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Approaches for AM in-process inspection using SRAS and OCT

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Overview

1. The opportunity and need for measurement
2. Techniques investigated
3. Limitations
4. Opportunities for further work and next steps.

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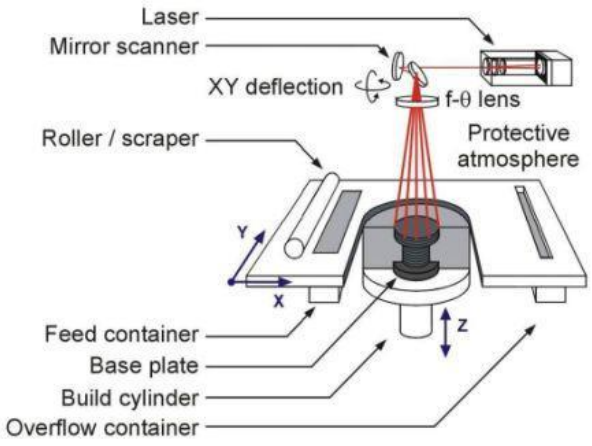
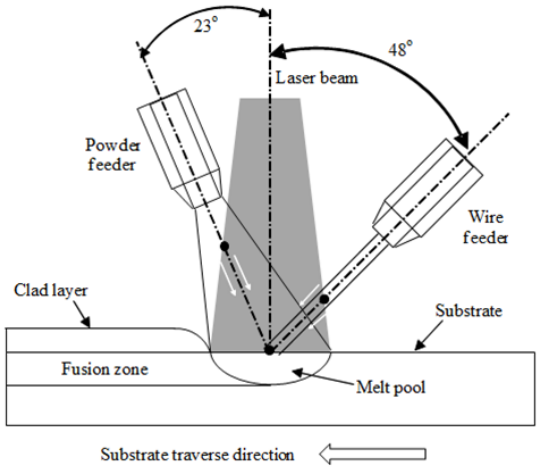
The Processes



Powder Bed / Additive Layer Manufacture or similar



DED, LENS, DMLS, WAM or similar

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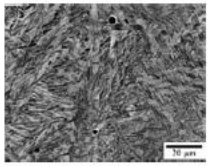
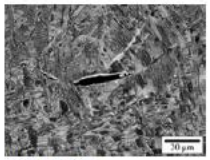
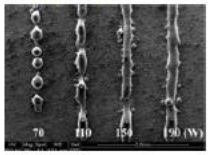
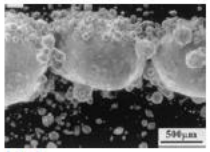
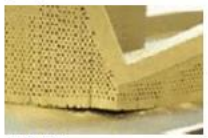
The Problem: Defects

Summary of PBF discontinuities.

Material discon.	Photo	Description	Typical sizes
(Gas) pores	 [33,36]	Entrapped gas pores within the bulk of the material. Material dependent.	~9.9 μm (electron beam-PBF) 5–20 μm (laser-PBF)
(Elongated) pores	 [33,36,43]	Lack of fusion pores in between layers of the AM process.	50–500 μm
Balling	 [38,39,44–47]	Molten material is not a flat layer, but instead creates large spherically shaped particles on the surface.	Part dependent – theoretically up to the length of the part.
Unfused powder	 [46]	The melt pool varies in size and unfused powder is present.	Satellite powder clumps: 100–150 μm.
Cracking	 [40,48]	Cracks can be within the component or more commonly, a disconnection of the part from the baseplate is seen.	Parts on bed: residual stress in the range of materials yield strength. Parts removed from bed: deformation may occur without heat treatment or further processing.

[Everton et al. 2016, Materials and Design]

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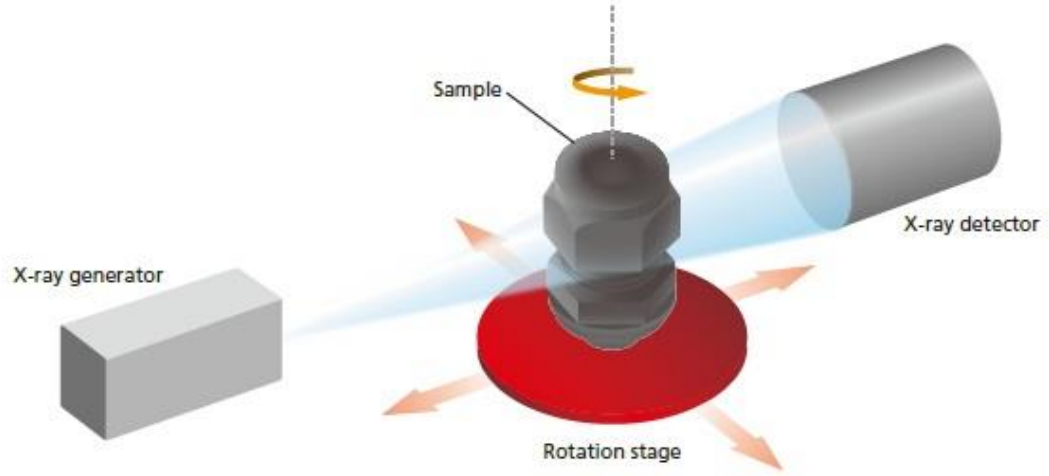
When can we measure?

Ex-situ



Gold Standard: X-Ray CT

Observing integrity in finished parts is all well and good but:

- It is expensive
- Time consuming
- Requires part/source/detector manipulation
- Resolution is material and geometry dependent
- It can be a pain to interpret large data sets.
- Cant fix failed builds

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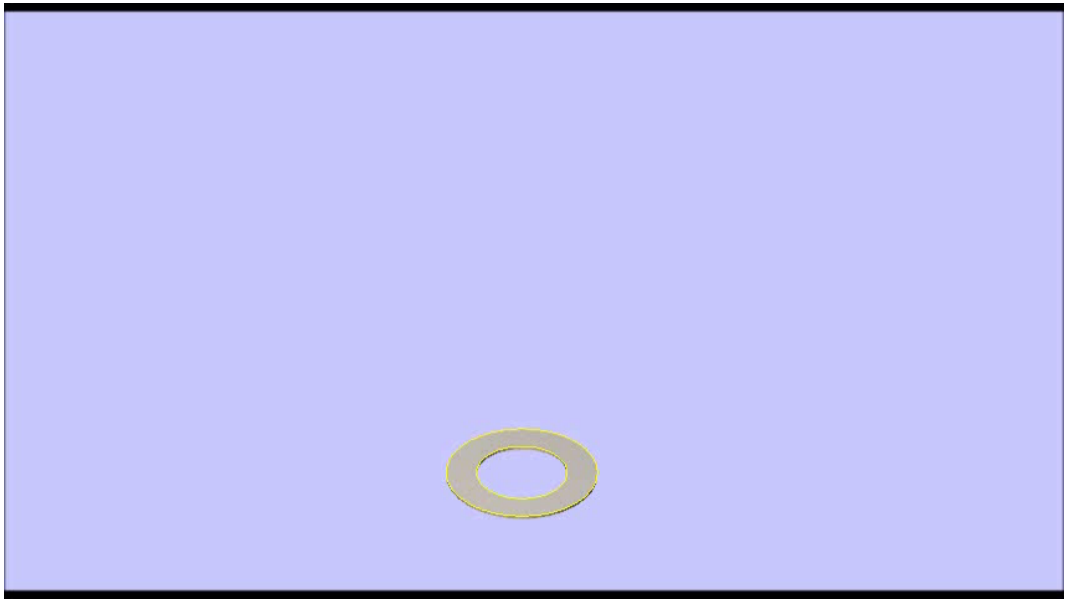
When can we measure?

In-situ



Integrate NDE into AM processes

- Measure each layer for full 3D part data
- Can spot a problem and cancel AM process
- Inform a repair algorithm in the AM process, to fix and continue building

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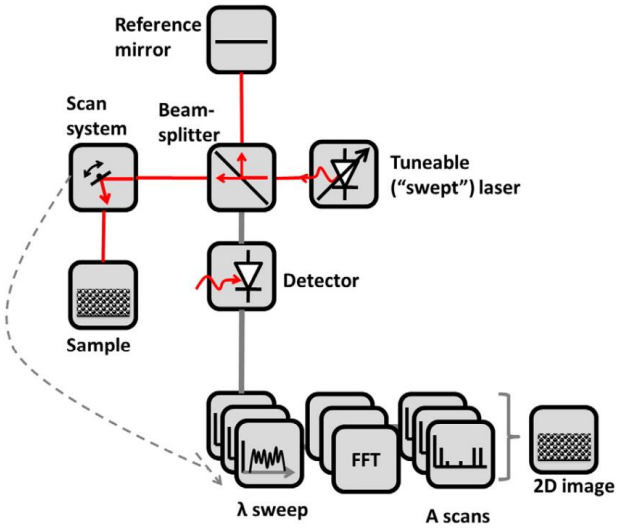
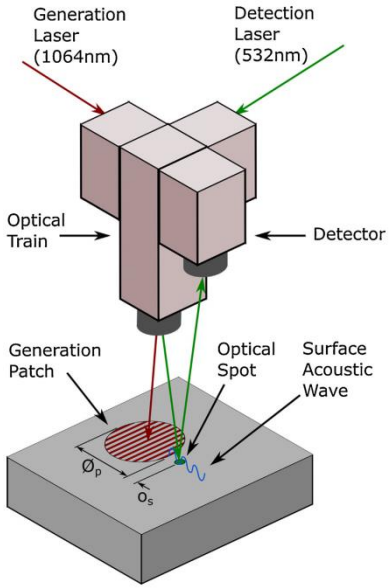
Our Solutions

- Two main instruments types:



Optical Coherence Tomography (OCT)

- for Selective Laser Sintering (Polymers)
- Interferometry technique for semi-transparent materials



Spatially Resolved Acoustic Spectroscopy (SRAS)

- for Selective Laser Melting (Metals)
- Laser Ultrasound technique, mapping surface acoustic waves

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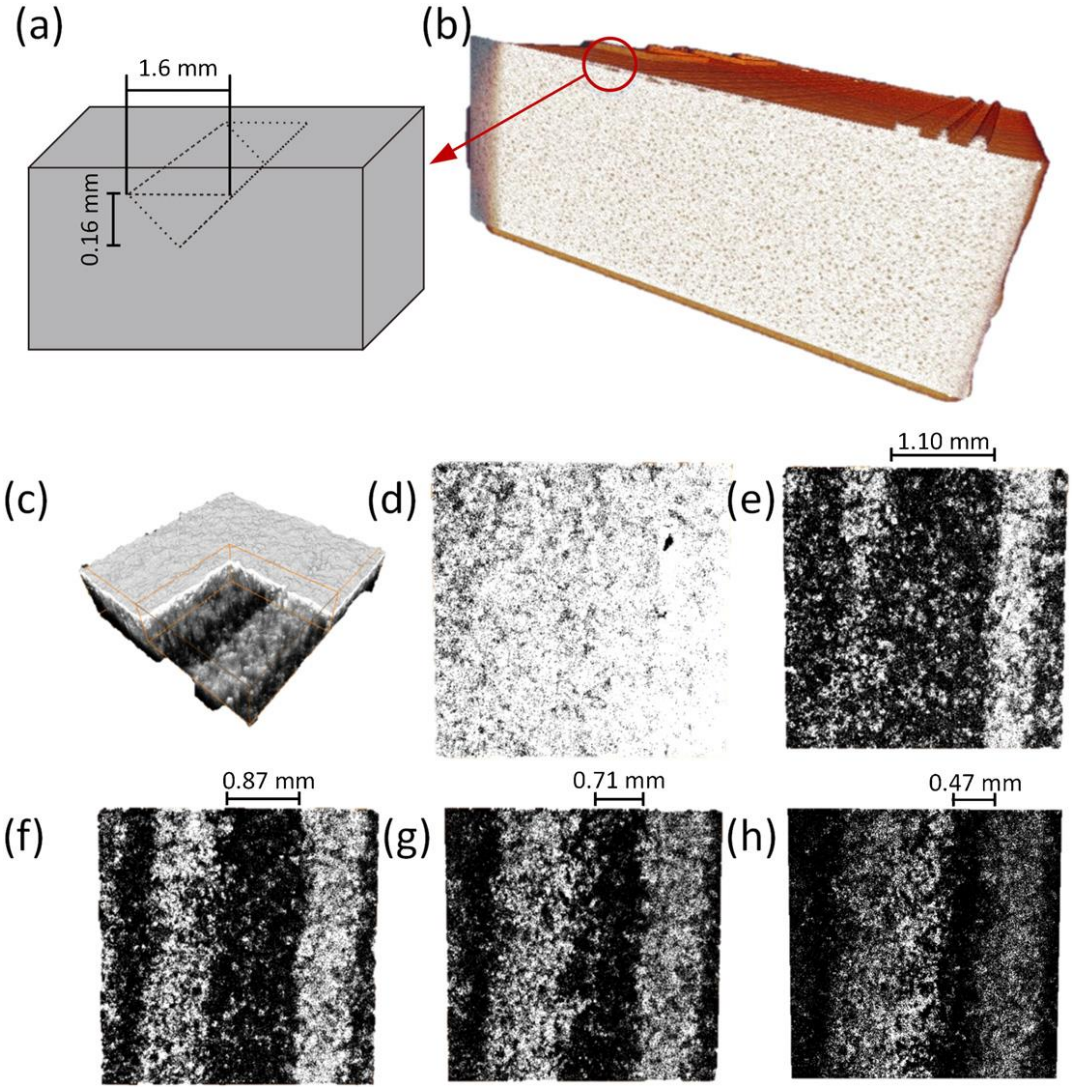
OCT Results

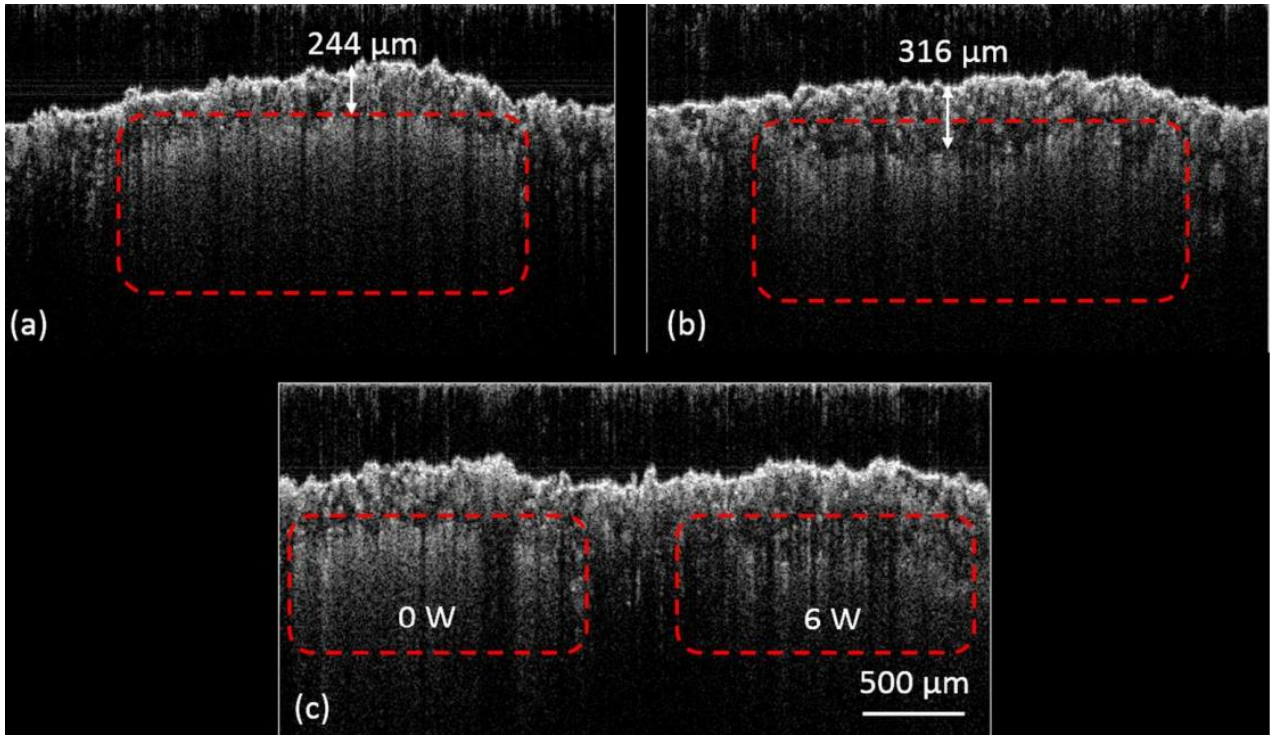
Detecting subsurface defects



[Guan et al., Materials & Design, 2015]

OCT Results

Intensity algorithm allows automatic subsurface unmelted powder to be detected.



[Guan et al., Proceedings Royal Society A, 2016]

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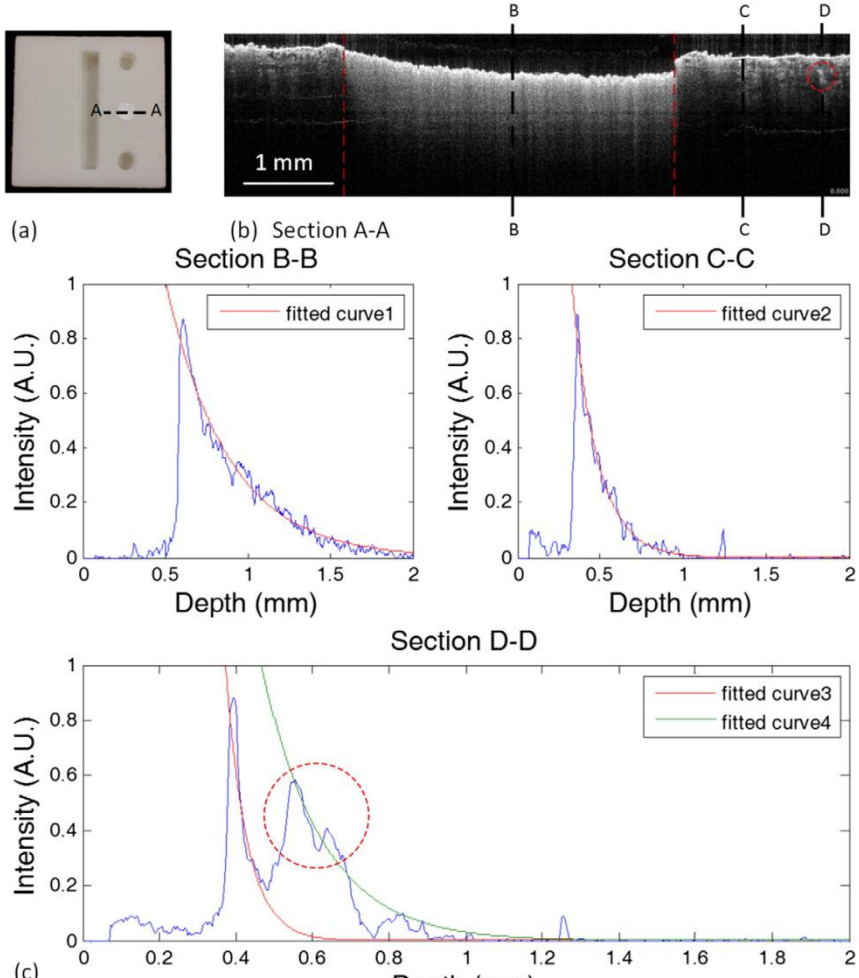
OCT Results

Detecting differences in unsintered powder and solid.



[Guan et al., Materials & Design, 2015]

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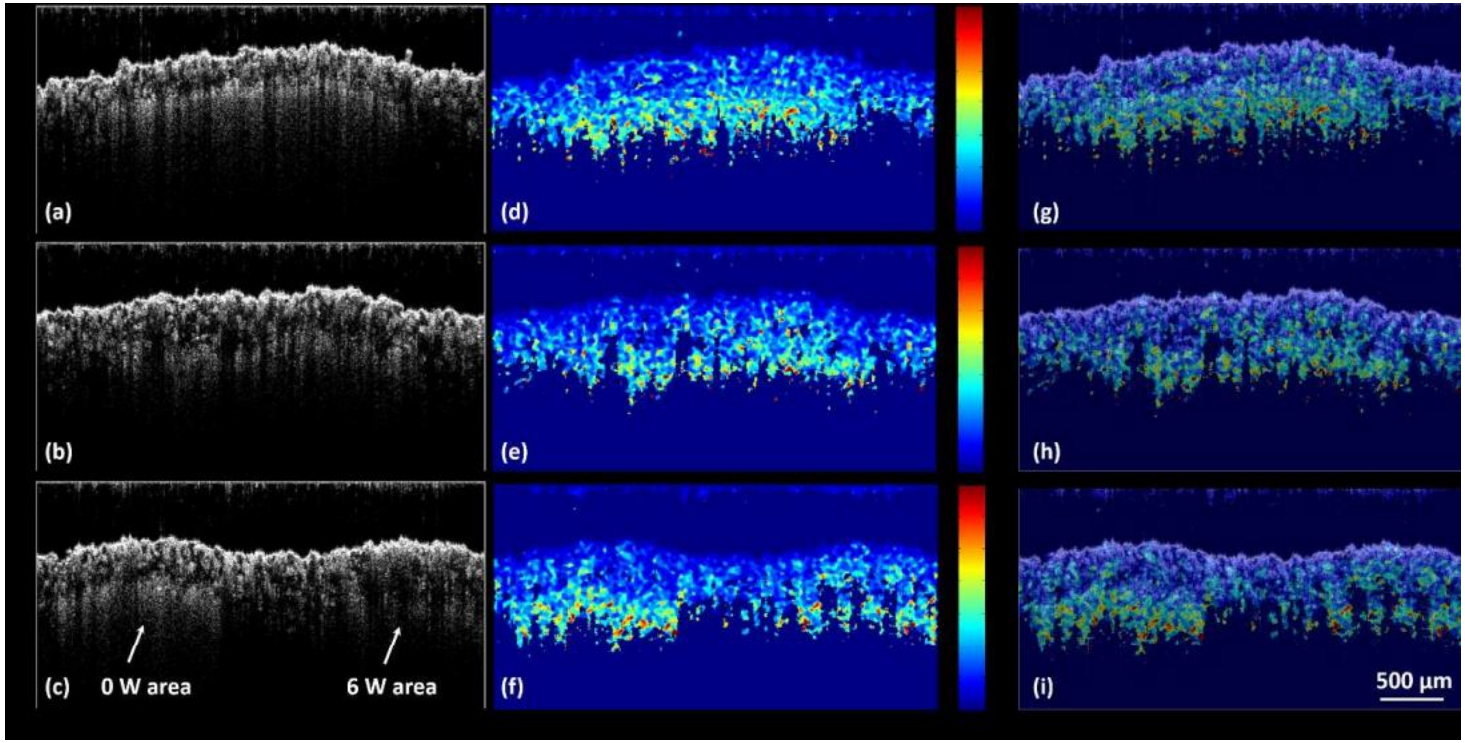
OCT Results

OCT a scans showing the dense outer layer which hides un-melted powder underneath. Not possible before…a first



[Guan et al., Proceedings Royal Society A, 2016]

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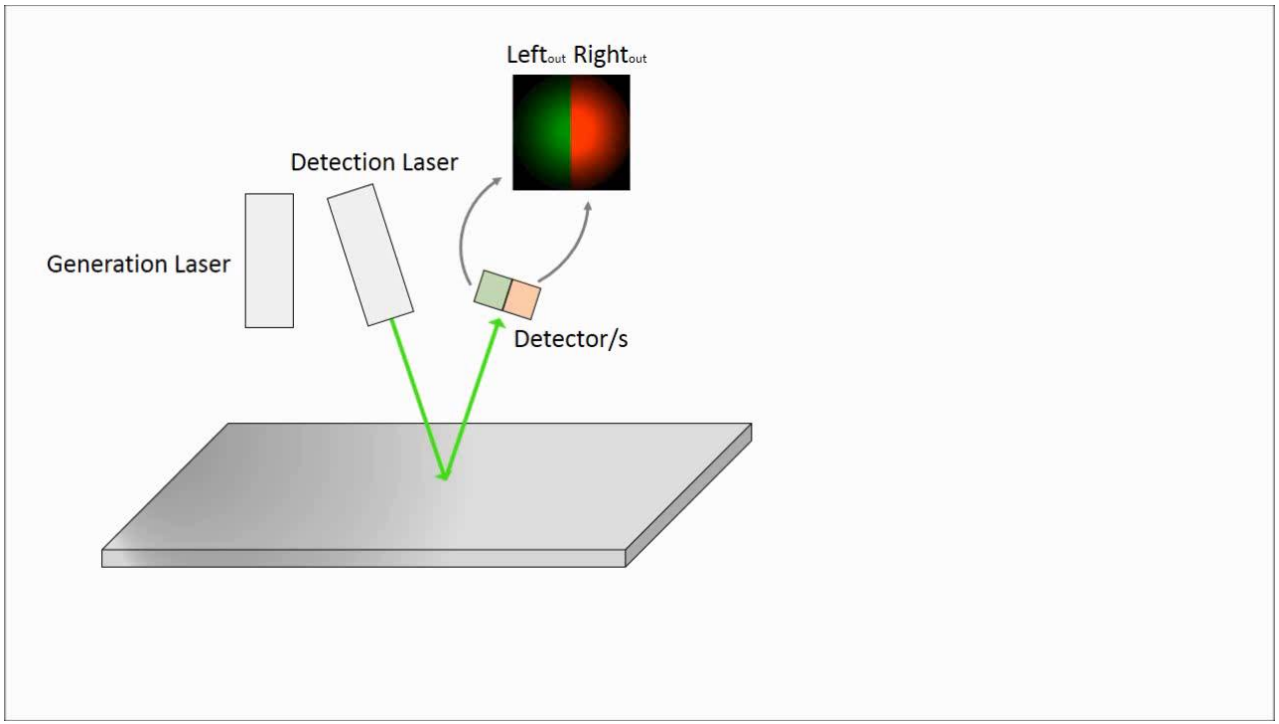
SRAS – Current Measurement technique

- Spatially Resolved Acoustic Spectroscopy
- - Laser ultrasonic NDE technique suitable for metals
- - Surface acoustic waves (SAW) generated using a pulsed grating pattern
- - Frequency of detected perturbation relates to wave velocity *where it is generated* (instead of measuring ToF)



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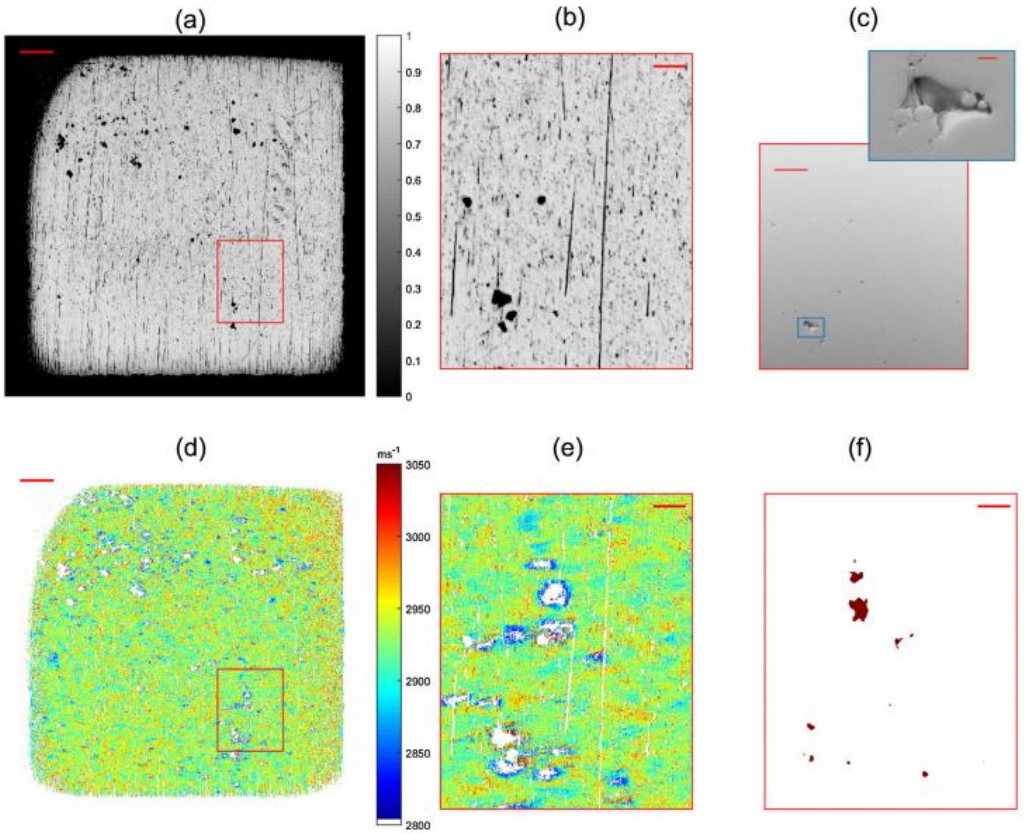
SRAS Results

- SRAS Optical data (a) and surface acoustic map (d) showing surface and subsurface defects, respectively
- Surface defects equated to SEM micrographs (c)
- Subsurface defects equated to XCT measurements (f)



[Smith et al., JMPT, 2016]

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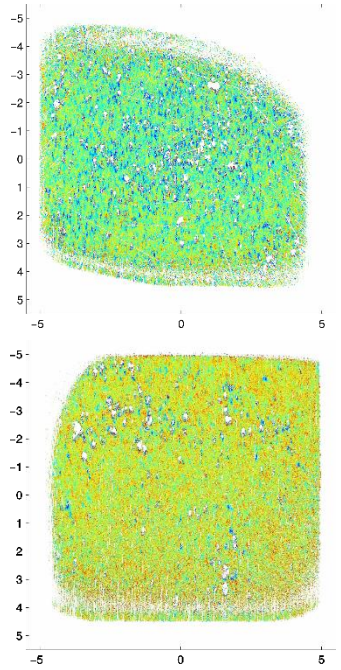
SRAS Results

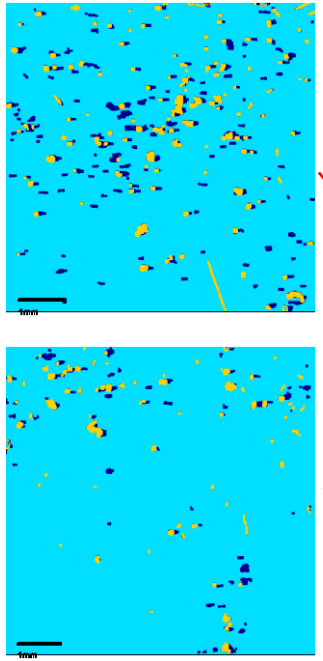
- What can we do with this information?

140W laser scan sample

190W laser scan sample



SRAS acoustic image



Pore analysis
yellow: surface pore
blue: sub-surface pore

SLM laser Power (W)	Mean pore diameter (µm)	Standard Deviation of pore diameter	Total Pore Count
140 Optical	115	44	126
140 Acoustic	137	56	182
190 Optical	119	47	70
190 Acoustic	134	63	95

[Smith et al., JMPT, 2016]

How good is an inspection process?

- Non-Destructive Evaluation Capability on AM
  - Is the interrogation technique appropriate?
  - What needs to be optimised?

$$NDE\ capability = Cap_{spatial}\ ; Cap_{temporal}$$

$$Cap_{spatial} = \frac{rD_{min}}{Cl_{min}(h_X, h_Y, h_Z)}$$

$$Cap_{temporal} = \frac{1}{Nt_{scan} + t_{latency}}$$

Where r is resolution; D_{min} is minimum Defect size; Cl_{min} is minimum Cluster size; h_x, h_y, h_z is step size; N is Number of data points; t_{scan} is scan time per data point; and $t_{latency}$ is latency time

[Hirsch et al., Journal of AM, 2016]

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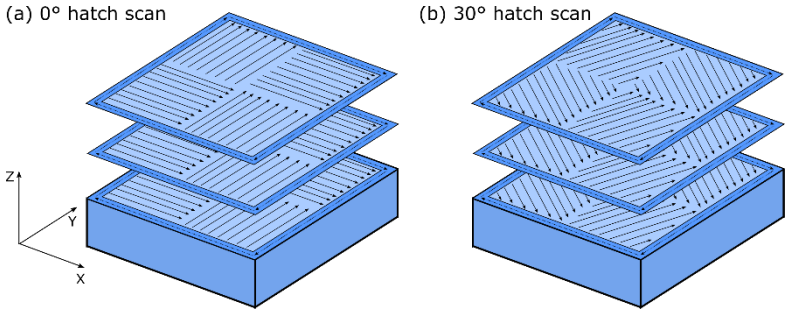
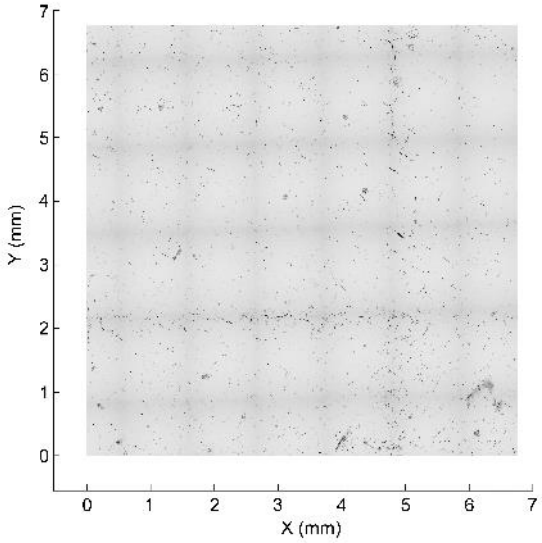
Texture Evaluation of SLM parts using SRAS

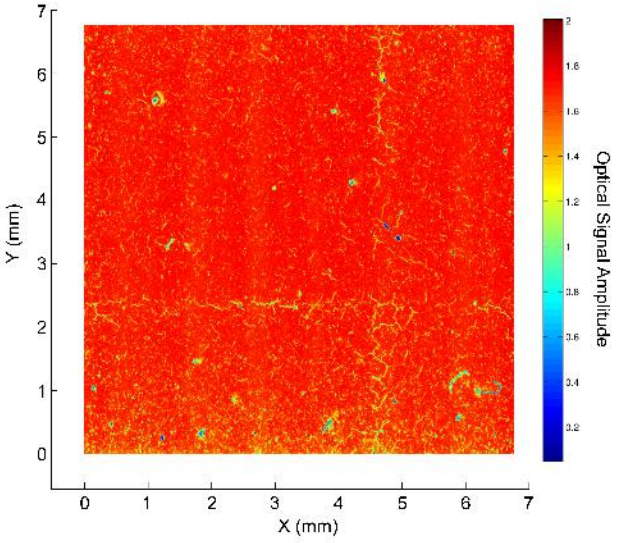
- CM247LC samples produced with varying layer rotation
- Highly cracking and porous surfaces
- Analysis through SRAS and Optical Microscopy scans



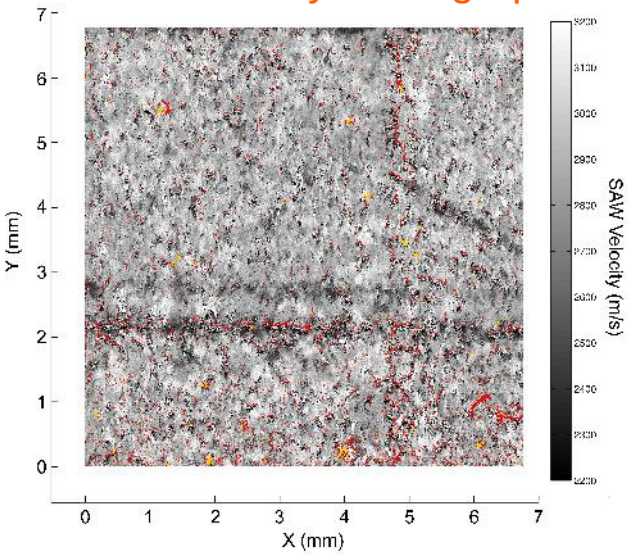
OM micrograph



SRAS Optical micrograph



SRAS Velocity micrograph



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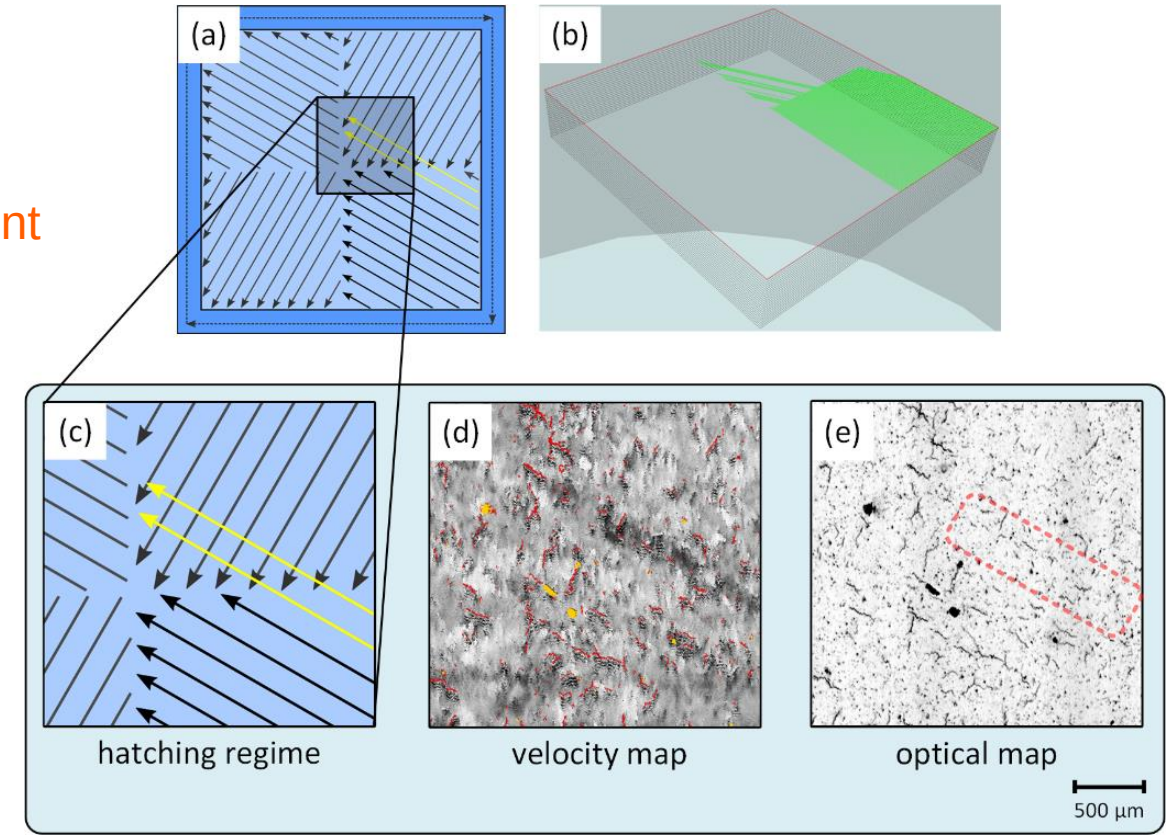
Texture Evaluation of SLM parts using SRAS

- (a) melting strategy
- (b) simulation of created toolpaths (observable error)
- (c) schematic of error
- (d) SRAS velocity data
  - Texture defect present
- (E) SRAS optical data
  - Texture defect not present



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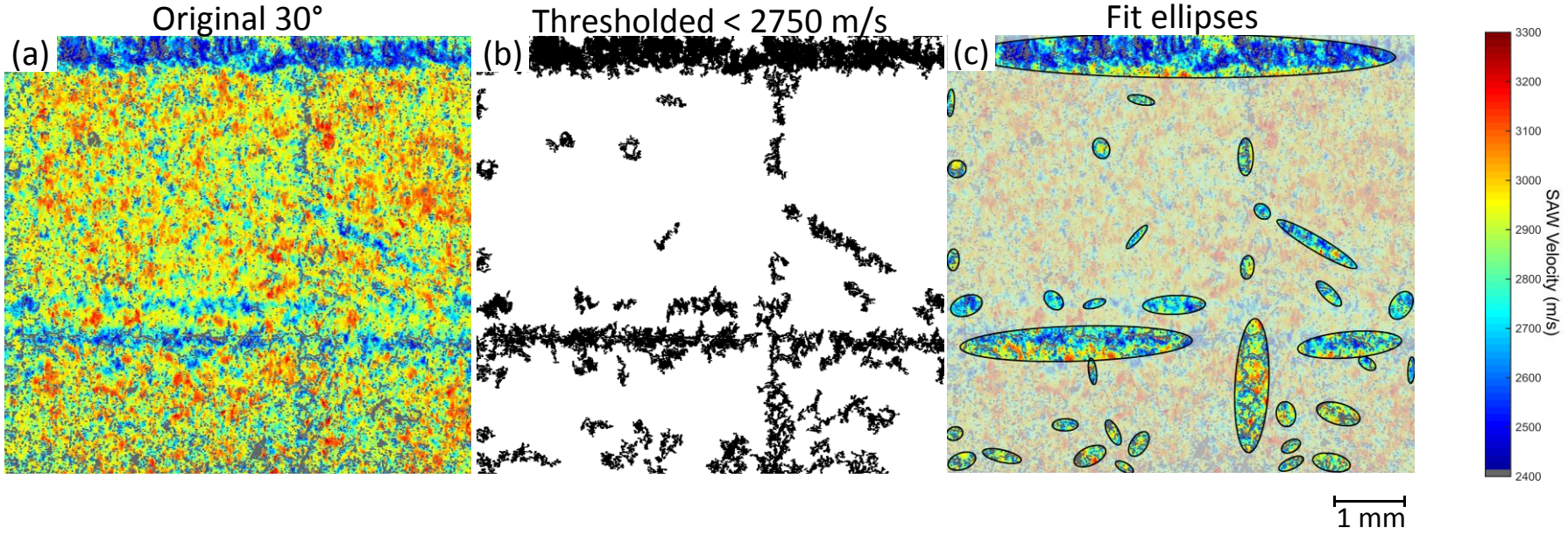
Texture Evaluation of SLM parts using SRAS

- What can we use this information for?
- Feed back into the manufacture process
- Defect density of 5.32% in affected areas versus 1.17% in bulk material
- Avoid ‘island interfaces’ in the scan strategy



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To Conclude

- Ex-situ works a treat……..
- Machine integration
- Make processes faster – this is not trivial
- Understand what **needs** measuring AND what does **not**

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Thank you