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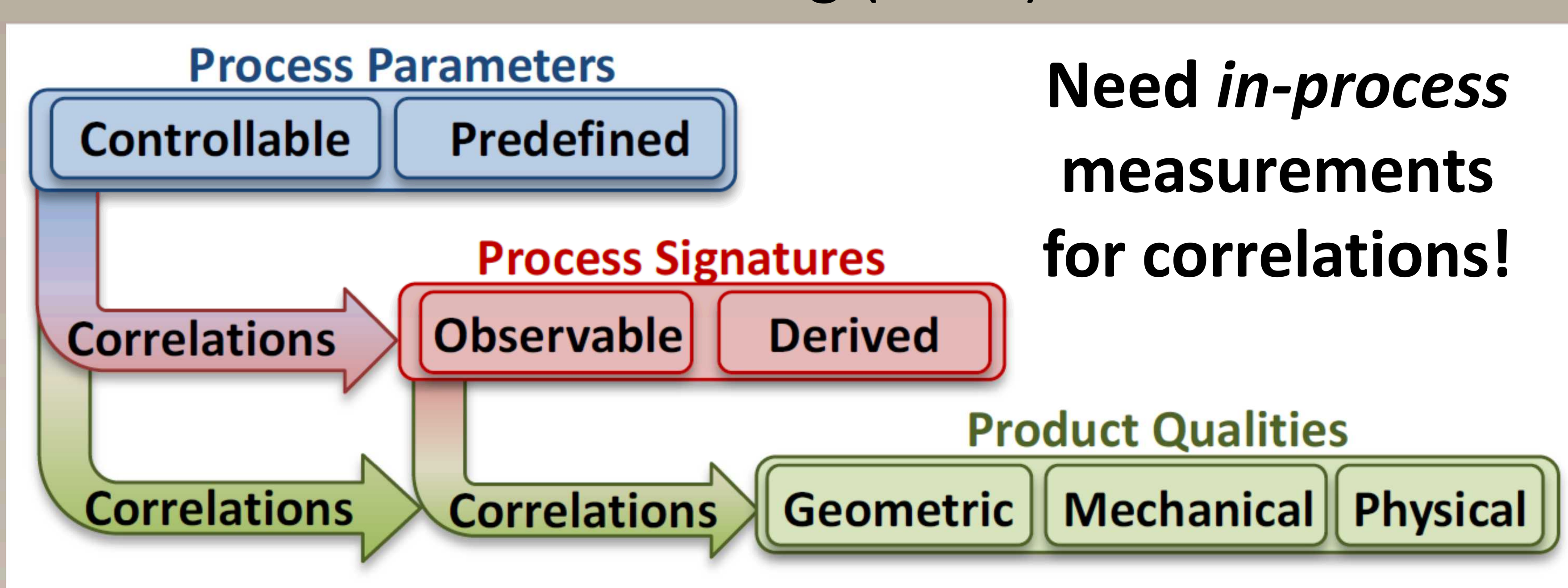
Towards *in-process* Materials Characterization in Laser-based Metal Additive Manufacturing

Andrew Kustas, David Keicher, Michael Brumbach, Brendan Nation, Nicolas Argibay
Materials Science and Engineering Center, Sandia National Laboratories, NM

Motivation

In-process materials characterization would enable closed-loop quality control, in-situ determination of material properties, and provide microstructural control…
– NIST, Measurement Science Roadmap for Metal-Based Additive Manufacturing (2013)



"Process parameters along with signatures in general have not yet been directly related to product quality…"
– NIST, Measurement Science Needs for Real-time Control of AM Powder Bed Fusion Processes (2015)

Parameters	Signatures		Qualities
	Melt Pool	*Solidified Material*	
Tunable: 1. Laser power, velocity and diameter 2. Layer thickness 3. Gas flow rates 4. Print pattern *Limited Control:* 1. Powder morphology 2. Layer thickness 3. Packing density 4. Composition 5. Build plate	Temperature, profile and history Shape, extent, temporal variation Ejection Plume (IR, thermal imaging, microwave)	Layer-by-layer Geometric Irregularities Incomplete Melting Defects Residual Stress Composition Microstructure	*Geometric:* Dimensional Deviations *Mechanical:* Strength Hardness Toughness Fatigue Life *Physical:* Stress Roughness Porosity Defects

Color Key: In Progress, Planned Implementation, Potential Candidates Identified, Impractical/TBD

BQ Project-Wide *in-process* Efforts: Cameras for melt pool and part geometry characterization and pyrometers for temperature measurements.

Task Objective: Compliment current BQ efforts by utilizing non-destructive characterization tools to obtain quantitative information about solidified material *in-process*.

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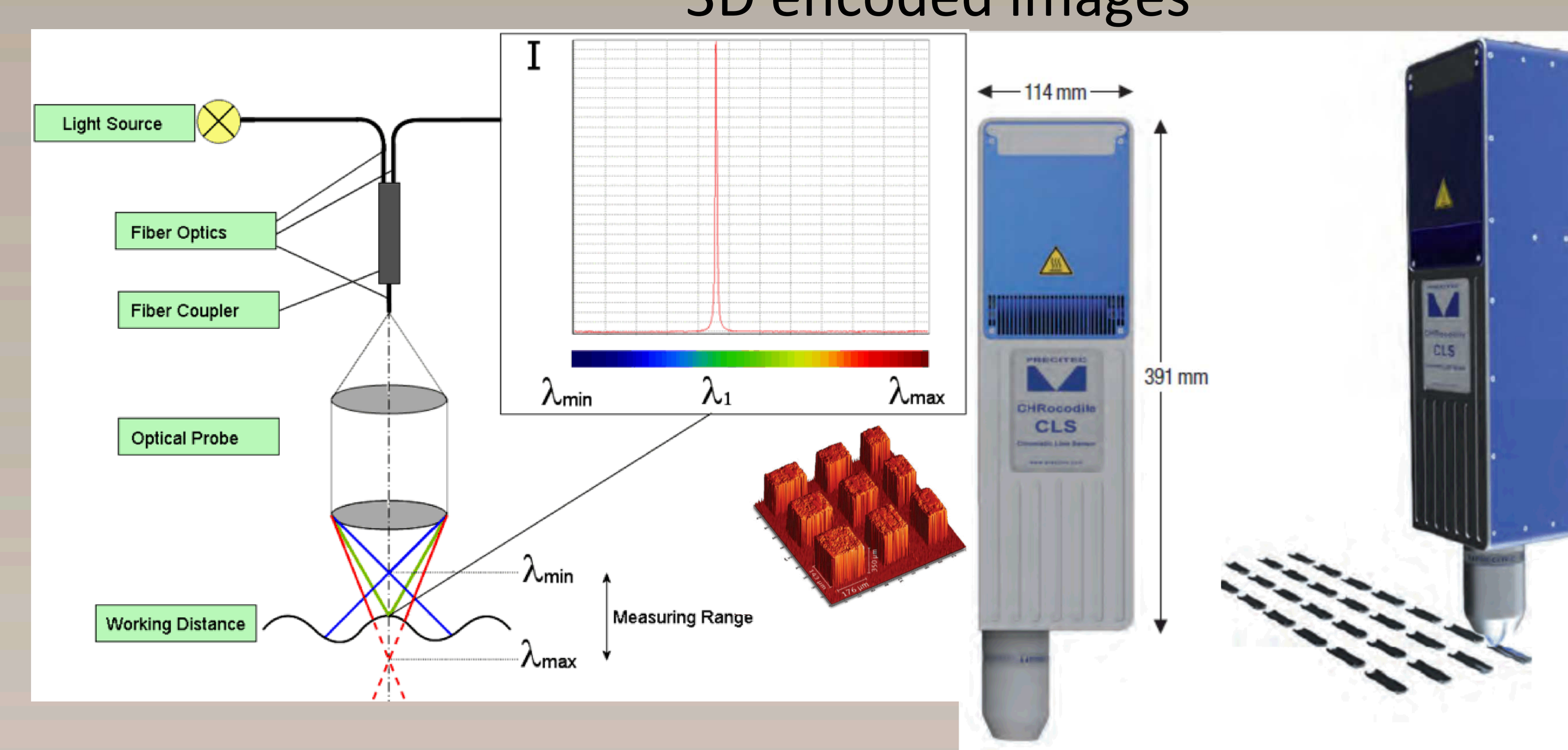
Proposed Approach

Method 1: Confocal Chromatic White Light Line Sensor

Information Gathered
- Layer-by-layer real-time surface roughness, defects and topography
- Particle packing density
- Geometric dimensions

Advantages
- Rapid
- Wide focal range
- Line and point probes
- Small probe size
- 3D encoded images

Challenges
- May require optical filtering
- Temperature sensitivity



Candidate Product: Precitec CLS 1 with CHRocodile Sensor

Probe Specs
- Measuring range = 1 mm
- Line length = 1.91 ± 0.01 mm
- Working distance = 18.5 ± 0.2 mm
- Spot size = 4 µm
- Lateral resolution = 2 µm
- Axial resolution = 80 nm

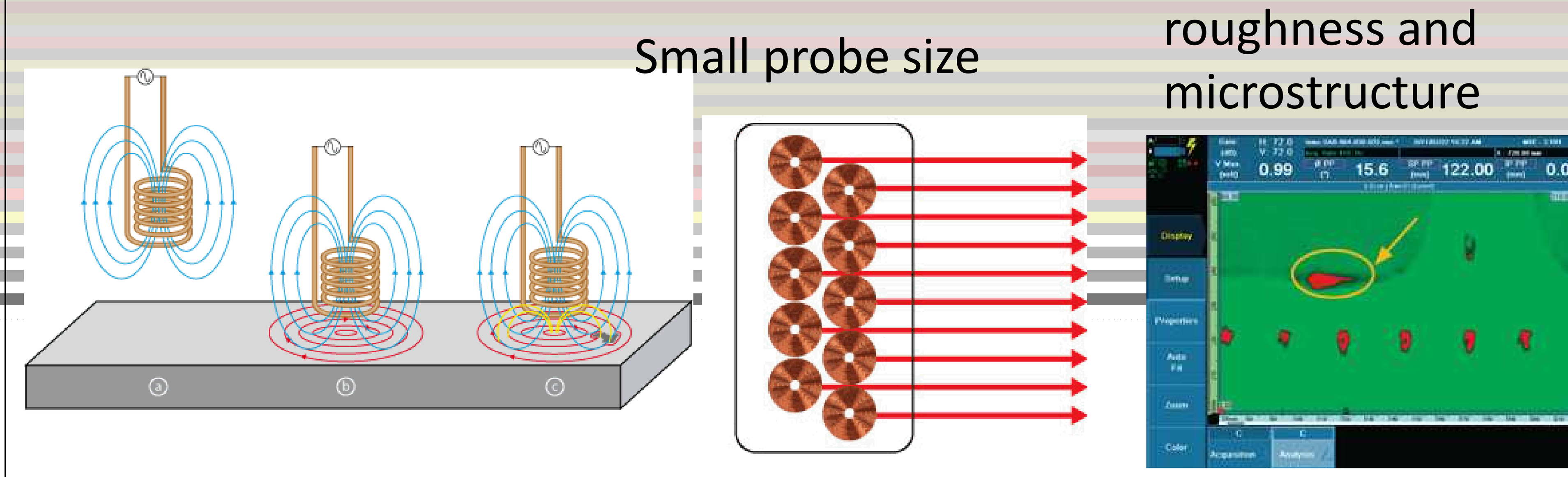
Sensor Specs
- Up to 2,000 lines/sec
- 384,000 data pts/sec
- 192 data pts/line
- LED light source
- 4 kg mass
- Up to 50 °C

Method 2: Eddy Current Array Testing

Information Gathered
- Surface and near-surface microstructural defects, cracks/voids

Advantages
- Rapid
- Encoded images of defects
- Small probe size

Challenges
- Close working distance of 50 µm
- Sensitive to surface roughness and microstructure



Candidate Product: Olympus OmniScan MX
- Supports conventional ECT, ECA and C-scan
- 1-4 ECT and 32 ECA channels
- Absolute, differential, bridge and reflection modes
- Up to 8 testing frequencies from 20 Hz to 6 MHz
- Maximum 15 kHz data acquisition

Additional Candidate Methods: Raman and Laser-induced Breakdown Spectroscopy (LIBS), Ultrasonic testing, X-ray diffraction (XRD), X-ray fluorescence (XRF).