EPSRC Centre for Innovative Manufacturing in LASER-BASED PRODUCTION PROCESSES

Selective Laser Melting of Refractory Metals

CIM-Laser One Day Conference

9th May 2017

Post Graduate Centre, Heriot-Watt University

Edinburgh

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Refractory Metals - Properties

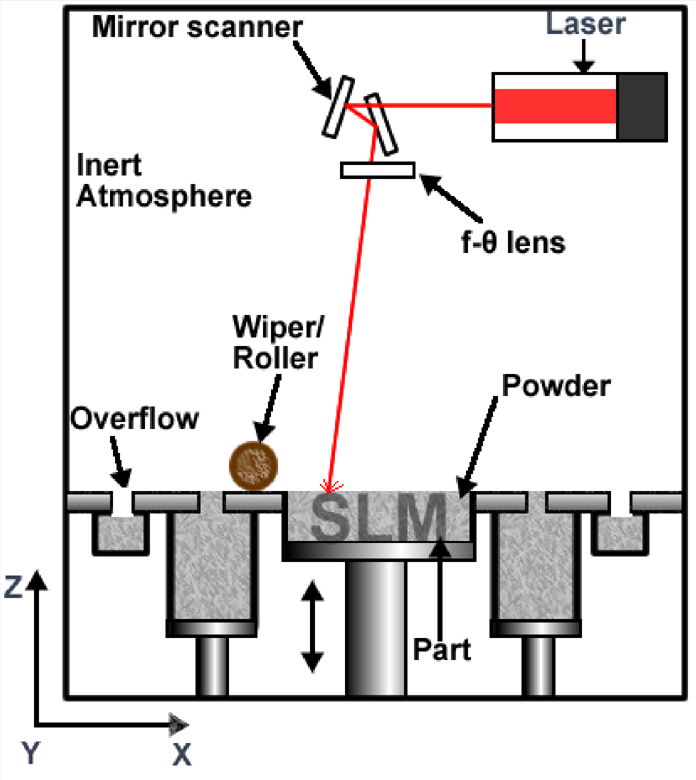
Properties of Refractory Metals	Tungsten	Tantalum
Density at 25 °C (g/cm^3)	19.2	16.69
Liquid Density (g/cm^3)	17.6	15
Melting Point (°C)	3422	2996
Thermal Conductivity (W.m^-1.K^-1)	174	57.5
Specific Heat (J.kg.K^-1)	134	140
Thermal Diffusivity (m^2/s)	0.068	0.025
Atomic mass	183.88	180.94
Tension Force (N/m)	2.361	2.07

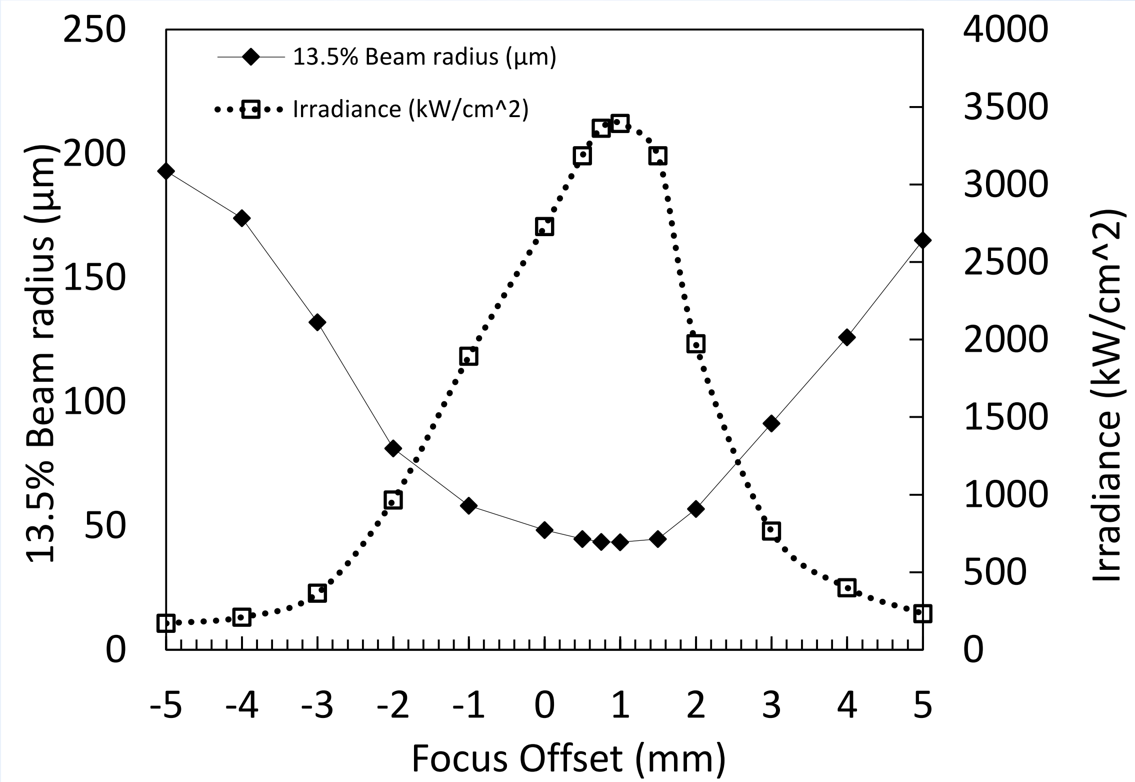
- Physical properties of tungsten and tantalum
- SLM of refractory metals difficult due to
  - high melting point,
  - high thermal conductivity
  - high viscosity
  - oxidation sensitivity.

Background and Applications

- Applications today include medical implants, rocket nozzles, support hardware, military, electro vacuum, crucible and heating elements
- High density of tungsten makes it ideal for radiation attenuation
  - Pinhole collimators
- However, these are difficult to machine because of small dimensions
- Refractory SLM process being driven slowly by industries

Laser Beam Profiling





- Schematic overview of the selective laser melting (SLM) process
- Renishaw AM125, ytterbium fibre, 1070nm

- Laser beam profiling on the Renishaw AM125 machine
- Sufficient intensity for melting Refractory metals can be reached only for the centre part of the geometry (diameter ~43 µm)

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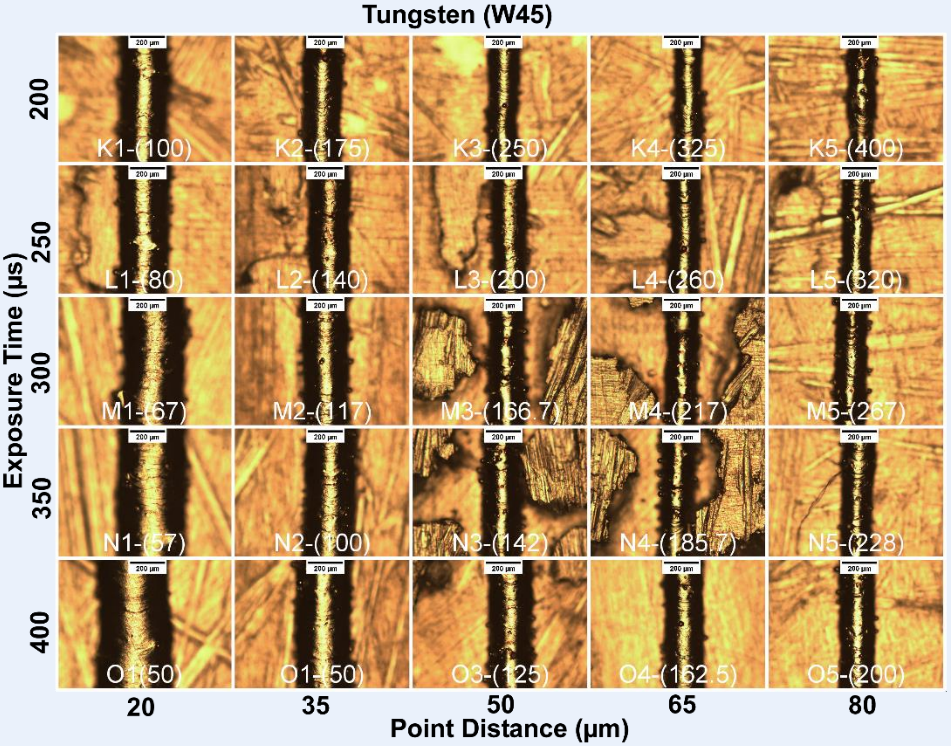
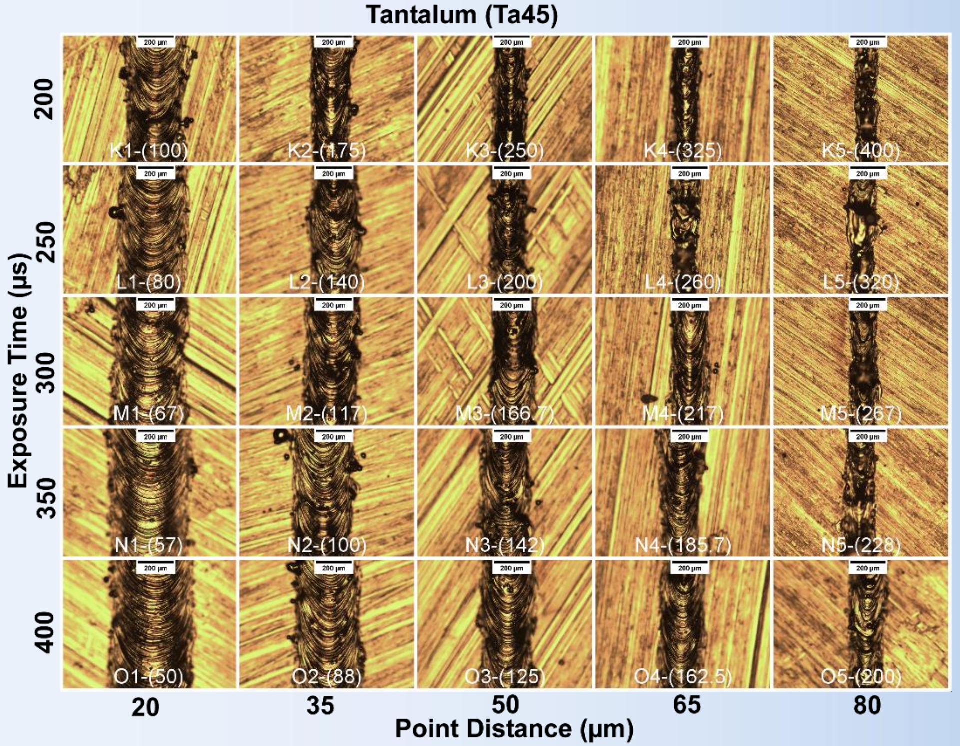
Process Window – W and Ta





- Single track melting results of tungsten and tantalum powder using different scan parameters at 200W Laser Power
- 100 to 200mm/s speed

Line Width v 1D Energy Density

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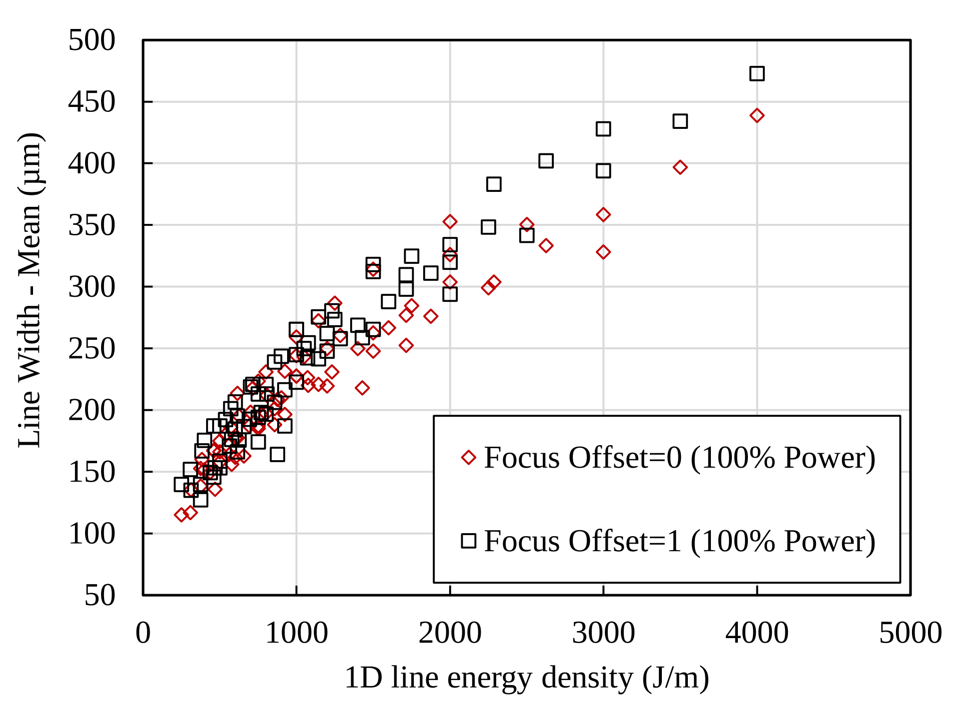

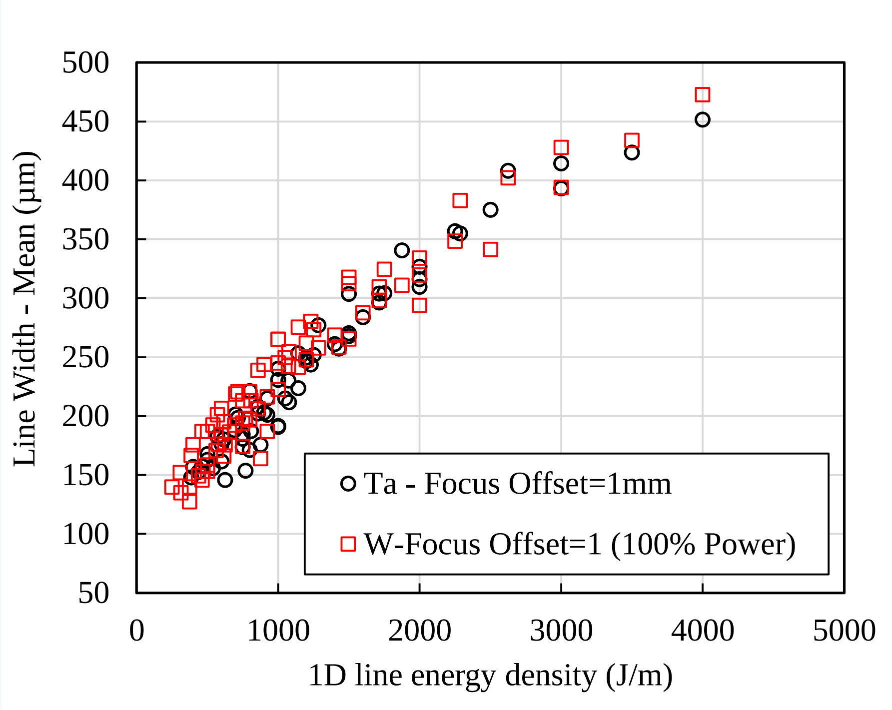

- Line width vs 1D line energy density for tungsten (W45) powder
- Laser focus offset study
- Line width vs 1D line energy density for tantalum (Ta45) powder
  - 1D Energy Density = Laser Power/ Scanning speed)

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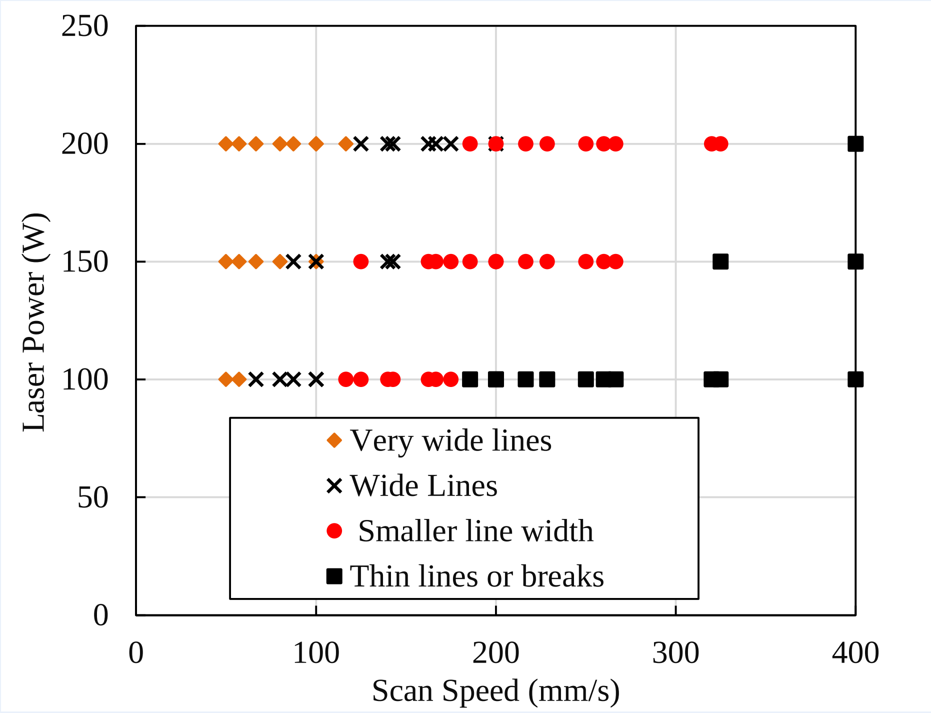
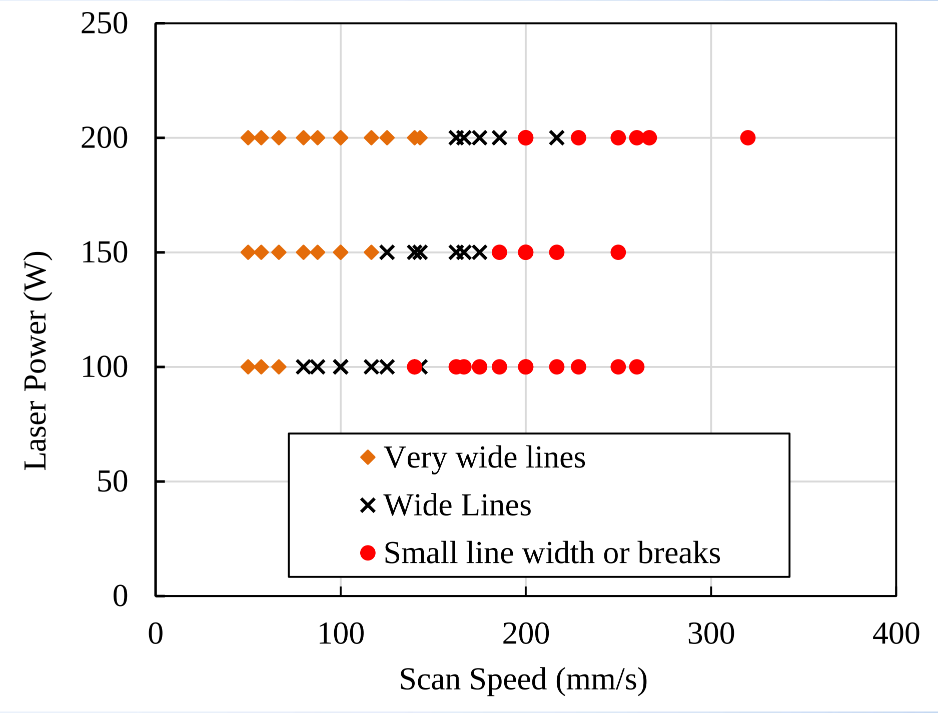
Process Window – W45 and Ta45





- Laser power vs scan speed for tungsten (W45) powder
- CP-Ti base plate

- Laser power vs scan speed for tantalum (Ta45) powder
- CP-Ti base plate

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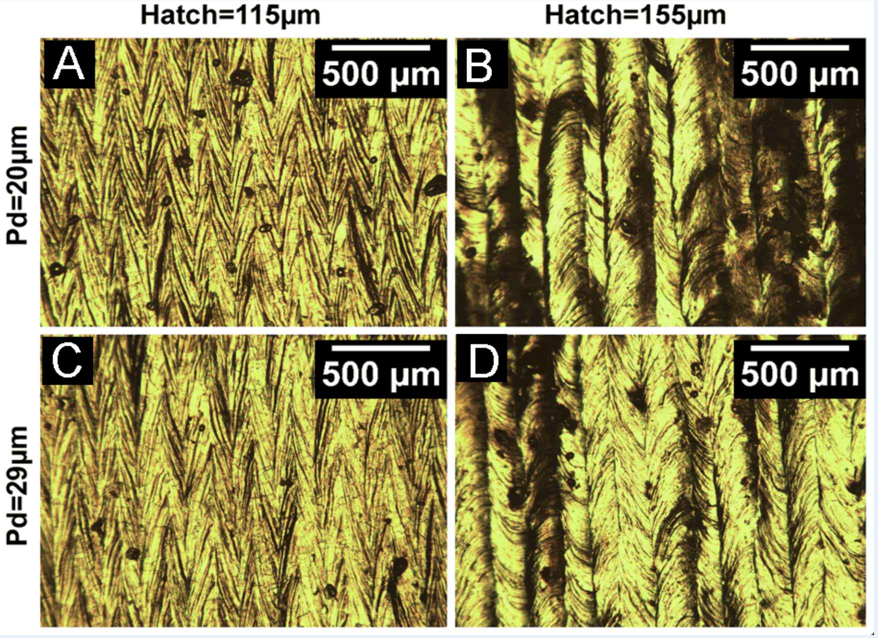
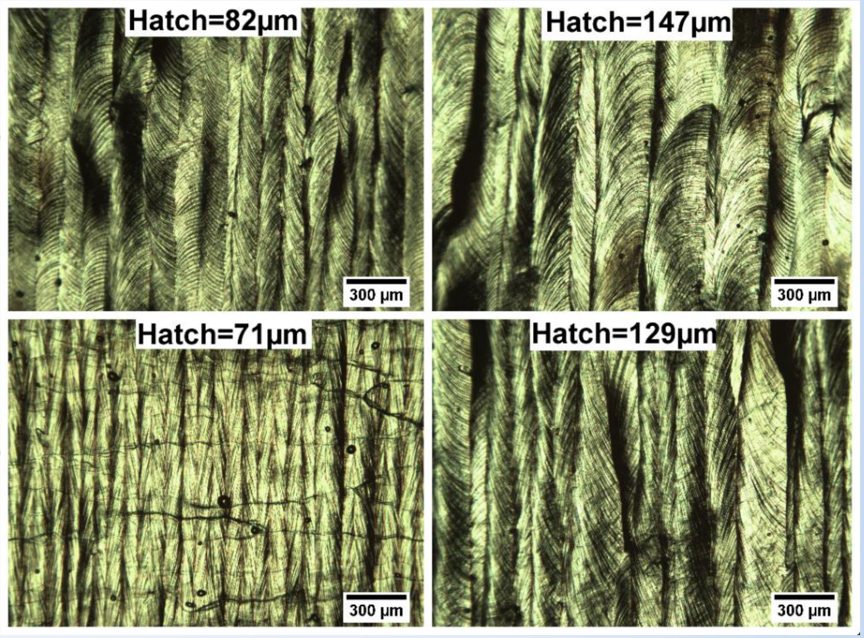
Process Window – W and Ta





- Single layer hatch patterns for tungsten (W45) using 4 different scanning strategies
- Single layer hatch patterns for tantalum (Ta45) using 4 different scanning strategies

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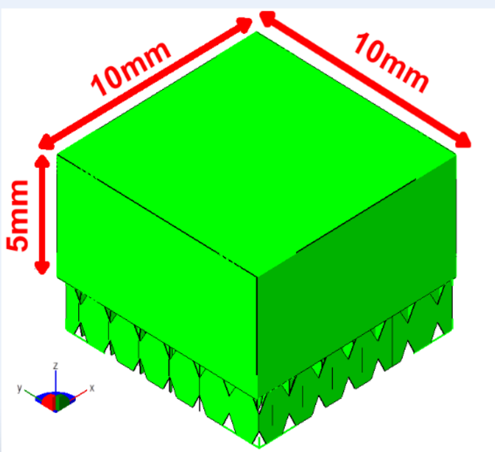
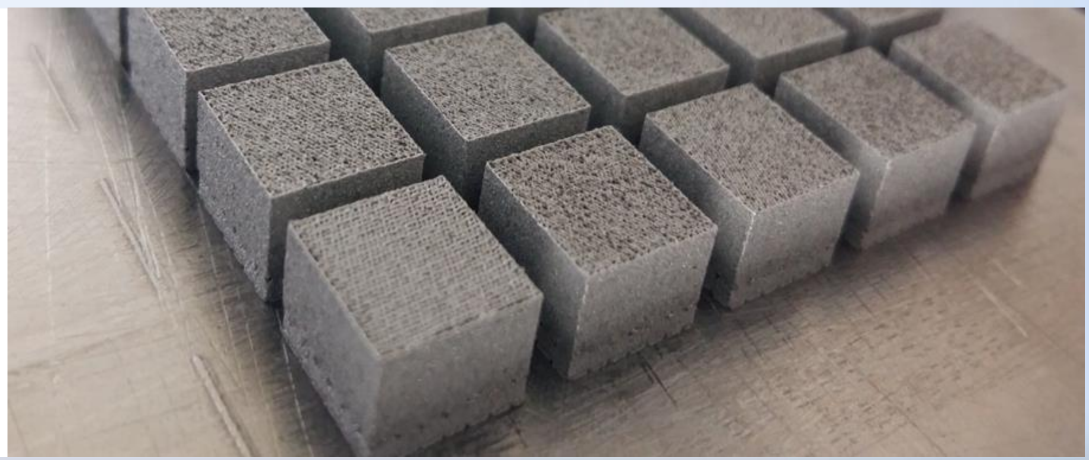
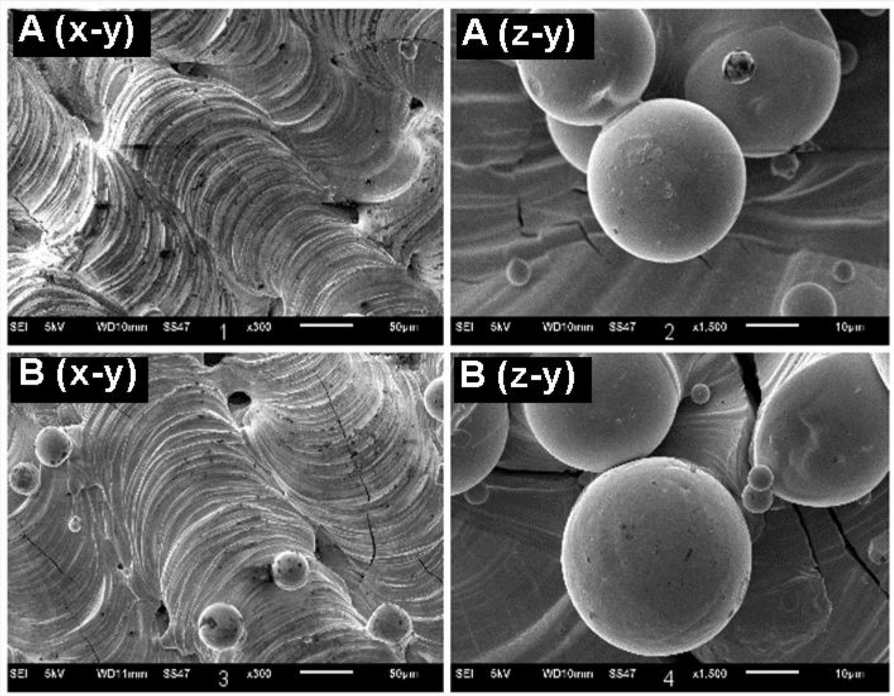
Process Window – W45

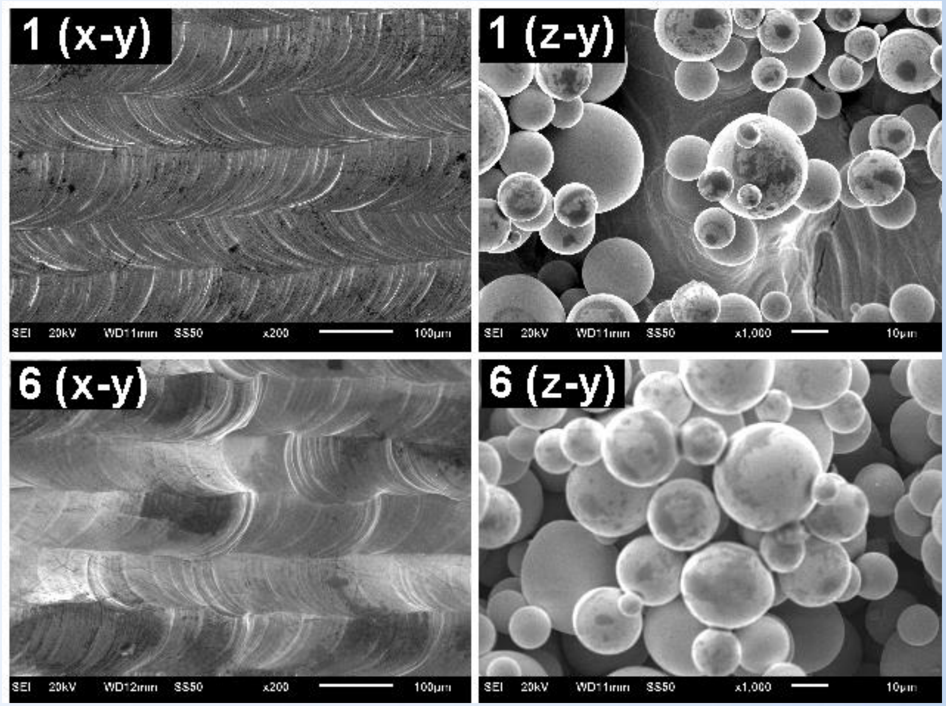
Laser Power = 200W, Exposure Time = 200µs Layer Thickness= 30µm		Point Distance (µm)	Hatch Space (mm)	Apparent Speed (mm/s)	3D volume energy density (J/mm^3)
A	C2 (sub 0)	**20**	**0.115**	100	578
B	C2 (sub 6)	**20**	**0.155**	100	434
C	C2 (0)	**29**	**0.115**	145	399
D	C2 (6)	**29**	**0.155**	145	299





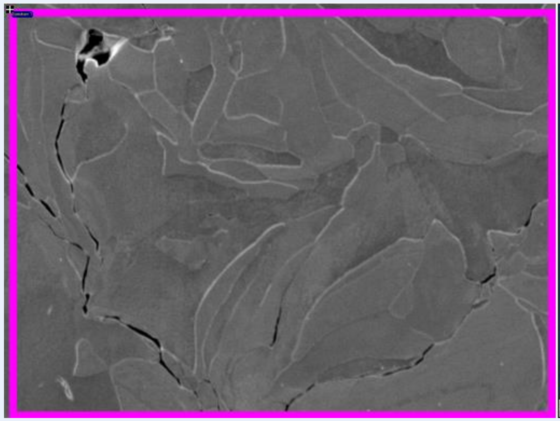
SLM of Refractory Blocks

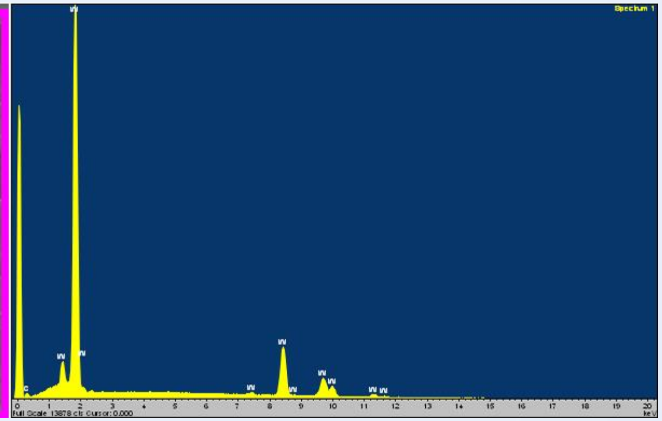




- Evidence of cracks in Tungsten
  - XY Horizontal top surfaces
  - ZY Vertical side surfaces
- Less evidence of cracks in Tantalum
  - XY Horizontal top surfaces
  - ZY Vertical side surfaces

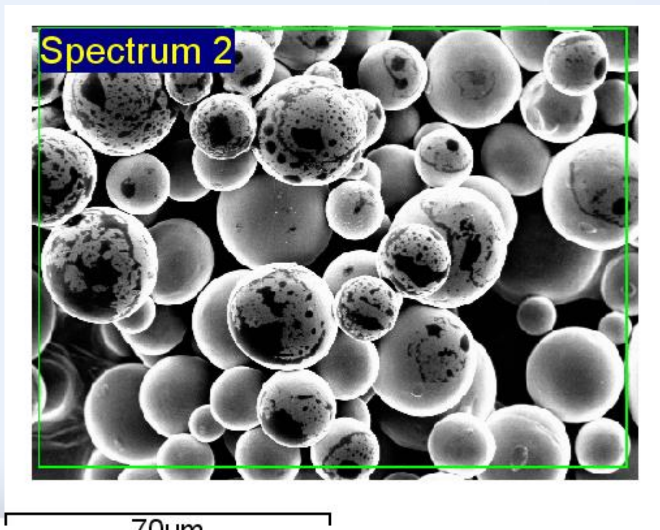
SLM of Tungsten – SEM and EDS

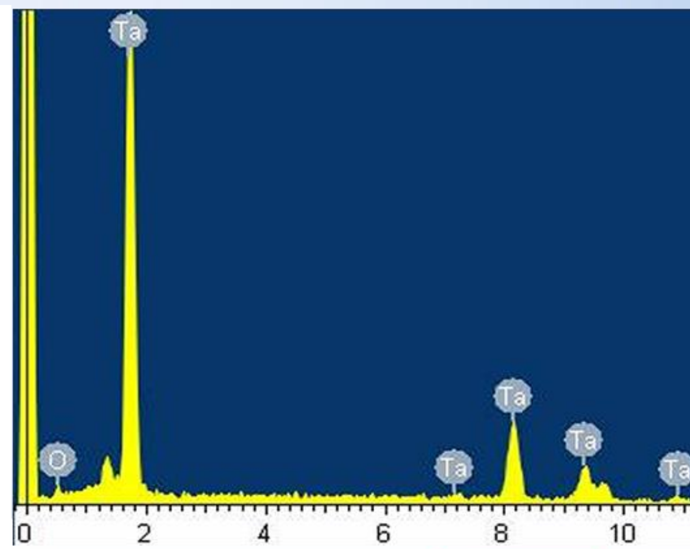




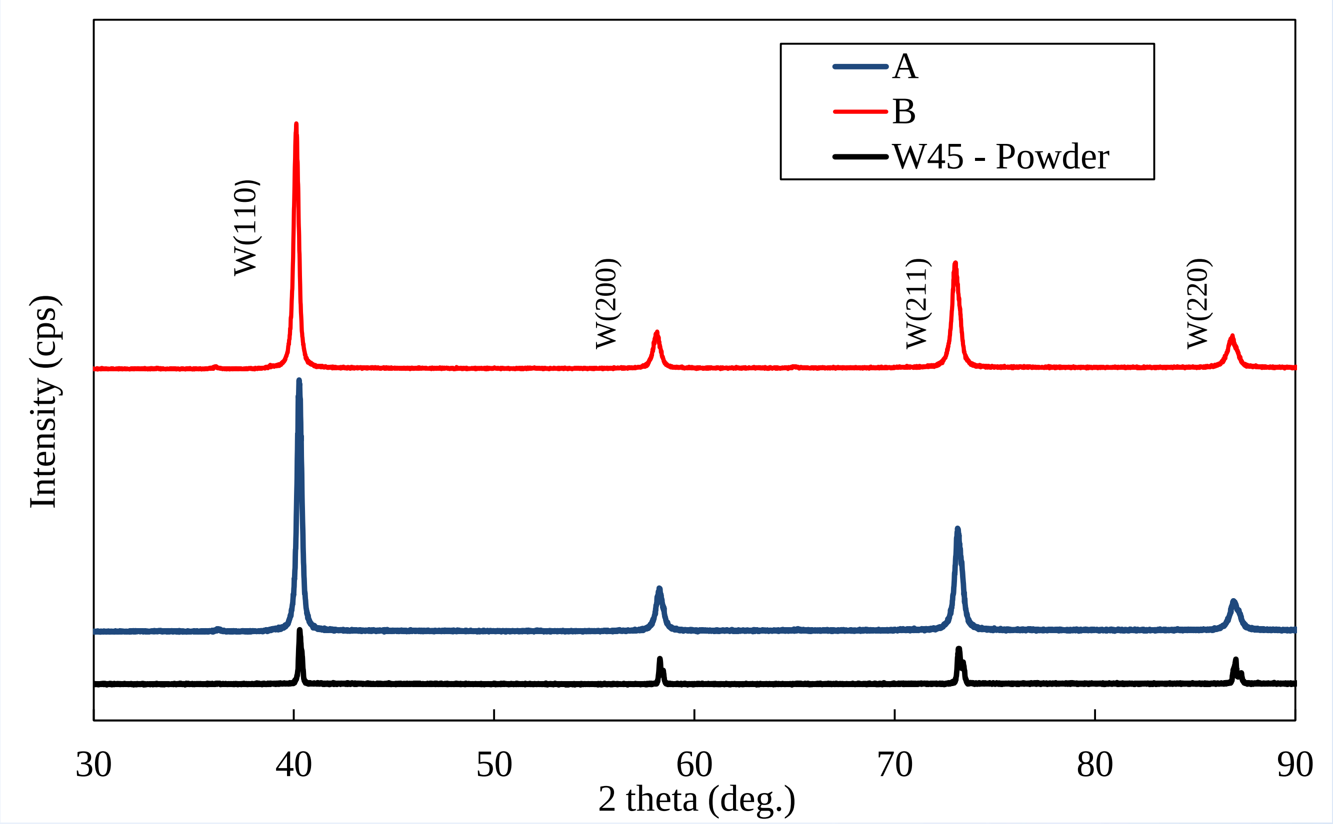
- SEM and EDS analysis of a tungsten (W45) SLM sample
- Sample B – XY Build Direction, etched

- SEM and EDS analysis of a tantalum (Ta45) SLM sample
  - ZY Build Direction, block





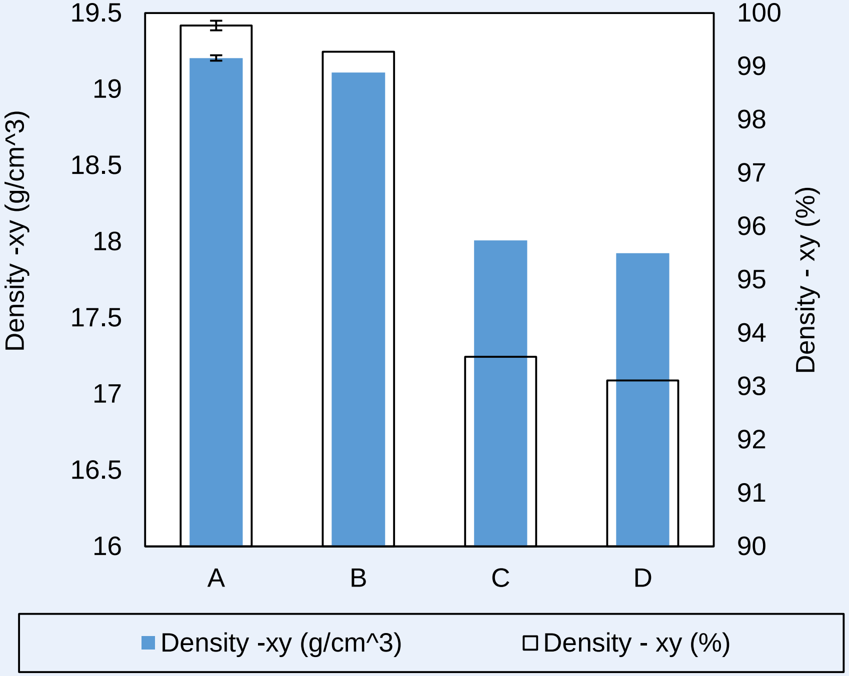
XRD of Tungsten (W45)



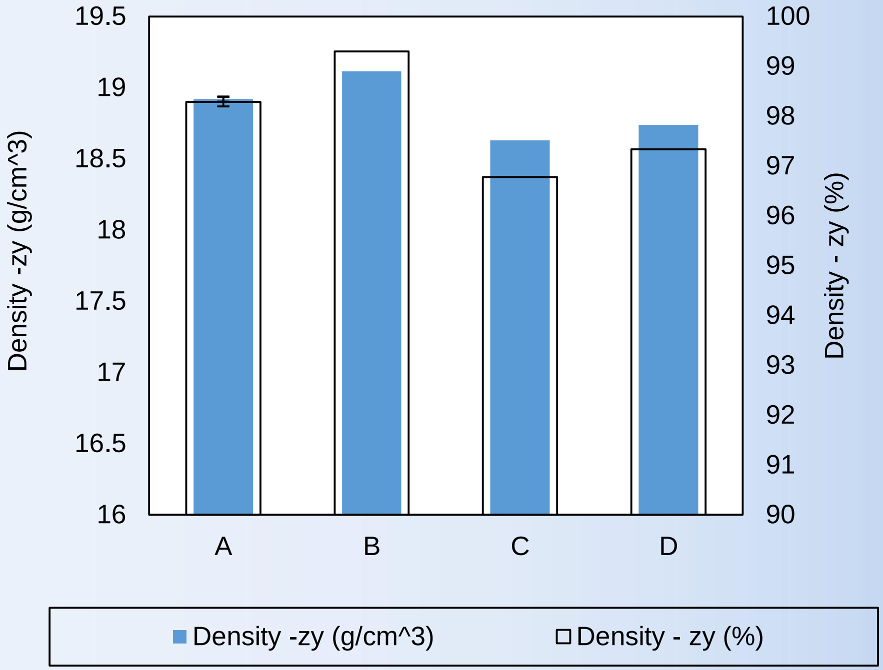
- X-ray diffraction plot showing W powder and SLM processed traces and peaks

Density of SLM – W45

- Cross-section view (x-y) view



- Build-direction (z-y) view



- Optically determined density of the cross-section (z-y) view of four tungsten (W45) samples fabricated using different parameters
- Highest density – Sample A (Pd=20µm, hatch=115µm), x-y view

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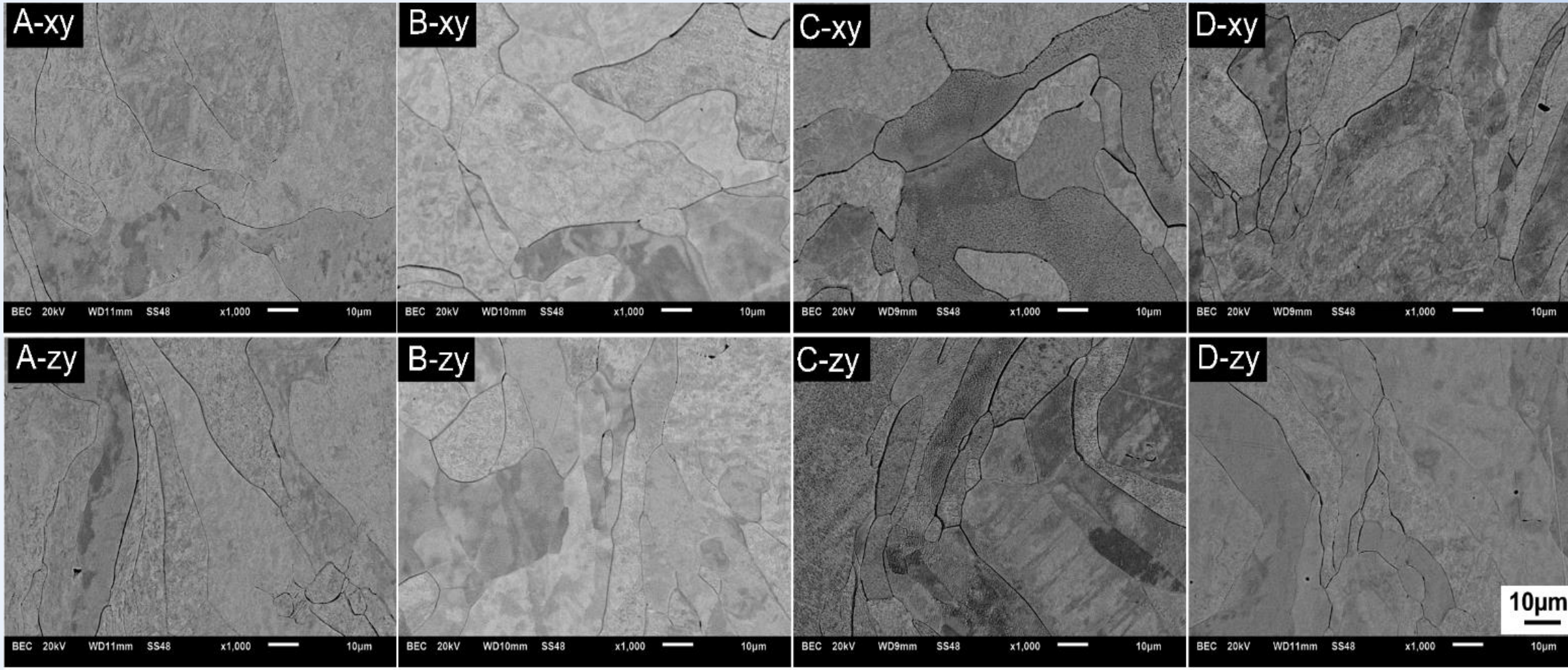
SLM of Tungsten – Grain structure



SLM Tungsten SEM's showing grain structures

- cross sectional lateral x-y view
- build direction cross-sectional z-y view

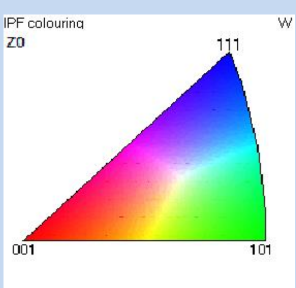
EBSD

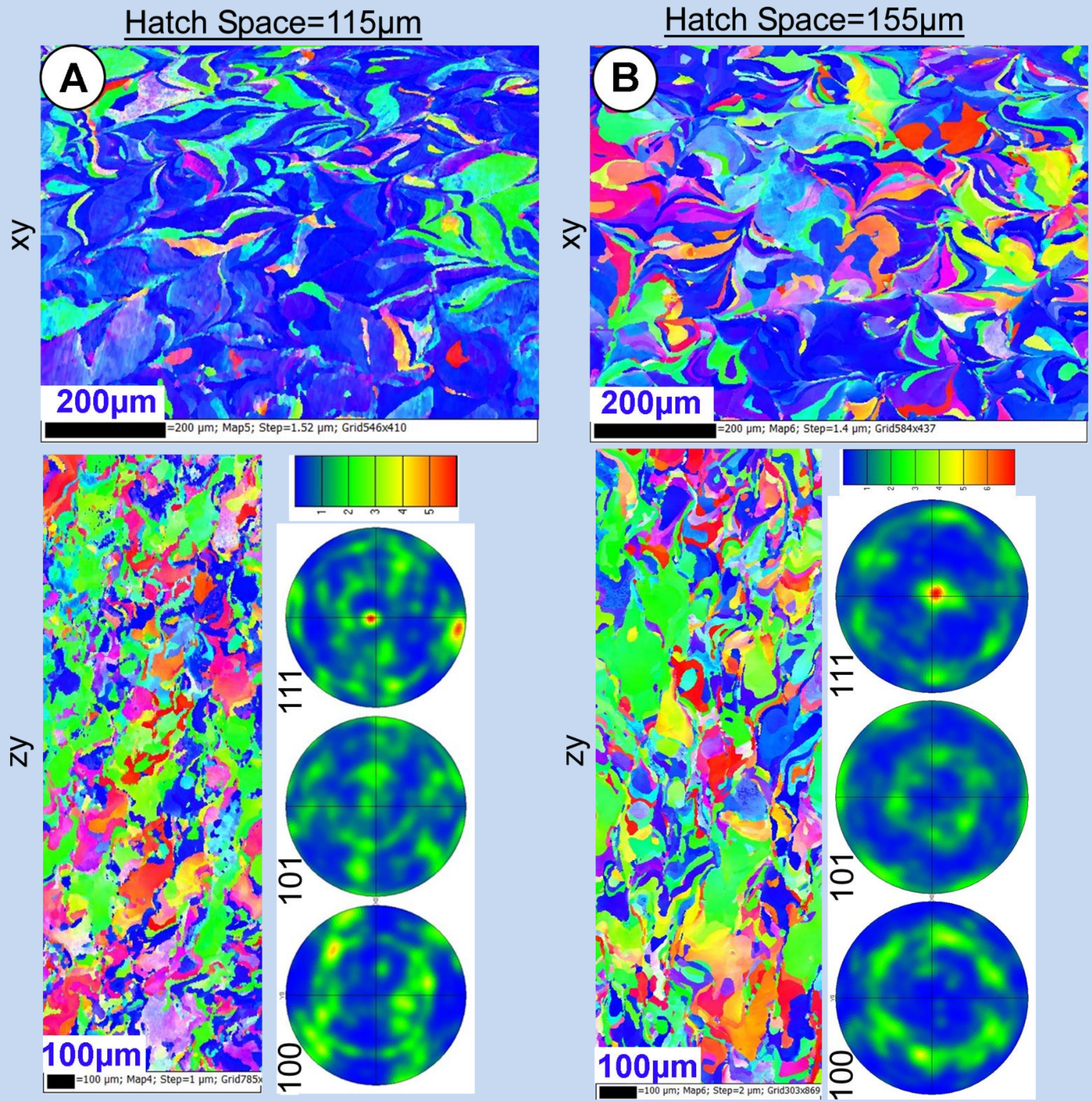
Pole figure of the 115 µm hatching space sample, suggesting a strong <111> preferential growth along the build direction

- Maximum intensity of 10 times random

Pole figure of the 155 µm hatching space sample, suggesting ***a relatively weaker <111> preferential growth*** along the build direction

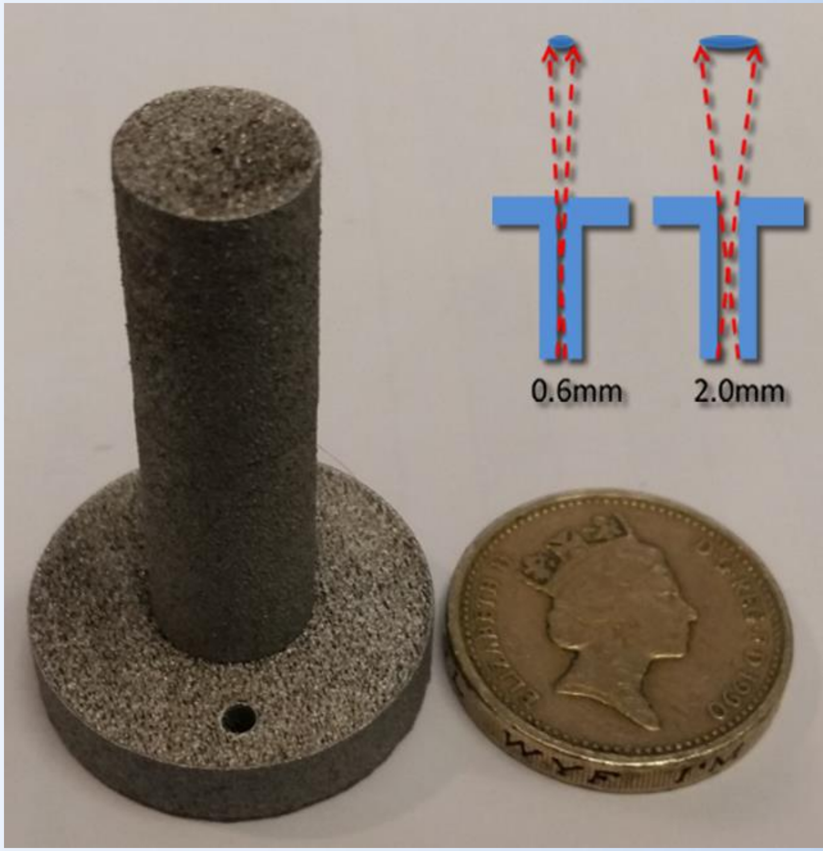
- Maximum intensity 7.1 times random





Applications - W

- The Nuclear physics instrumentation group previously had a choice of 1mm or 2mm collimation
- SLM was used to fabricate a finer collimator which resulted in a narrower beam spot (0.6 mm nominal)
- More accurate scan results but at the expense of number of gamma rays per second
- The SLM Tungsten 0.6mm collimator allowed higher resolution scans giving better detector characterisation results



SLM of Refractory Metals

Outlook and future work

- Transmission Electron Microscopy (TEM)
- 3D Xray Tomography
  – Collaboration with Manchester University
- Elimination of cracks
  – Heat treatment, heated bed or alloying
- SLM of Tungsten sub 25 µm powder
  – Effect of powder particle size
- SLM of Tantalum
- System modification

Thank you for your attention

Acknowledgements - University Of Manchester