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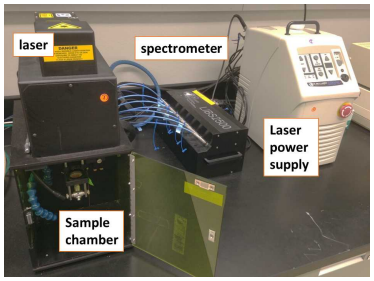

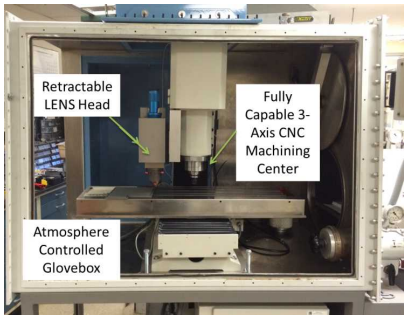

Surface and Compositional Characterization of Additively Manufactured Alloys Using Laser Induced Breakdown Spectroscopy

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Snapshot: how does Additive Manufacturing (AM) for metals work?

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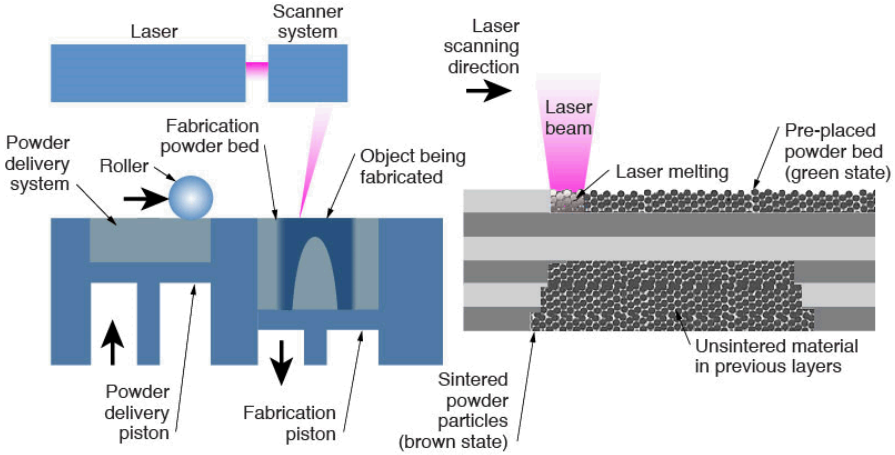
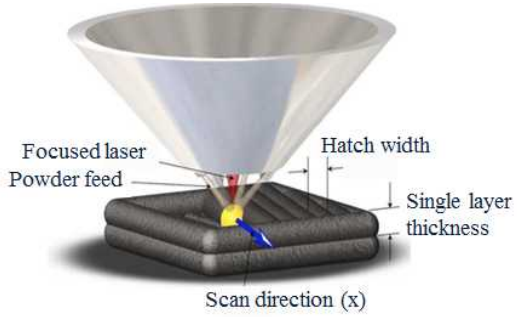
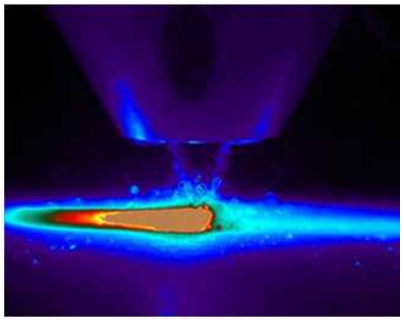
Powder bed fusion "glimpse"



- Powder in a bed container is consolidated layer-by-layer using a high power laser
- Laser moves rapidly (meters/sec), part remains stationary
- Rapid cooling rates up to 10^6 K/s and a fine melt pool (~100s of microns)

Laser Engineered Net Shaping (LENS) "glimpse"





- Powder stream injected into the focal point of a high power laser to fabricate a part layer-by-layer
- Part moves relatively slowly (~ 100s mm/min), laser and powder feeder unit are stationary
- Rapid cooling rates (~10^2 – 10^4 K/s) and larger melt pools (millimeters)

What's the big deal – why is AM a hot topic right now?

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The vision and the promise:

- Crazy shaped parts – cheap
- Reduced machining
- Improved/unique alloys
- Improved performance
  - Corrosion resistance
  - Consistency
  - Strength, weight
- Reduced waste

Today's realities:

- Restricted to a small set of conventional engineering alloys
- Parts have highly variable and suboptimal properties from unfavorable microstructures
- Lack of in-situ process monitoring and characterization tools

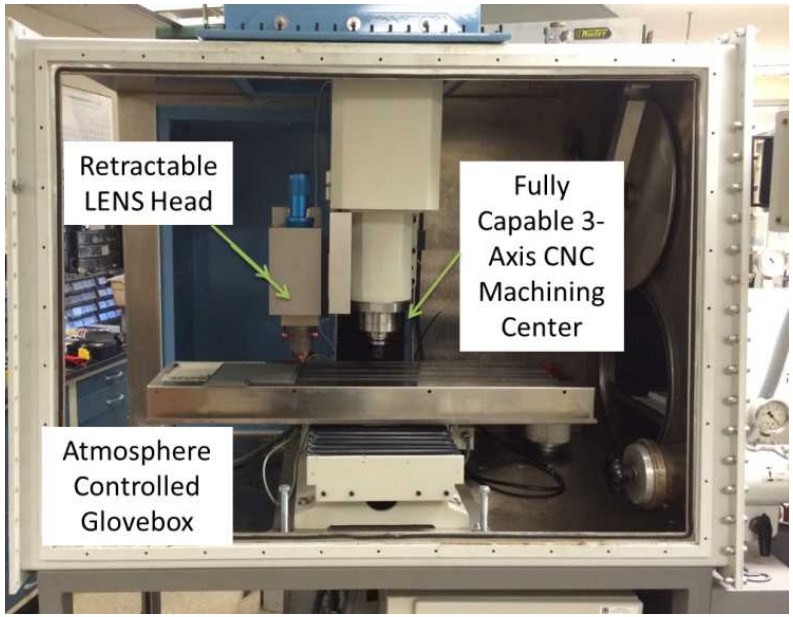
What **is** improving?
What **needs** improving?
What don't we know?

- Variable part microstructures, chemistries, and performance have inhibited the commercial adoption of AM.
- A lack of understanding of the processing physics and process-structure-properties of produced parts.
- National Institute of Standards and Technology (NIST) has identified *in situ* and in process monitoring tools are critical for answering the unknowns of the AM process.
- Unique violent processing and extreme temperatures make *in situ* diagnostics difficult.

It's all about control – to realize the potential – and get the desired product.

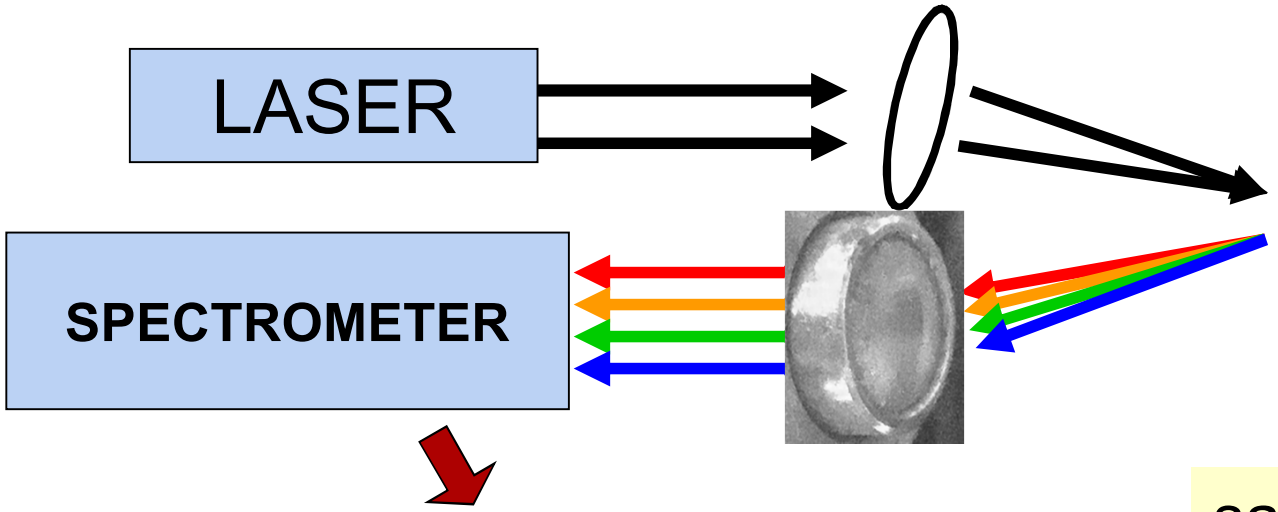
The equipment

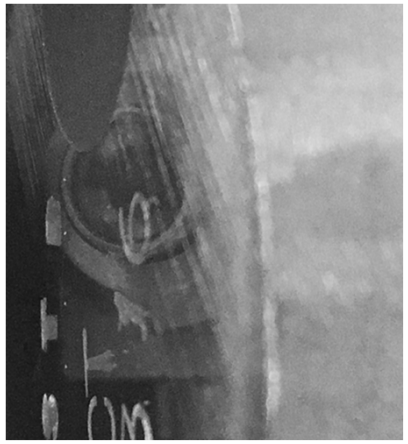
- Laboratory-scale LENS setup on Tormach CNC 770 frame.
- YLS-2000 Laser from IPG Photonics with 2 kW maximum output at 1064 nm.
- Powder feed is controlled through feed wheel and carrier gas to fluidize the powder.

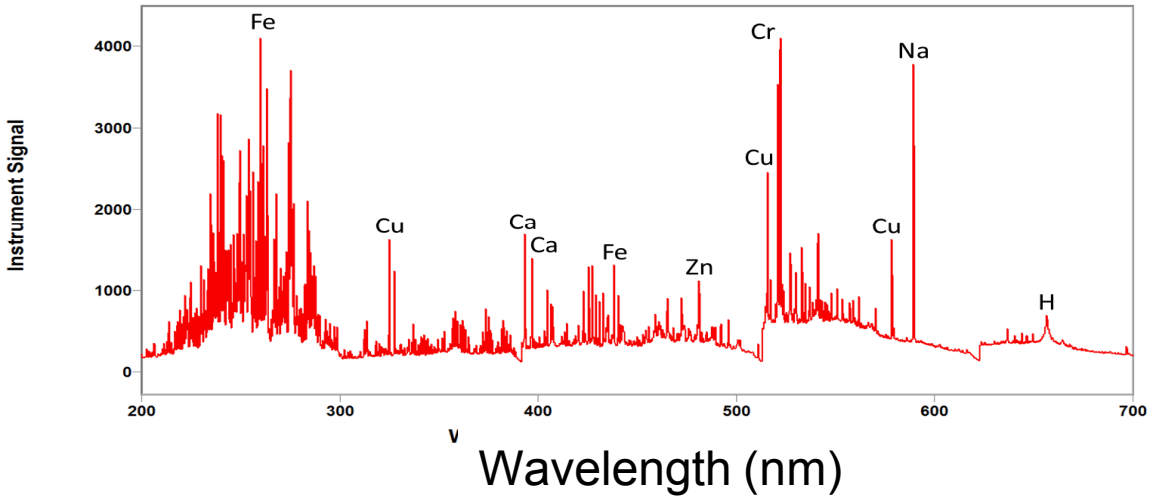


- 3D Systems ProX DMP 200.
- 300 W fiber laser at 1070 nm with a powder spreading roller.

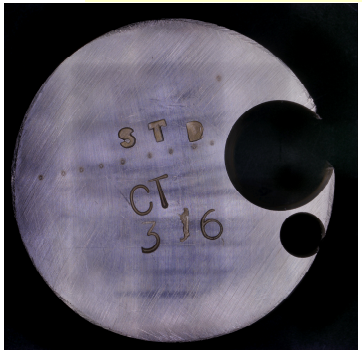
LIBS could determine AM surface and composition – but what is LIBS?

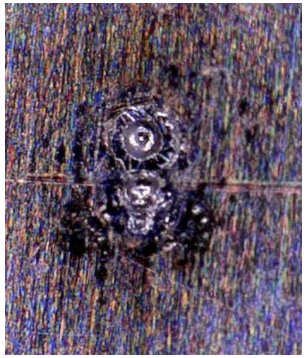






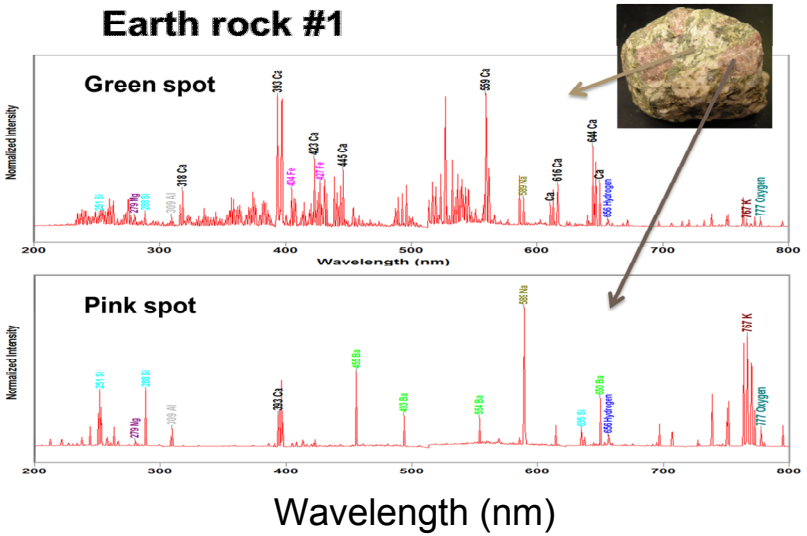
sample contains:
Cu, Zn, Fe

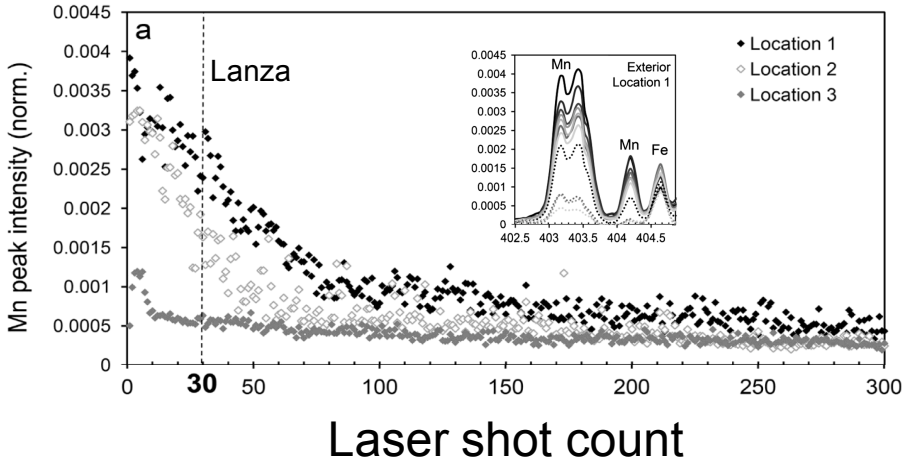




LIBS is used mostly for quick qualitative work but can be applied to many problems.

- Advantages
  - No sample prep
  - Rapid
  - Many configurations possible
    - IR, UV, VIS laser, single/double pulse
  - Distance
    - Mars Rover 12m!
- Disadvantages
  - Rarely quantitative
    - Only in specific applications
  - Destructive on small scale
  - Signal is matrix dependent





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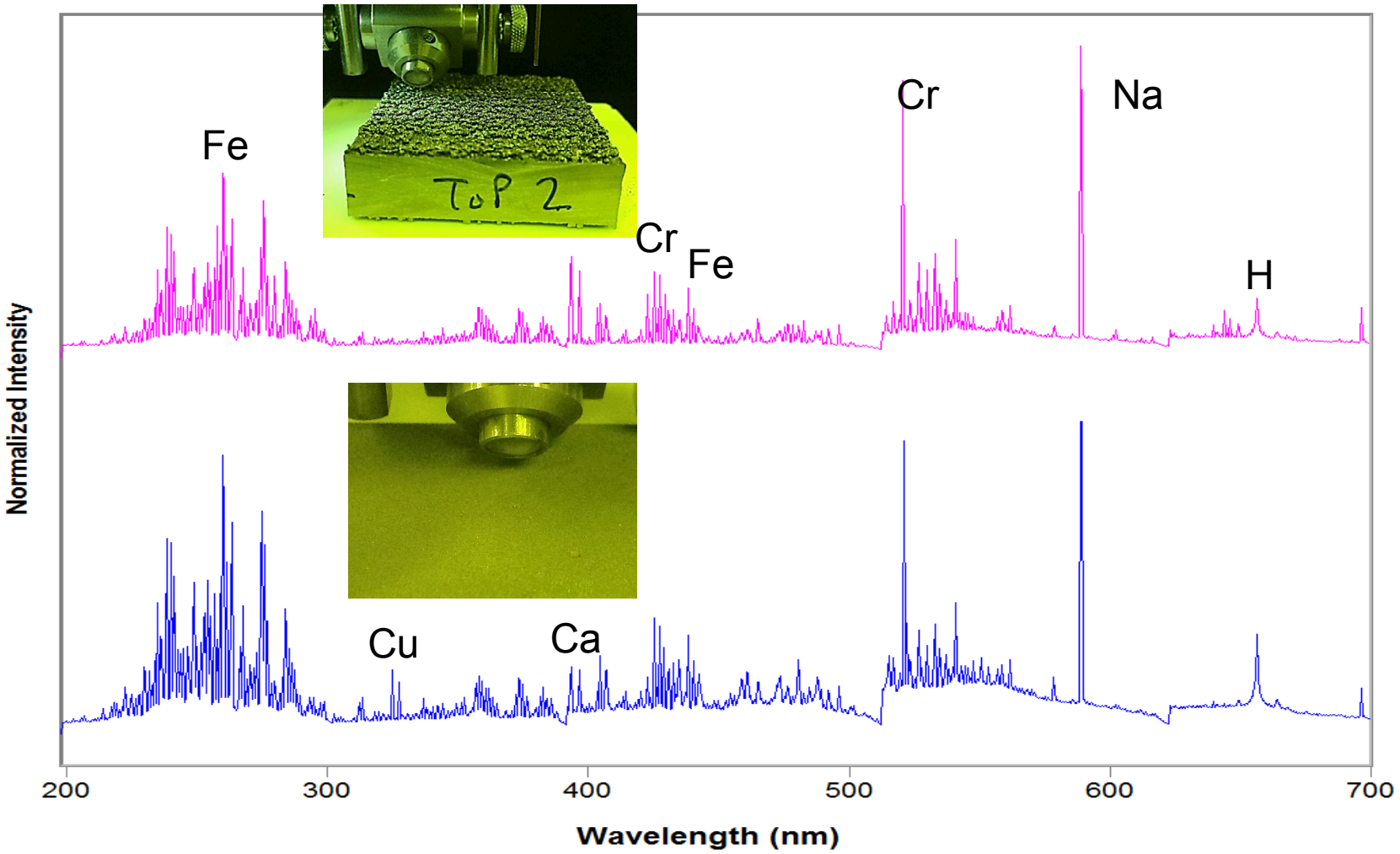
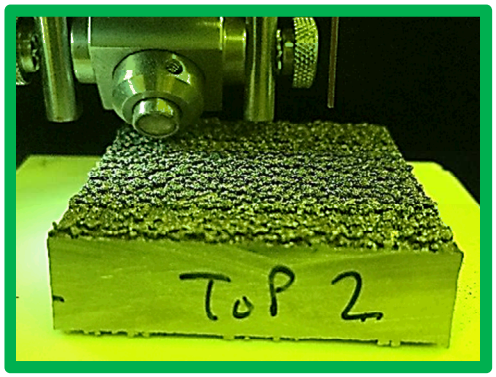
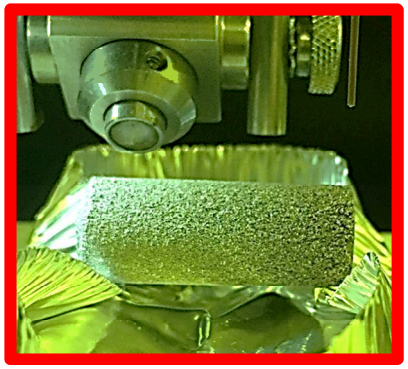
What information can you get for metals?



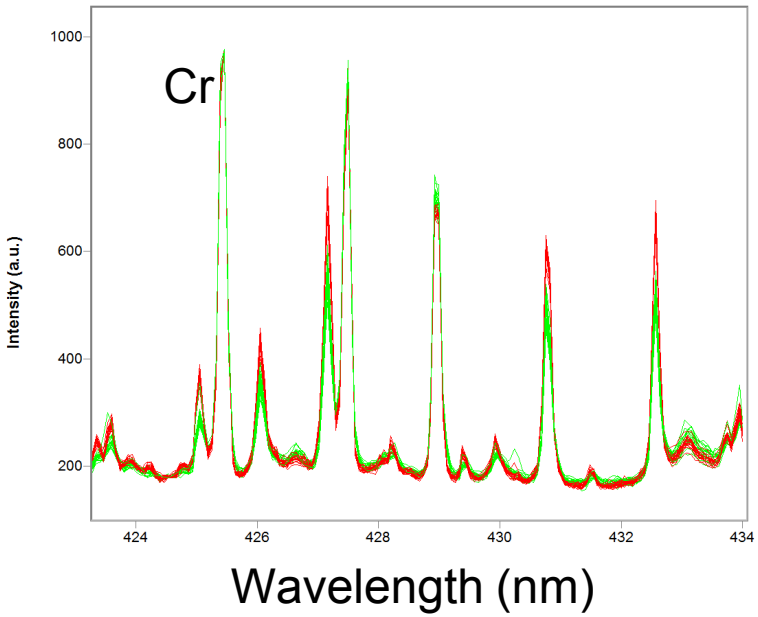
The data: can you tell the difference?

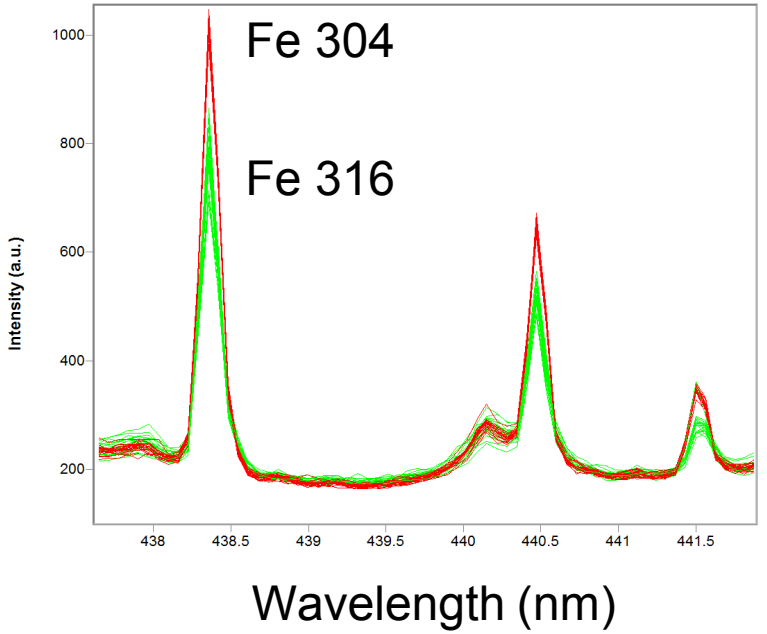




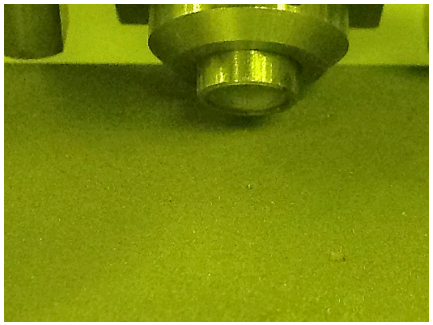
Compare spectra of 304 and 316

Normalized against Cr,
Fe levels different



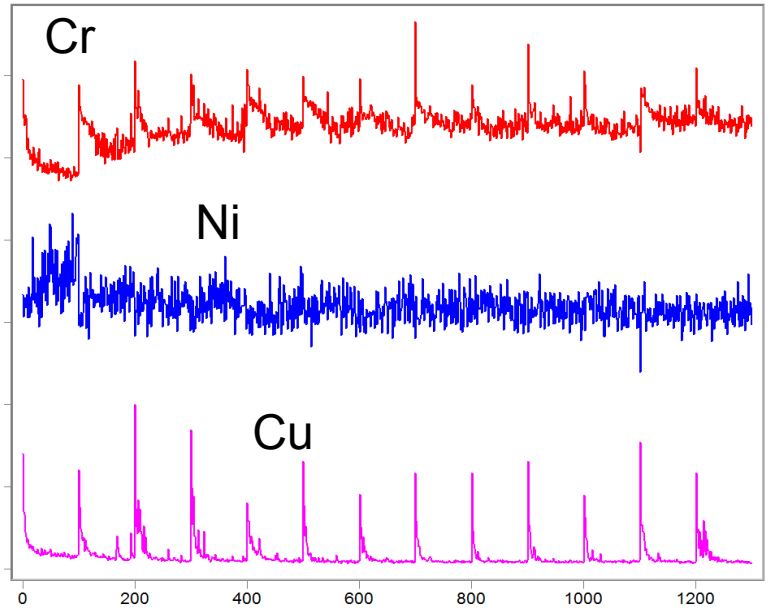


What's on the surface? Trace elements expected and unexpected……



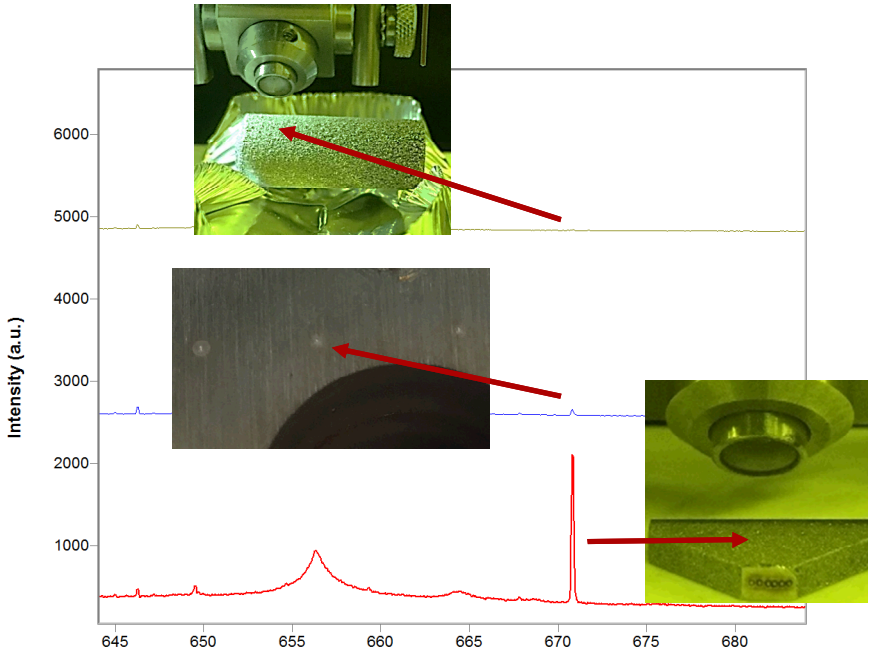
Also on surface:
Mg, Ca, ~~Li~~

100 shots, 13 different spots



Laser shot count

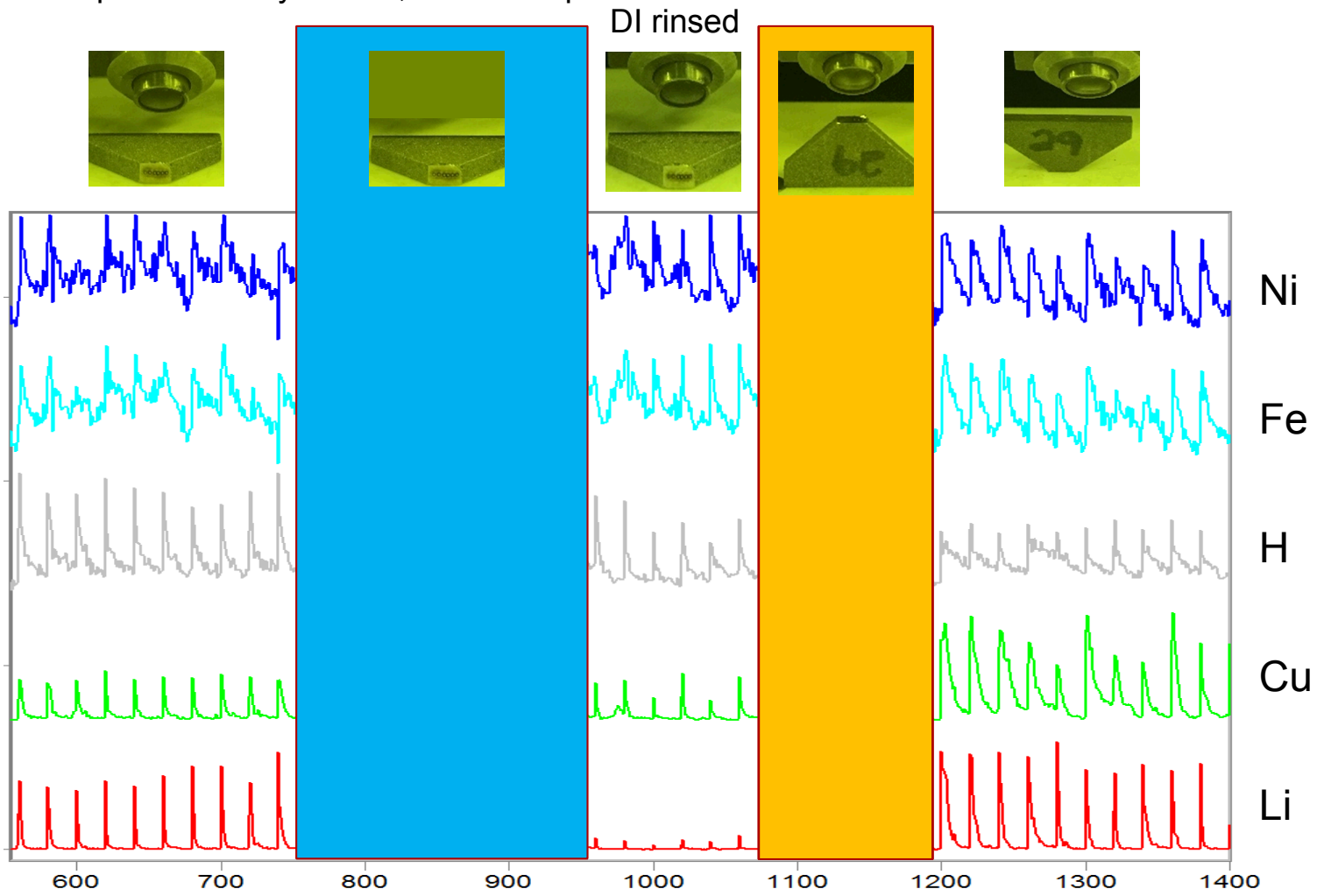
Compare Li signal various samples



Wavelength (nm)

Taking multiple shots and digging deeper

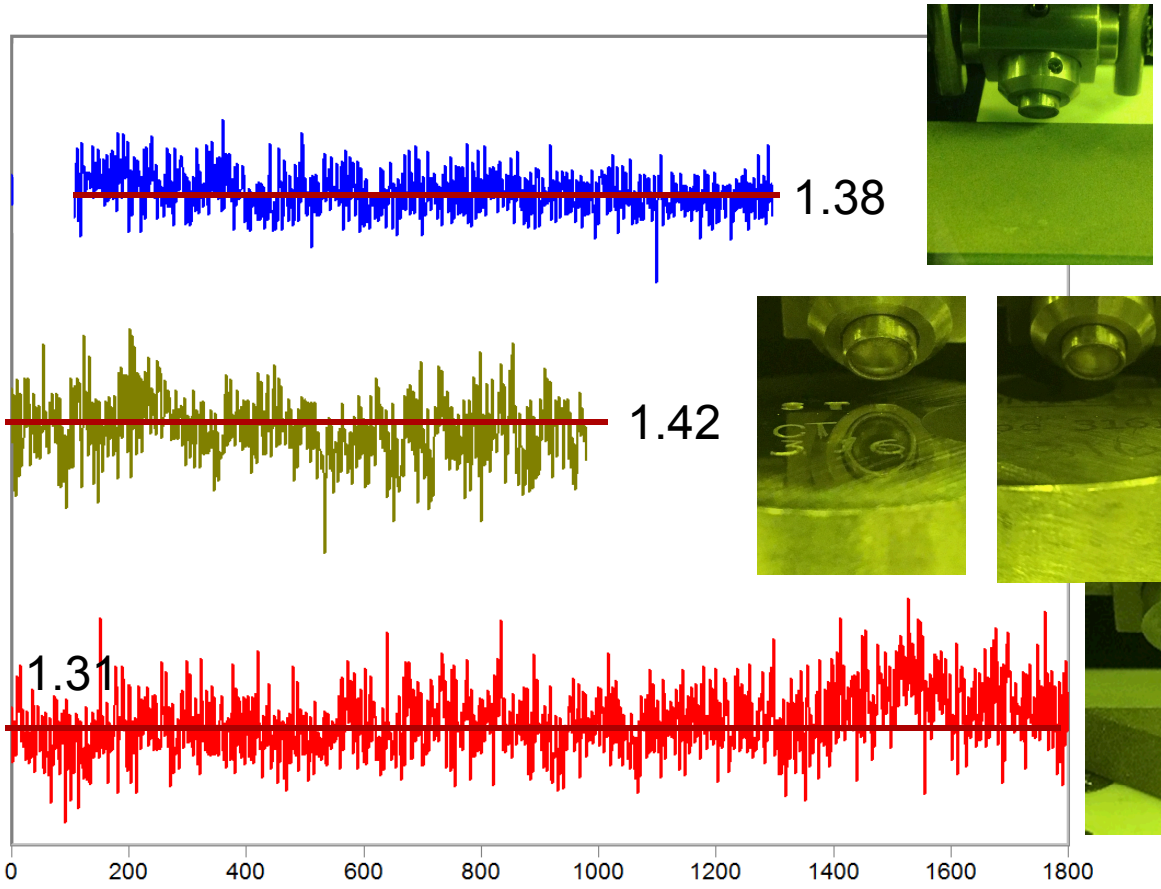
Raw peak intensity shown, 20 shots/spot.



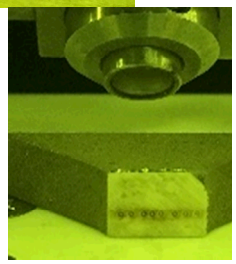
DI rinsed: 18Mohm water ~5min

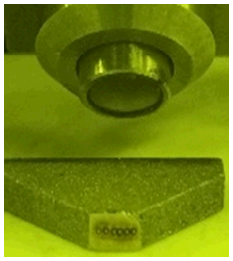
Comparing AM to wrought standards

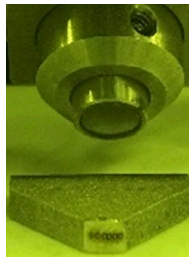
Ni (361nm) to Fe (375nm) signal ratio



12.86% avg. certified







Summary conclusions

- Additive manufacturing has bright future
- Control is key, now and tomorrow
- Predictable performance will rely on many factors
- LIBS can measure many different elements
  - Rapidly and without preparation
  - With little damage
- LIBS could provide data and contribute to
  - Understanding of AM
  - Control of AM