



**Open your mind. LUT.**

Lappeenranta **University of Technology**

# Online monitoring in additive manufacturing

Ville-Pekka Matilainen

Lappeenranta University of Technology  
School of Energy systems  
Laser processing

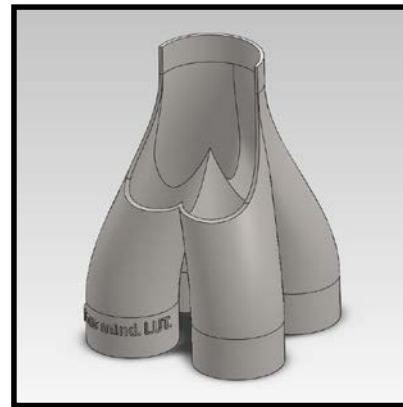


June 5<sup>th</sup> 2015

Hub of Application Laboratories for Equipment Assessment  
in Laser Based Manufacturing

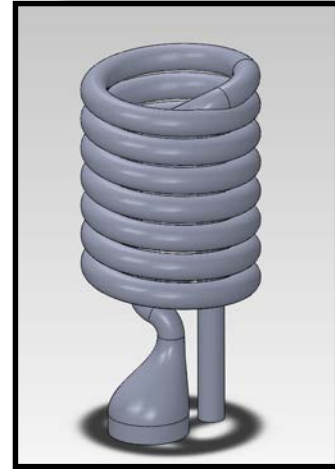
# Additive Manufacturing activities at LUT

- AM (Additive Manufacturing) research at LUT started on 2009 with real-time process monitoring
- Research AM machine (represents EOSINT M-series machines) was received in 2011
  - First and so far only AM machine for metals at any university in Finland
- AM teaching started in 2013
  - Course for M.Sc. Students in spring term
- AM teaching for industry at LUT started in January 2014



# AM research at LUT

- Process monitoring and control
- Application research
- Support technology
- Weldability of AM work pieces
- Dimensional accuracy of AM parts
- Mechanical properties of AM parts
- Metallurgical properties of AM parts
- Optimization of structures with AM
- Etc.

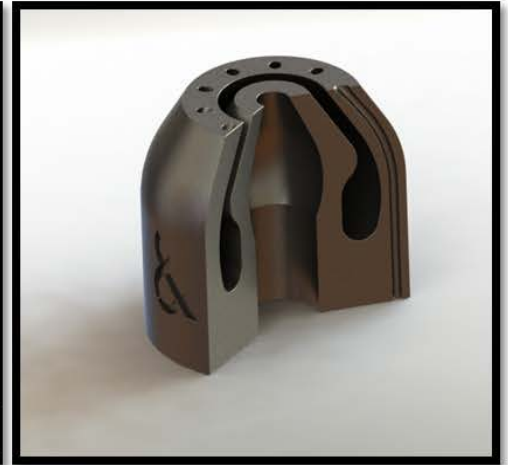
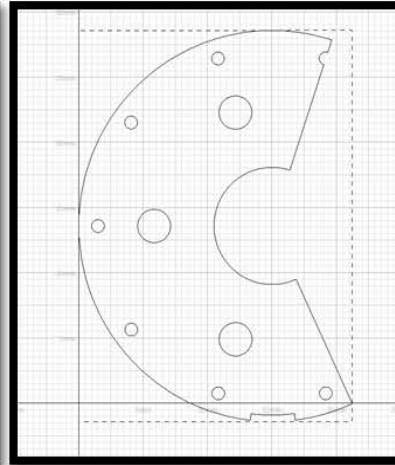
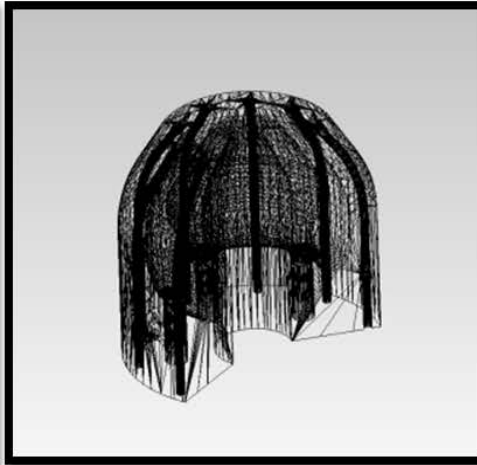
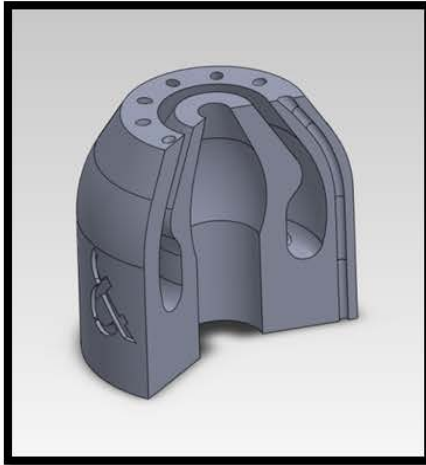


# AM projects at LUT

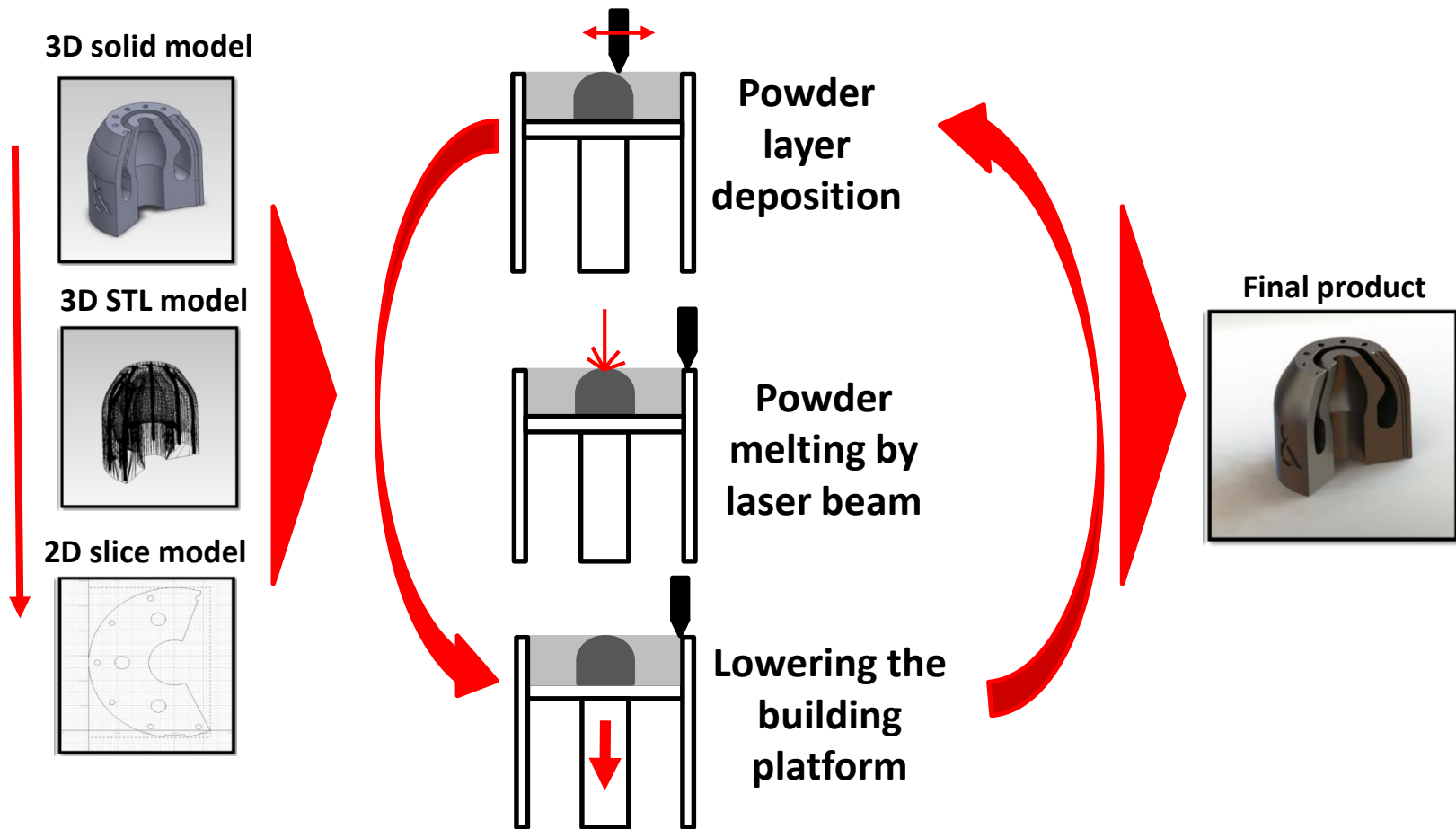
- Industrial case studies
- Understanding of AM process
- Quality and quality control systems
- Optimization of weight/strength ratio of structures
- Metallurgical and mechanical properties
- New materials

# Principle of powder bed fusion (PBF)

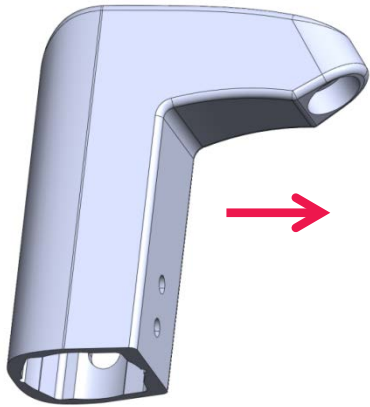
- Phases of additive manufacturing:
  1. Digital 3D model of part
  2. STL-conversion
  3. Slicing the 3D model;
  4. Ready physical 3D model.



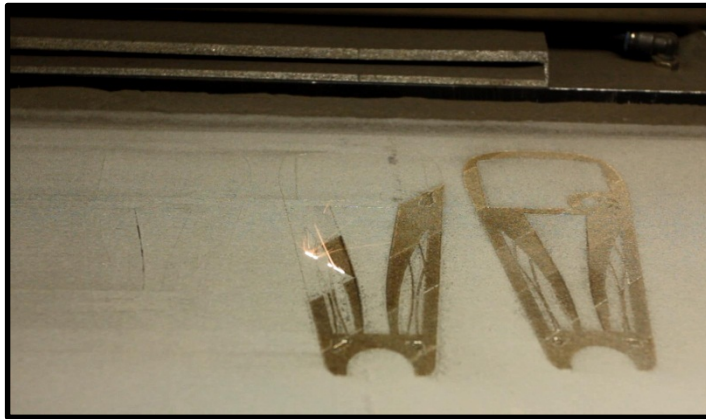
# Principle of powder bed fusion



# Application, LUT Laser



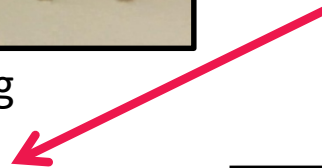
3D model



PBF manufacturing



Loose powder is removed



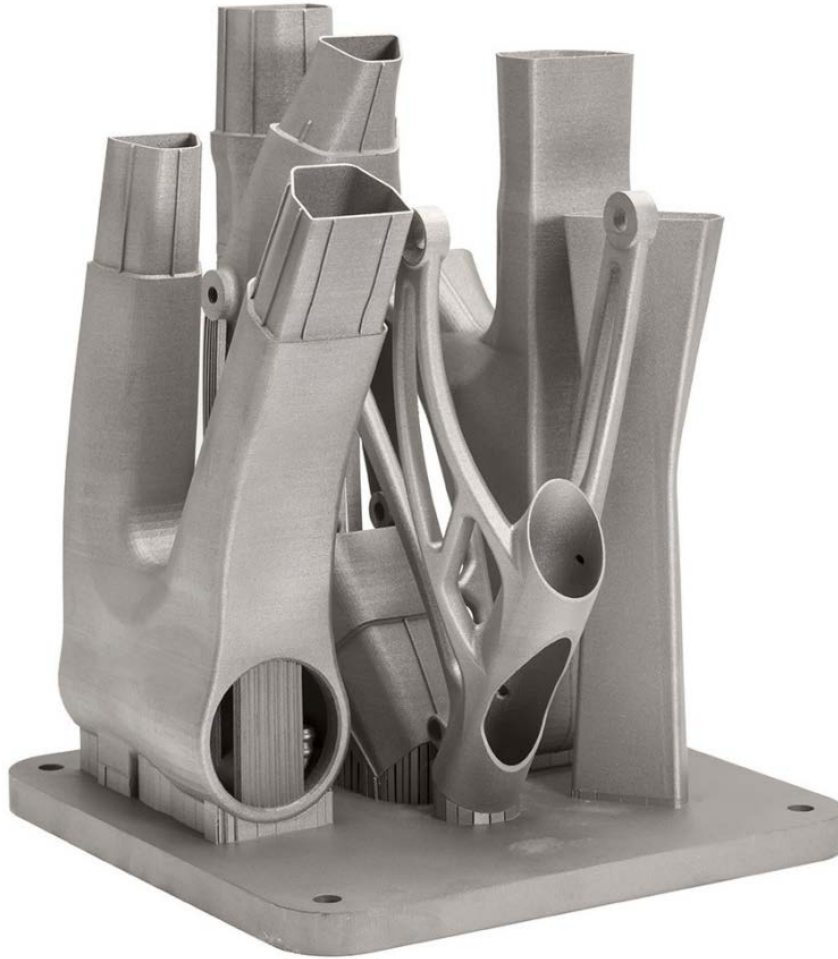
Before and after finishing



Finished faucet



# Application



- Weight of AM bike frame  
1.4 kg
- Titanium
- Parts joined together with  
structural epoxy adhesive
- Manufactured at once,  
build time 90h

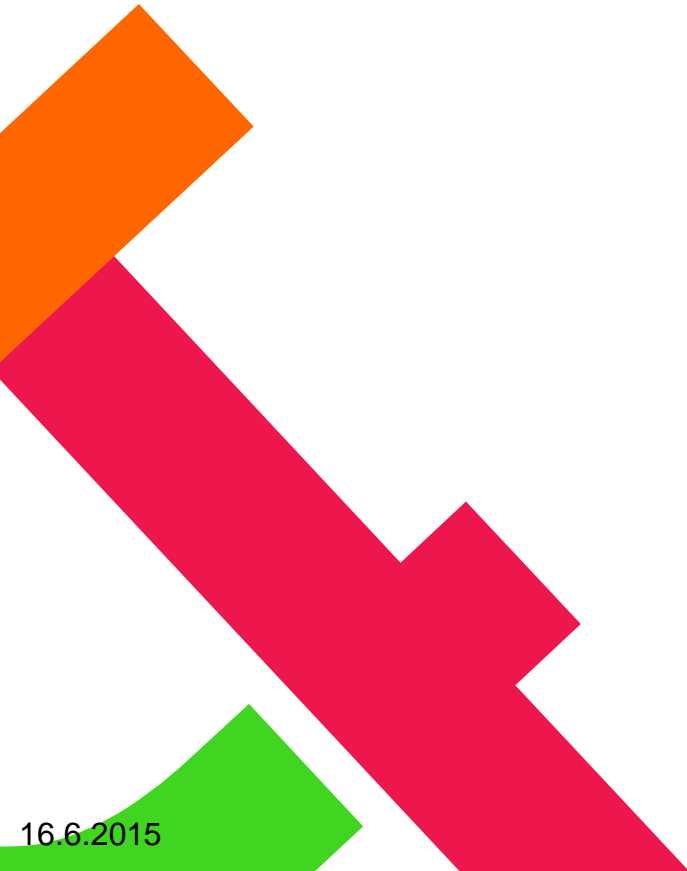
# Application



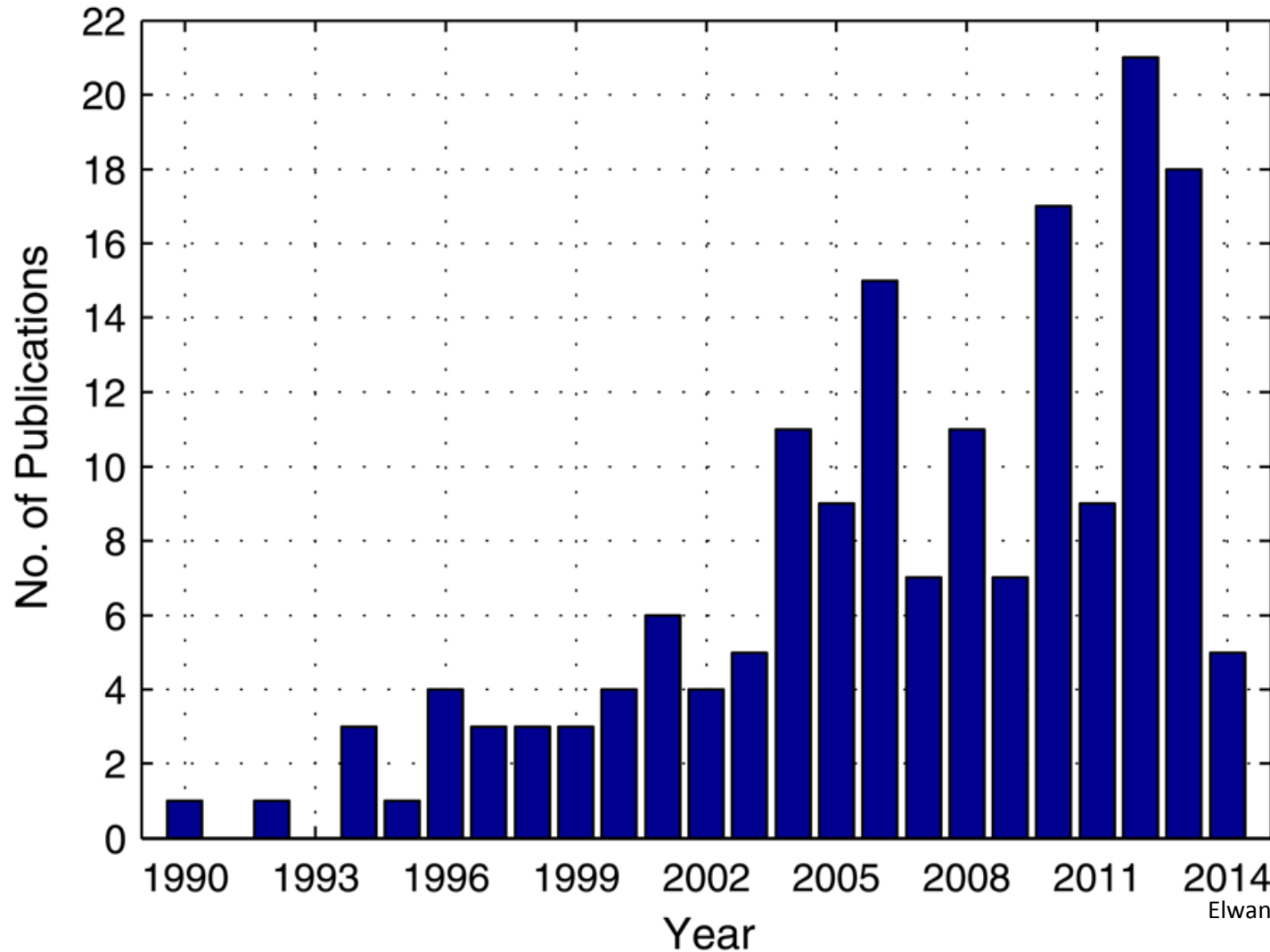
**RENISHAW**  
apply innovation™

**EMPIRE**  
CYCLES LTD

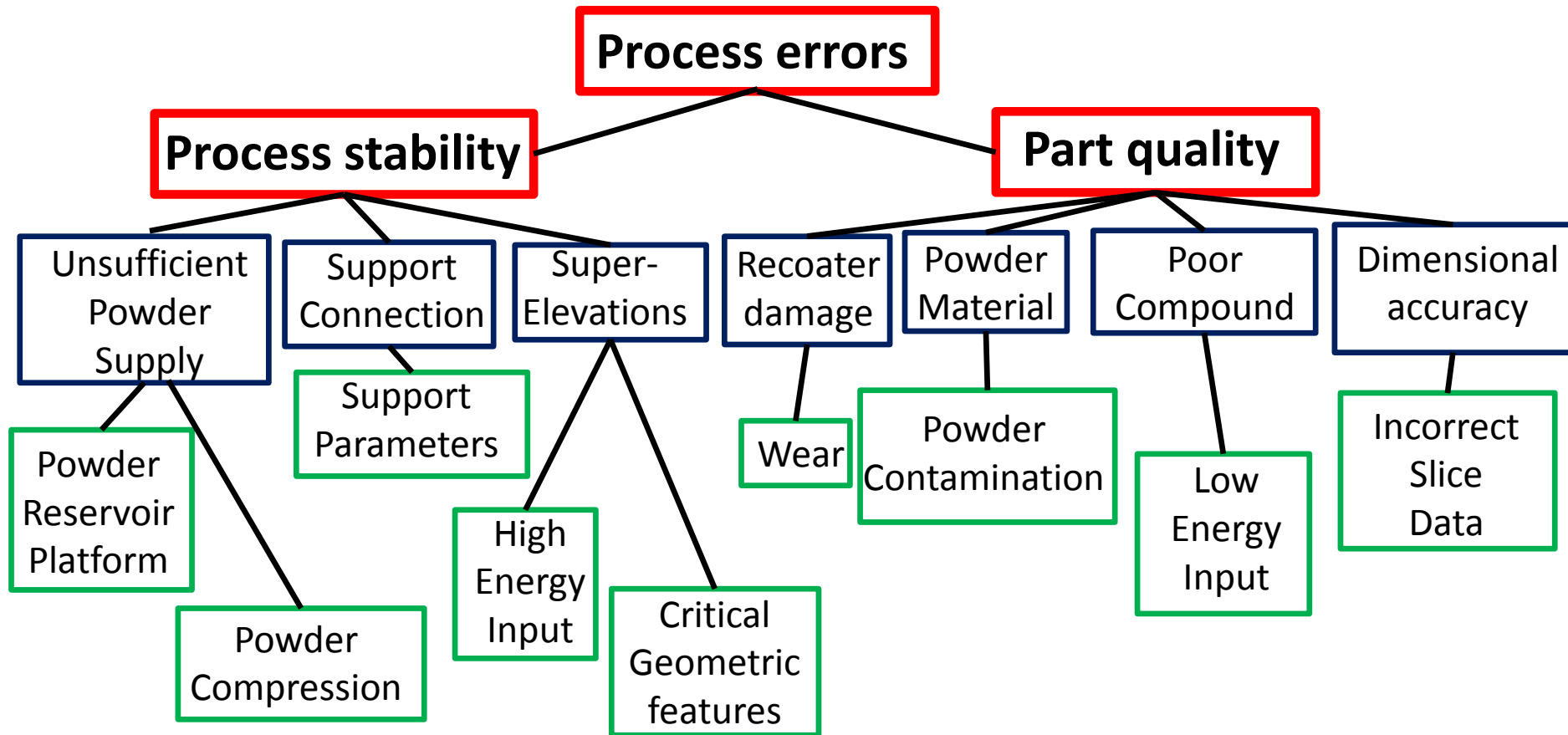
# **Monitoring of additive manufacturing**



# Monitoring of additive manufacturing



# Typical process errors in PBF



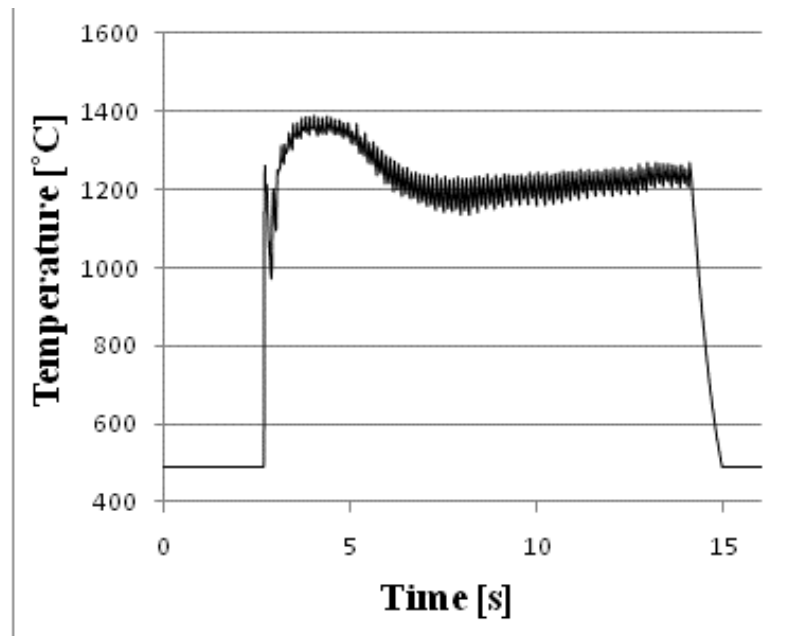
Kleszczynski et al. 2012

# Monitoring of additive manufacturing

- In most AM processes the key process variables can be taken as proxies of part quality.
- The behavior of these key variables correlate directly to the properties of manufactured parts.
- E.g. in powder bed fusion process the energy density input is a variable that effects straight to the microstructure and surface quality of manufactured part.
- If relevant process variables are identified, monitored and properly modified, the process control can be done.

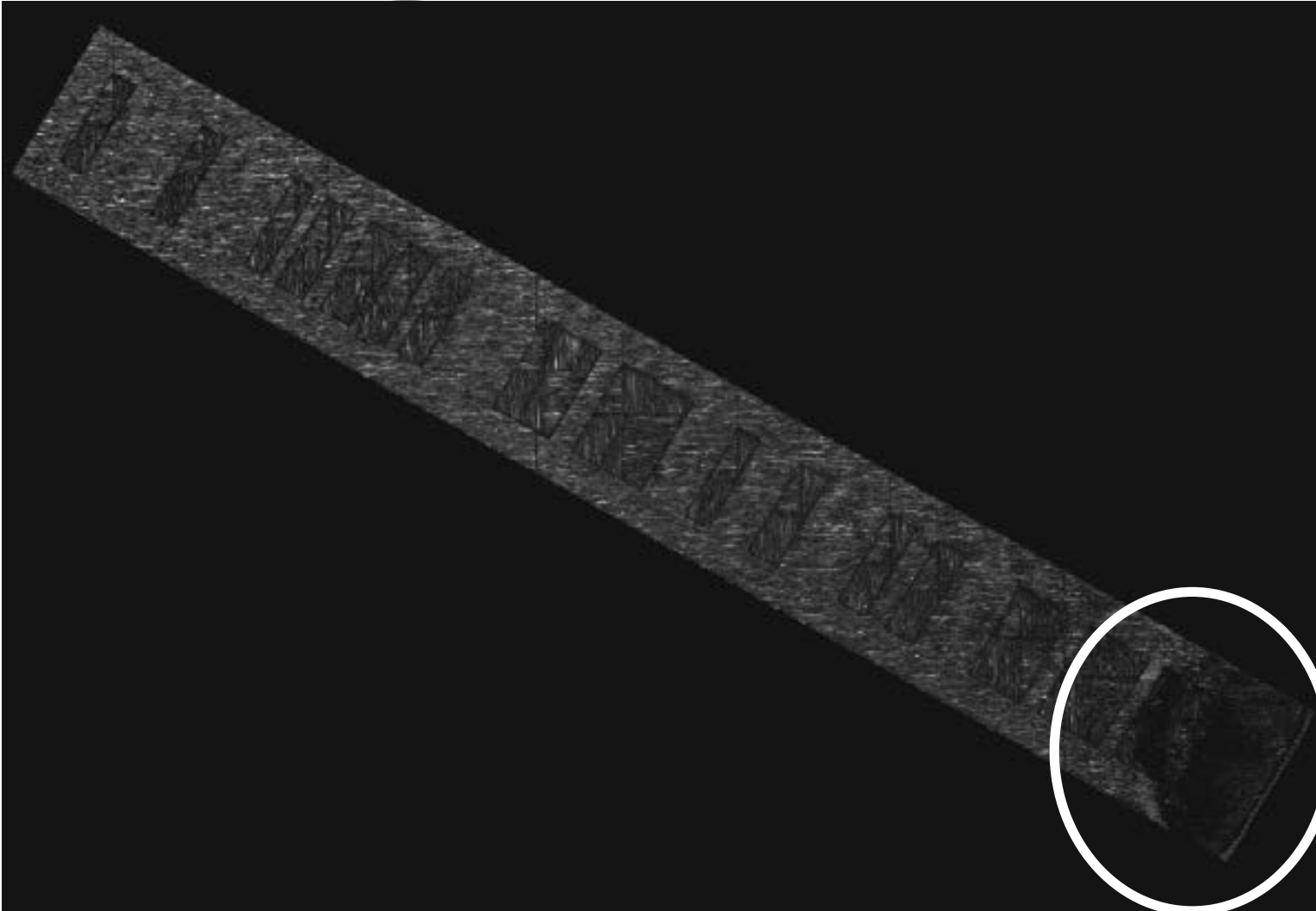
# Monitoring methods for AM

- Since the PBF use focused thermal energy source to melt and fuse metallic powder, pyrometer is used in many studies to monitor the process.
- Homogenous temperature field during fabrication results better part quality.



Lehti et al. 2011, Zeng et al. 2012

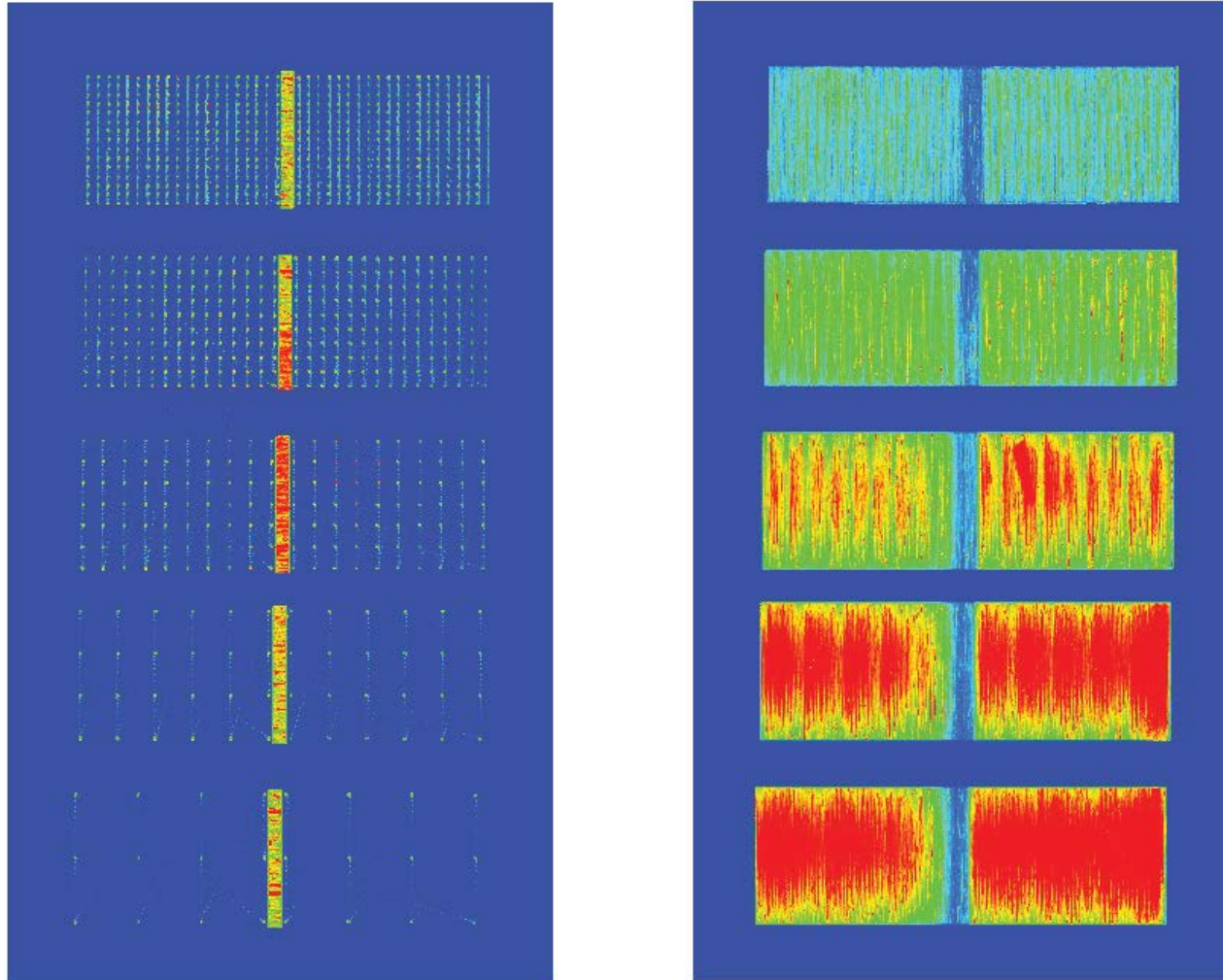
# Monitoring methods for AM



Craeghs et al. 2012



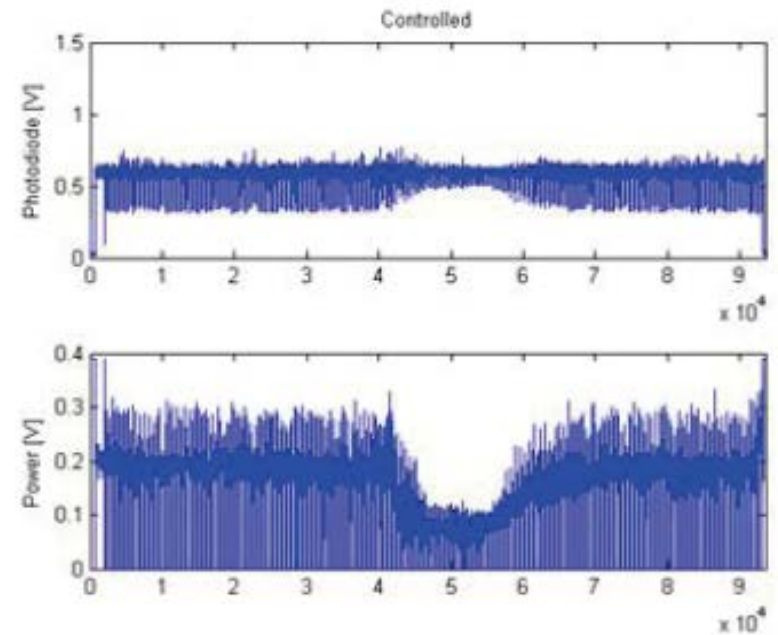
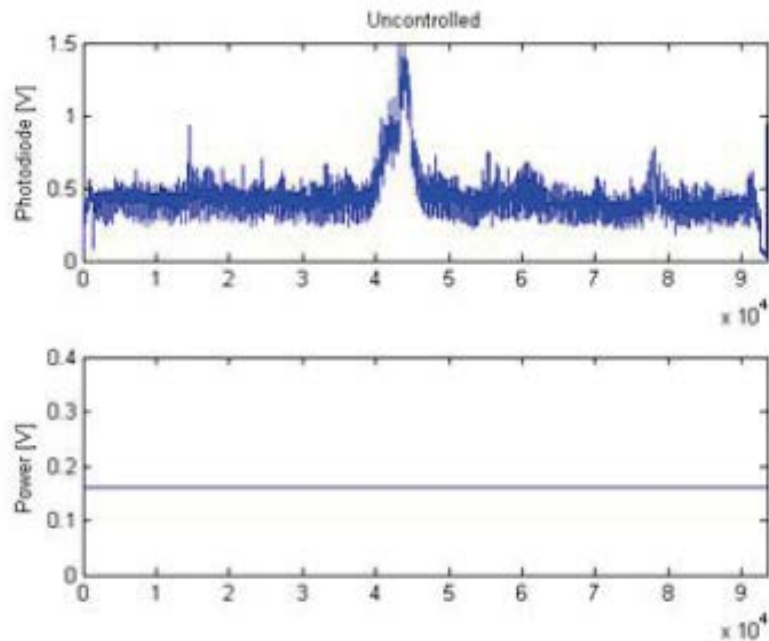
# Monitoring methods for AM



Craeghs et al. 2012

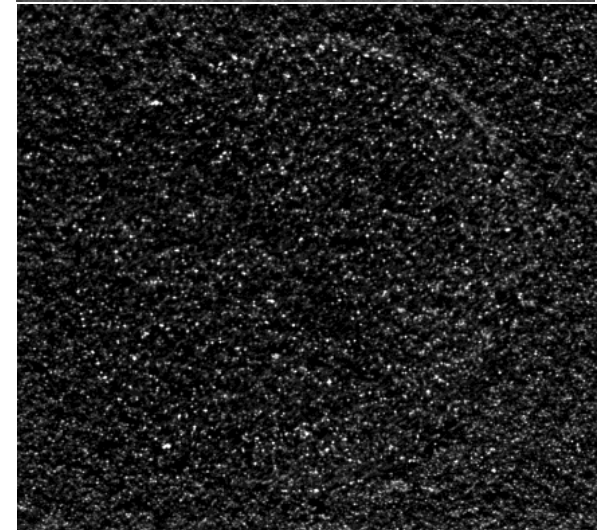
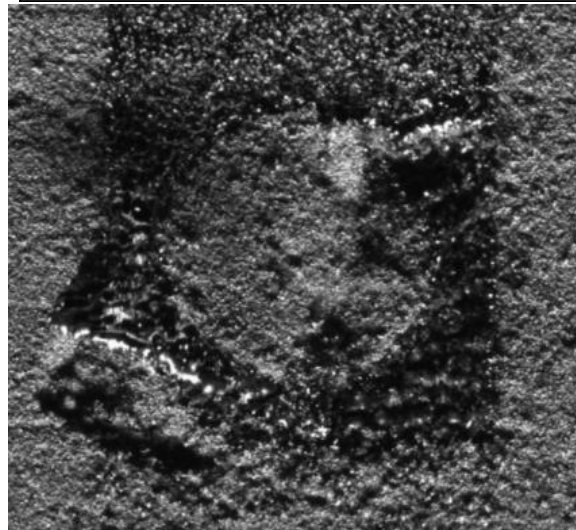
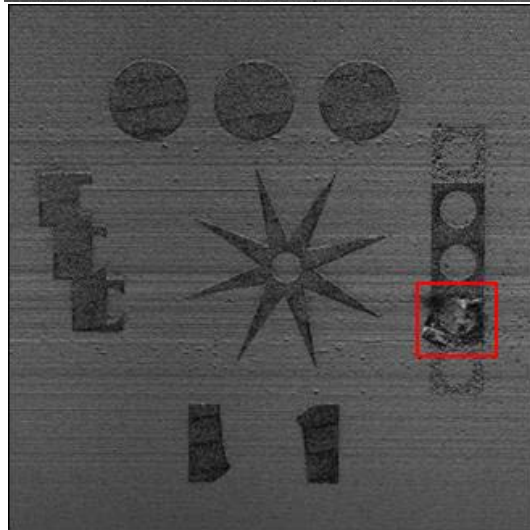
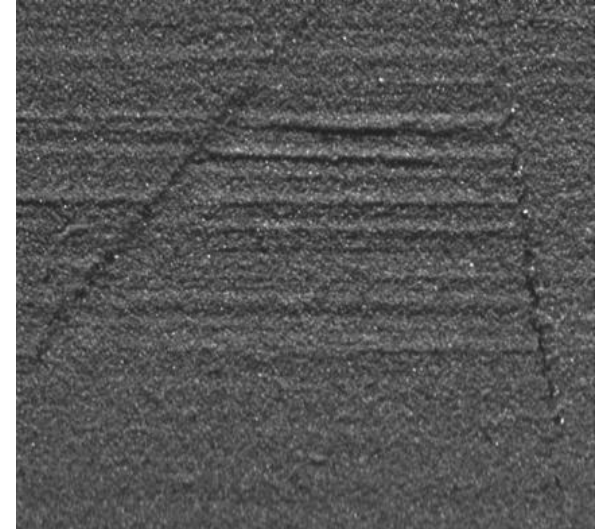
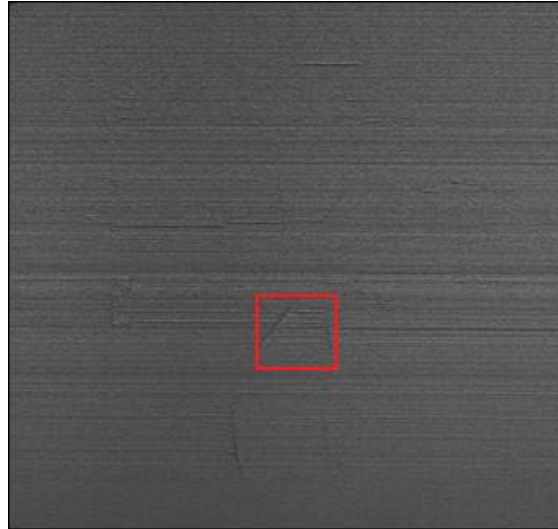
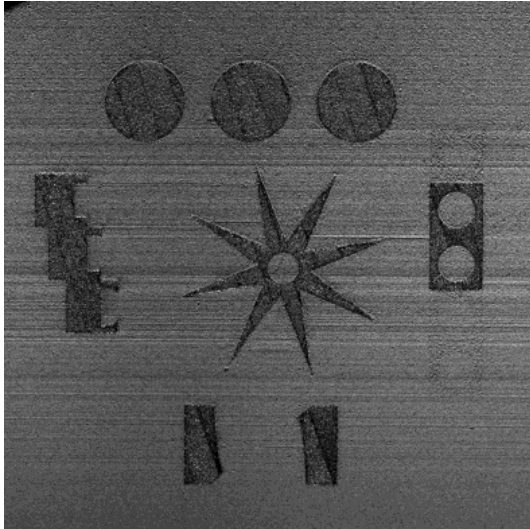
# Monitoring and feedback control of AM

- Using photodiode and CMOS camera + specially



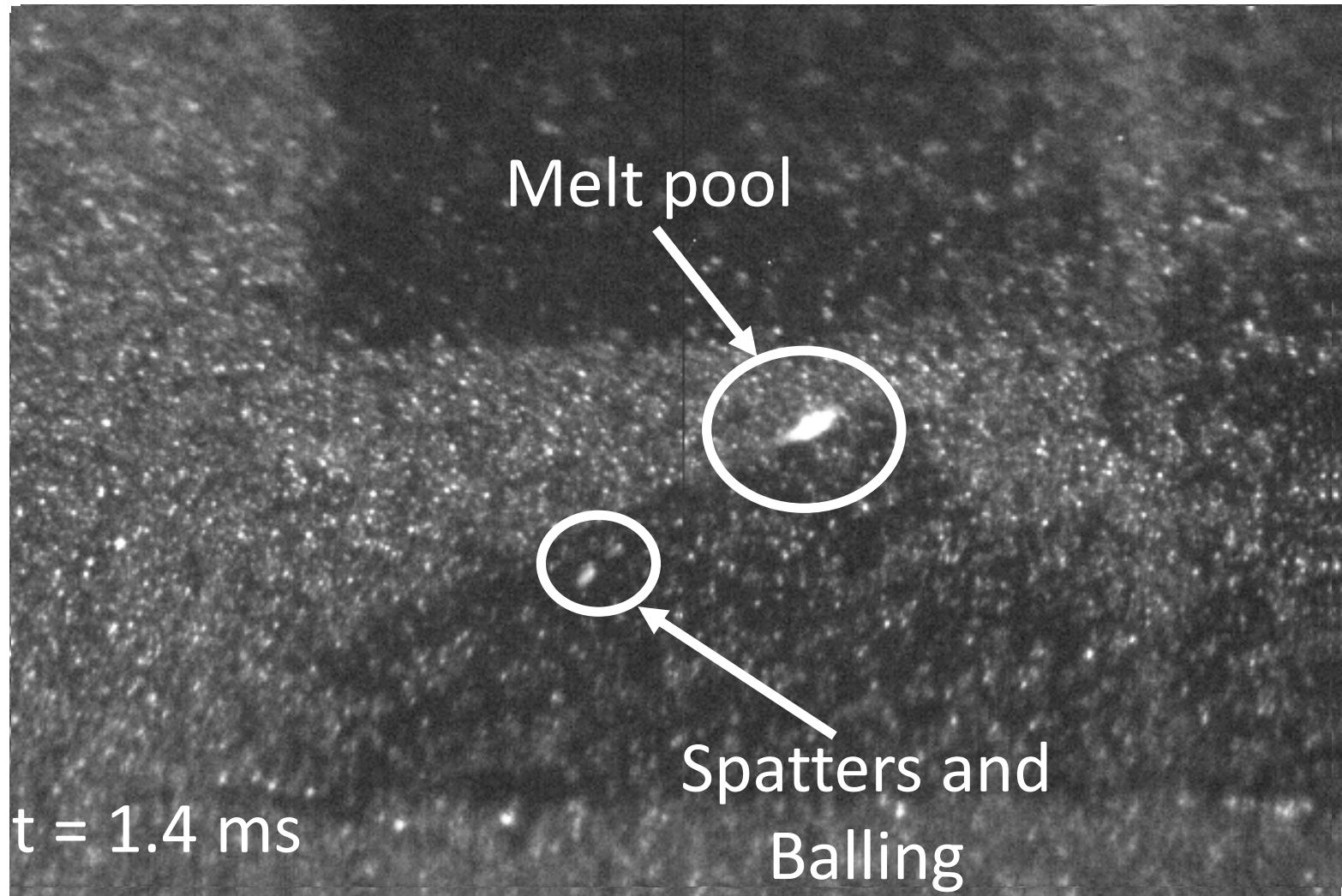
Craeghs et al. 2010

# Detecting errors with high-resolution imaging





# High-speed camera & Active illumination



# Conclusions

- AM processes have unique capabilities to be game changing technologies.
- However, the quality assurance of the manufactured parts needs still more work to do.
- Majority of monitoring is focused on temperature monitoring.
- High speed imaging and melt pool mapping with photodiodes gives lots of useful data about the process.

# Thank you for your attention!

Lappeenranta University of Technology

Laser Processing Laboratory

For more information:

Doctoral Student Ville-Pekka Matilainen

[ville-pekka.matilainen@lut.fi](mailto:ville-pekka.matilainen@lut.fi)

Professor Antti Salminen


[antti.salminen@lut.fi](mailto:antti.salminen@lut.fi)



# References

- Elwany, A., Tapia, G., A Review on process monitoring and control in metal-based additive manufacturing, Journal of Manufacturing Science and Engineering, 2014, Vol.136
- Kleszczynski, S., zur Jacobsmühlen, J., Sehr, J.T., Witt, G., Error detection in laser beam melting systems by high resolution imaging, Proceedings of Solid Freeform Fabrication Symposium, 2012
- Lehti, A., Taimisto, L., Piili, H., Nyrhilä, O., Salminen, A., Correlation between pyrometer monitoring and active illumination imaging of laser based additive manufacturing of stainless steel, Conference Proceedings of ICALEO 2011
- Zeng, K., Pal, D., Stucker, B., A Review of thermal analysis methods in laser sintering and selective laser melting, Proceedings of Solid Freeform Fabrication Symposium, 2012
- Craeghs, T., Clijsters, S., Kruth, J-P., Bechmann, F., Ebert, M-C., Detection of process failures in layerwise laser melting with optical process monitoring, Physics Procedia 39, 2012
- Craeghs, T., Bechmann, F., Berumen, S., Kruth, J-P., Feedback control of layerwise laser melting using optical sensors, Physics Procedia 5, 2010
- [www.renishaw.com](http://www.renishaw.com)
- [www.empire-cycles.com/article.php?xArt=31](http://www.empire-cycles.com/article.php?xArt=31)



An aerial photograph of the LUT University campus in Lappeenranta, Finland. The campus is a cluster of red-brick and white buildings situated on a green peninsula. It is surrounded by a vast body of water with numerous small, forested islands. The sky is blue with scattered white clouds.

**Do you have any questions?**

16.6.2015



Open your mind. LUT.  
Lappeenranta **University of Technology**

**LUTLaser**  
[www.lut.fi/laser](http://www.lut.fi/laser)