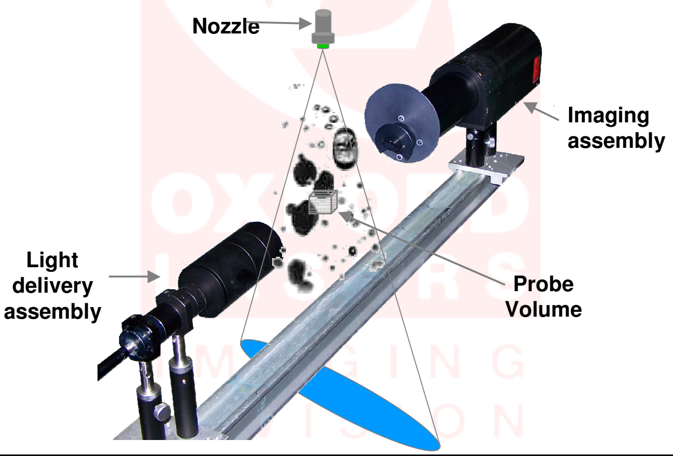
Application Technique

Particle Sizing & Particle Velocity



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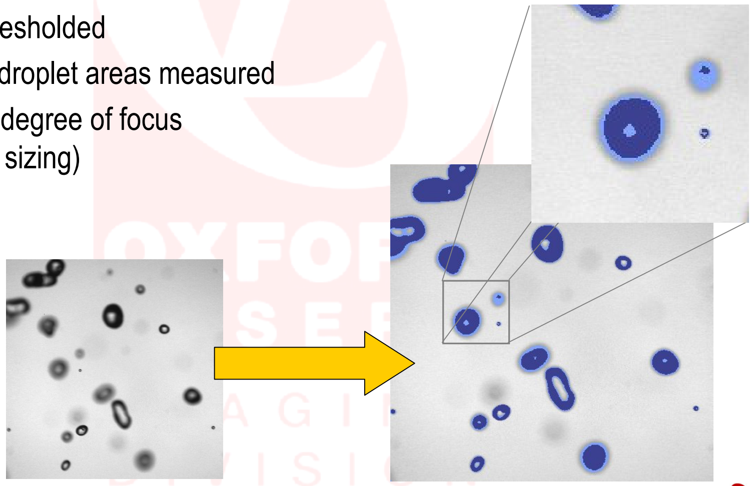
Application Technique

Particle sizing

- Image thresholded
- Particle / droplet areas measured
- Identifies degree of focus (accurate sizing)



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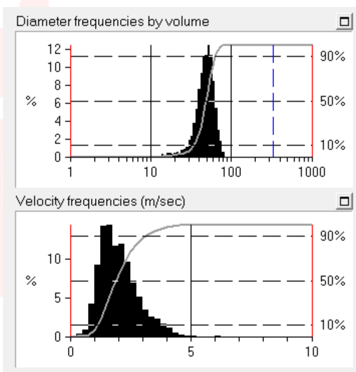
Application Technique

- **Mean diameter (by number, area or volume)**
- **Volume and number median diameters**
- **10%, 50%, 90% volume and number percentiles**
- **Cumulative volume distribution**
- **Span**
- **Mean shape factor**
- **Size vs. velocity**
- **Others on request**



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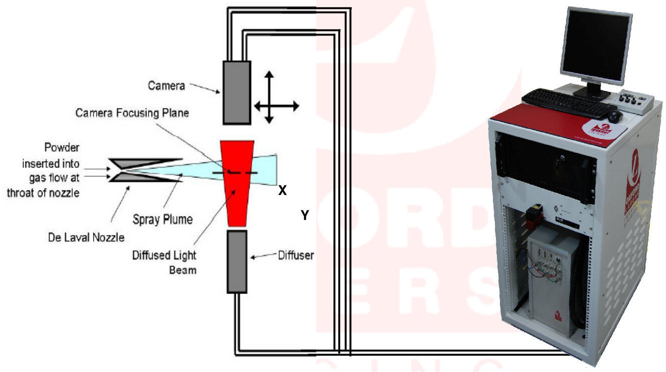
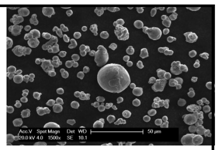
Application Technique

Case 1 – System behaviour with changes in powder type, gas



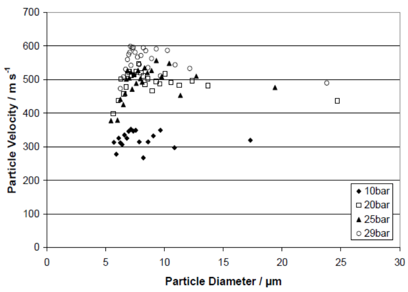
Referance: T.S. Price, Cold Gas Dynamic Spraying of Titanium Coatings. Doctor of Philosophy Thesis
Submission University of Nottingham, May 2008



Experimental Results
Velocity Measurement - Copper Powder

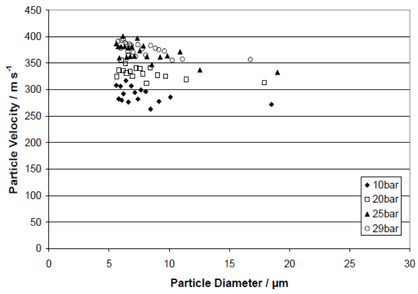
- a. Change in particle velocity with particle size
- b. Change in particle velocity with operating pressure and particle size

Helium Gas



(a)

Nitrogen Gas



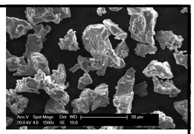
(b)

For 11um particle Velocity range 252 to 530 m/s

Below stagnation pressure of 10Bar No effect

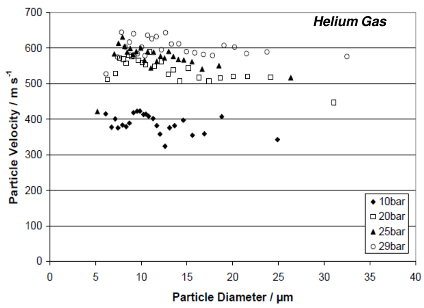
Velocity lower then Helium

For 11um particle - Only see a rise of 75 m/s
Increase to 300m/s

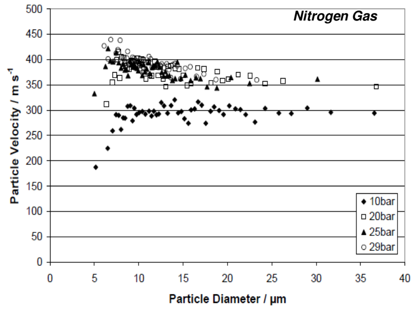


Experimental Results
Velocity Measurement – Titanium Powder

- a. Change in particle velocity with particle size
- b. Change in particle velocity with operating pressure and particle size



(a)



(b)

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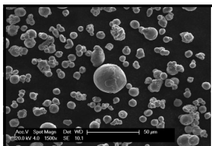
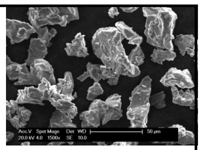
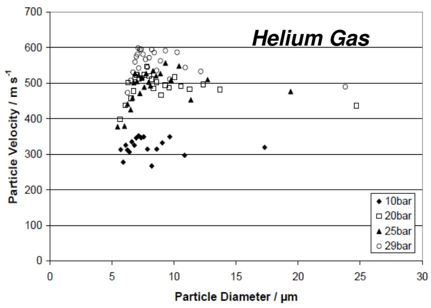


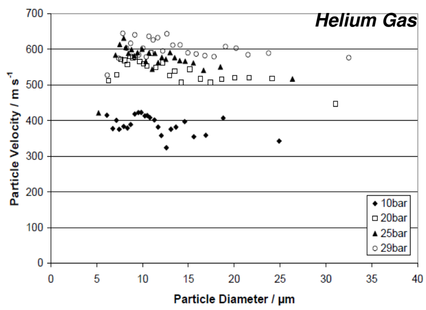
Copper Powder

Titanium Powder





(a)



(a)

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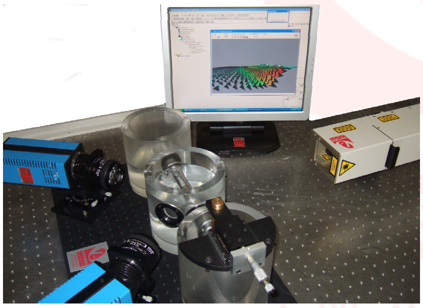
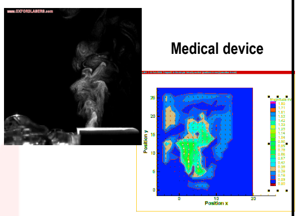
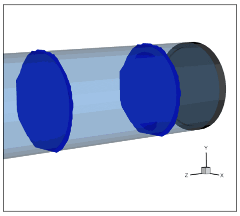
Application Technique

Flow Field Vector Analysis







Heart Valve

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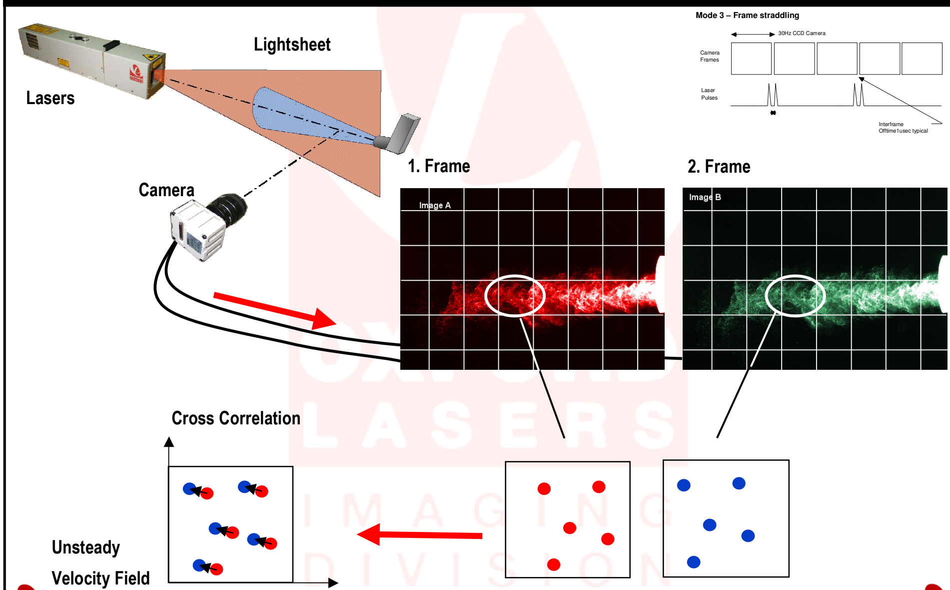
Application Technique



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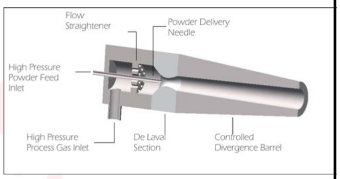
Application Technique
Case 2 – Nozzle Design

CGDS – “Solid Free-form fabrication”

Needs of the process-

- Ability to Accelerate powder through entrainment into a high velocity gas flow.
- Speed in excess of the critical deposition velocity
- Critical factor is the Particle velocity
- Drag force experienced by the particle affect the velocity
- Imaging system used to –
  - Collect experimental data on the performance of the nozzle under changing conditions,
    - Focus on individual components
    - Gas & Particle velocity



Referance: J. Pattison, S. Celotto, R. Morgan & W. O'Neil, Cold Spray Nozzle Design and Performance Evaluation using Particle Image Velocimetry University of Cambridge

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Application Technique
CGDS – Nozzle Design

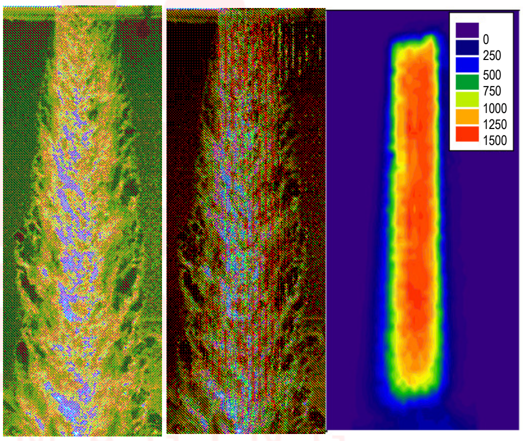
Gas Flow Velocity

up to 1480 m/s

CFD with in 2%

Titanium Dioxide

Average size 0.5um



Referance: J. Pattison, S. Celotto, R. Morgan & W. O'Neil, Cold Spray Nozzle Design and Performance Evaluation using Particle Image Velocimetry University of Cambridge

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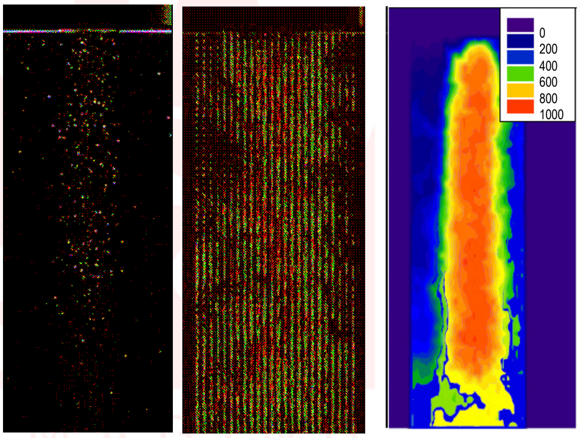
Application Technique
CGDS – Nozzle Design

Particle Flow Velocity
up to 950 m/s

Aluminium Powder
Average size 12.3um



Referance: J. Pattison, S. Celotto, R. Morgan & W. O'Neil, Cold Spray Nozzle Design and Performance Evaluation using Particle Image Velocimetry University of Cambridge

Any Questions

If you need any additional information on this presentation
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