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# Tailoring Mechanical Properties in Ti-6Al-4V

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# Engineering Goals

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As-printed parts exhibit varying mechanical properties depending on the loading direction.

- Post-processing is required
- Hot isostatic press (HIP) removes anisotropy

## Engineering Goals:

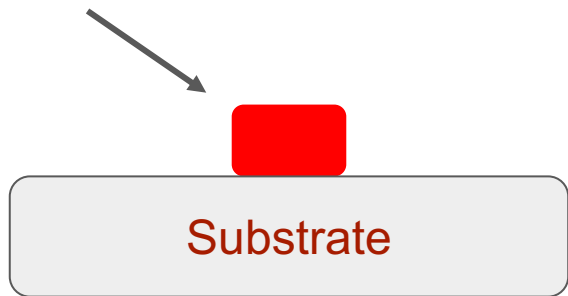
- Obtain desired mechanical properties as-printed
- Utilize mechanical anisotropy for tailoring mechanical responses



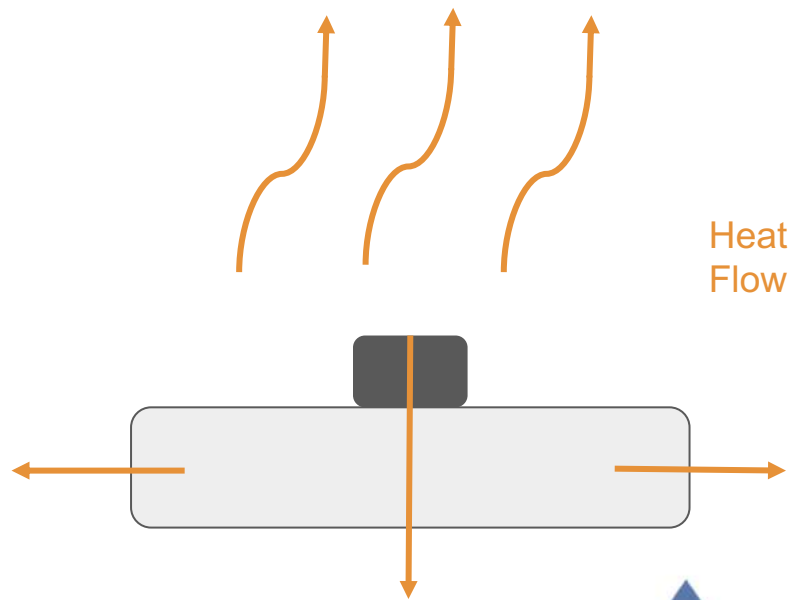
# Thermal Cycling

1st Layer

Molten



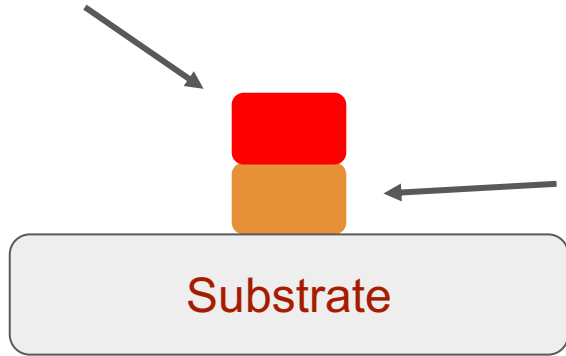
Cooling



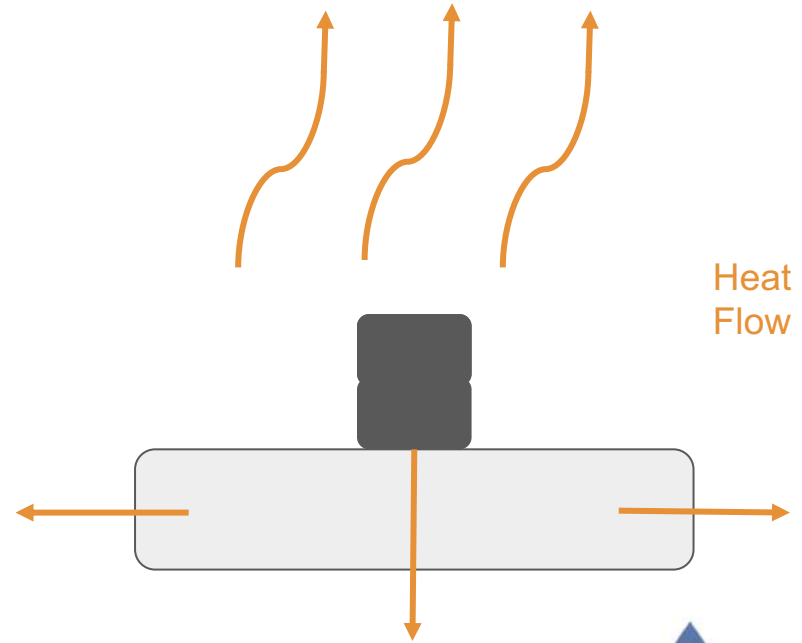
# Thermal Cycling

2nd Layer

Molten



Cooling

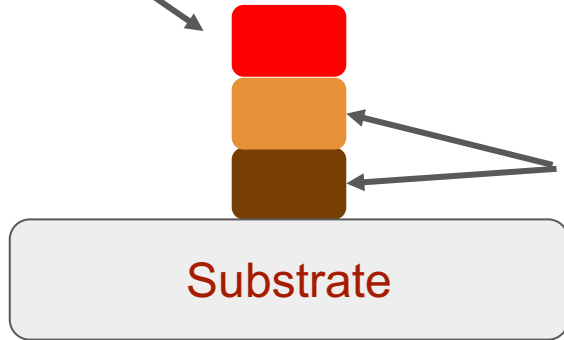


# Thermal Cycling

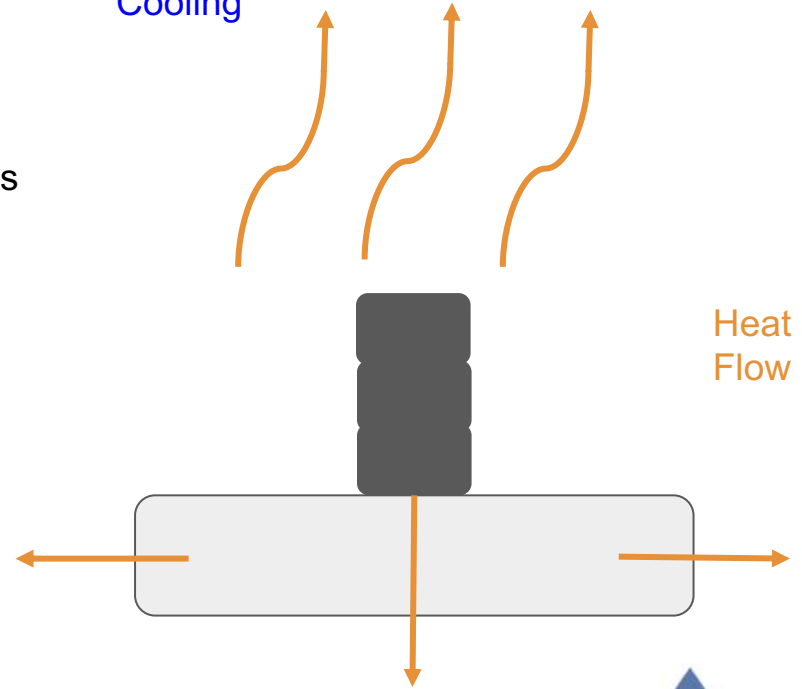
3rd Layer

Underlying layers are being thermally cycled as printing occurs.

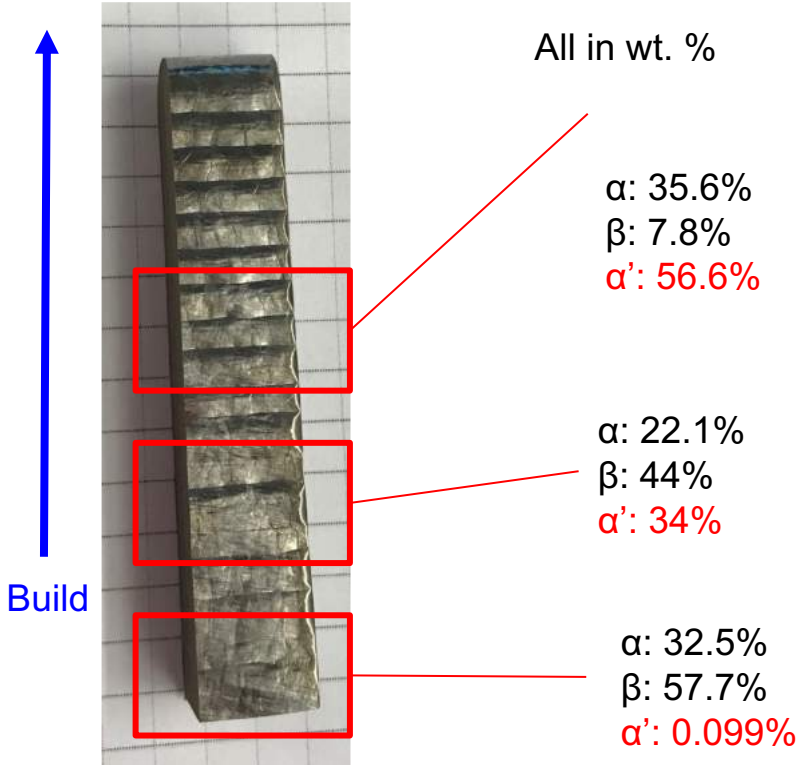
Molten



Cooling



# Thermal History in AM: Phase formation



Martensite phase fraction increases with build direction

Mostly  $\alpha$ : Higher ductility, lower UTS<sup>1</sup>  
Equiaxed  $\alpha/\beta$ : Lower ductility, higher UTS<sup>1</sup>  
Columnar  $\alpha/\beta$ : Middle<sup>1</sup>



# No Need to Reinvent the Wheel

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## Solidification with different thermal gradients

- Impacts types of phases that form
- Impacts mechanical anisotropy
- Well characterized process

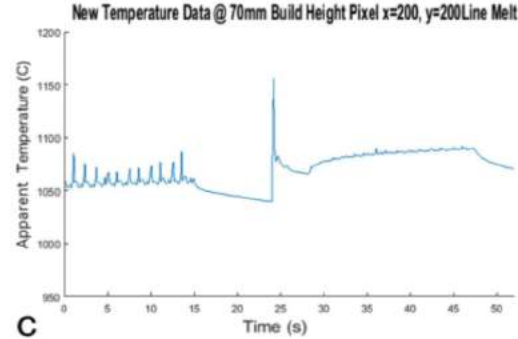
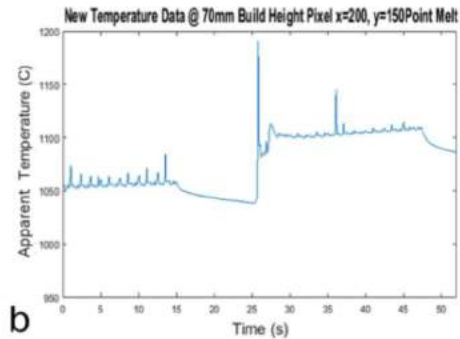
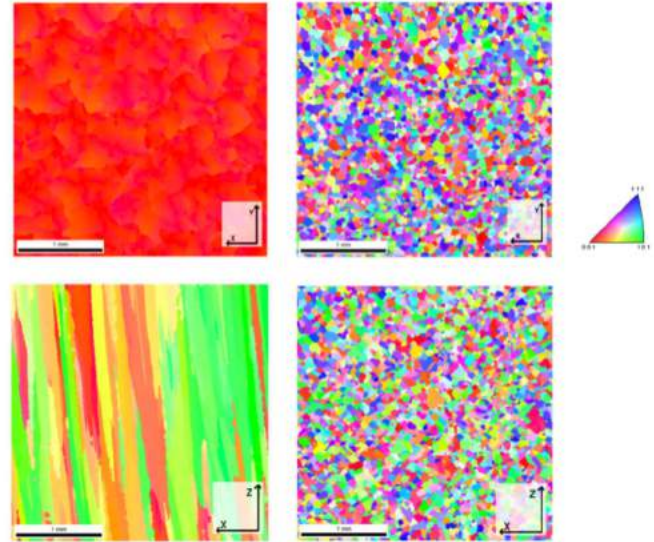
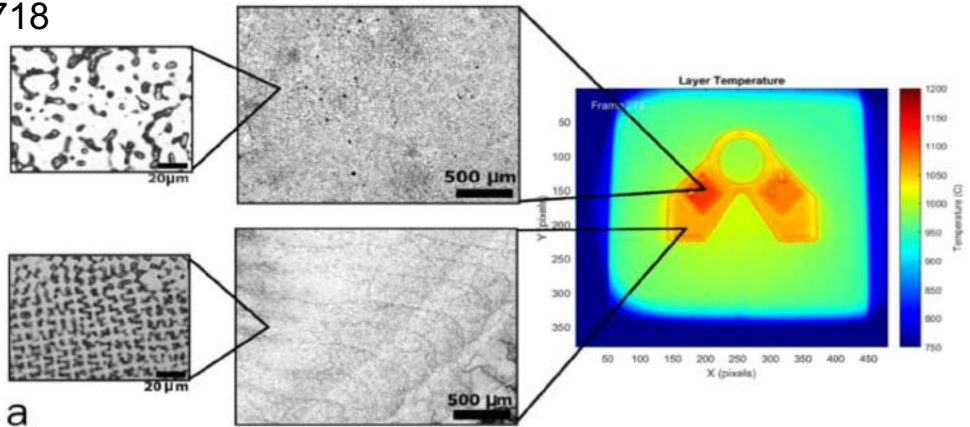
## Solid state transitions due to thermal cycling

- Causes formation of martensite
- Impacts mechanical anisotropy
- Well characterized process



# No Need to Reinvent the Wheel

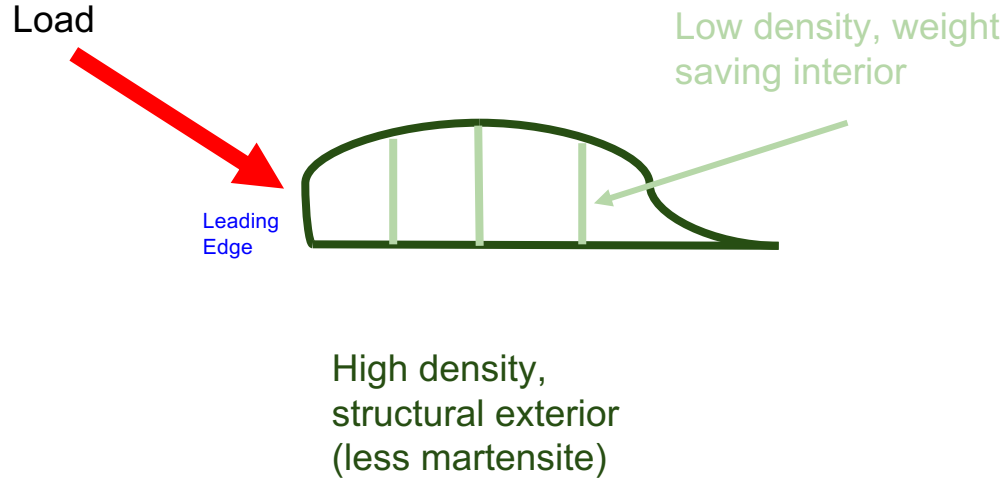
IN718



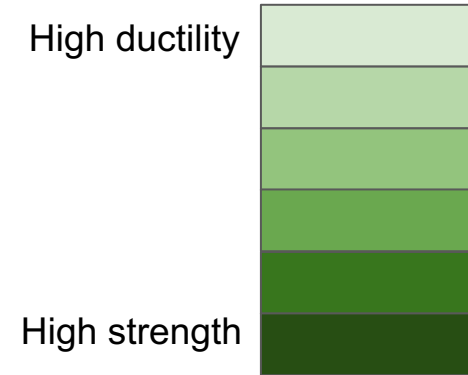


# Applications

Control density, save weight



Spatially graded properties



# Future Steps

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## Progress to date:

- Understand how thermal cycling impacts mechanical properties for simple geometries
- Characterized microstructure of as-printed parts
- Begun formatting data for use with Citrination

## Next steps:

- Measure thermal gradients, heat flow and radiation
  - Necessary for engineering the microstructure
- Build parts with different geometries
  - Need to understand how heat flow direction impacts an/isotropy
- Use Citrination to predict manufacturing conditions
  - Electron beam dwell time, deposition rate, cycling between depositions, etc.

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Thank You.



# Experimental Outline

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## Degrees of Freedom:

- Bead diameter (boundary condition)
- Wall height (boundary condition)
- Deposition rate
- Time between deposition
- Location of deposition (relative to other layers)
- Others?

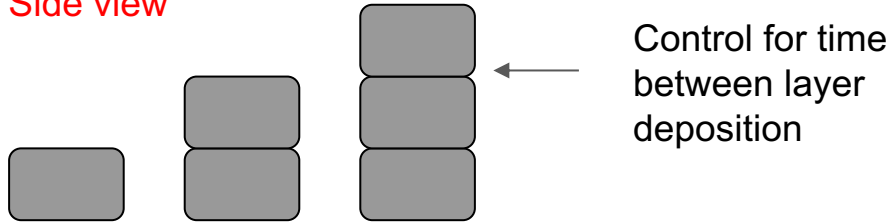
## Measurables:

- Instantaneous temperature
- Instantaneous thermal gradient
- Temperature history
- Thermal gradient history
- Phase fraction
- Texture
- UTS
- Ductility
- Others?

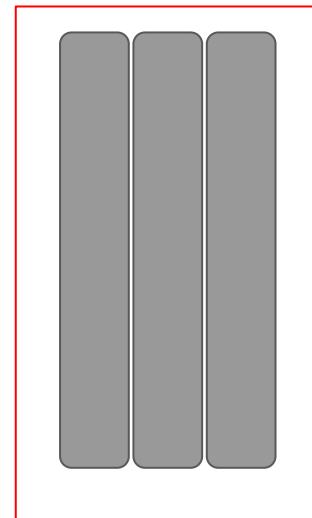
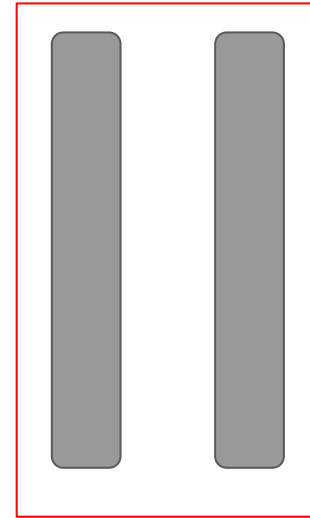
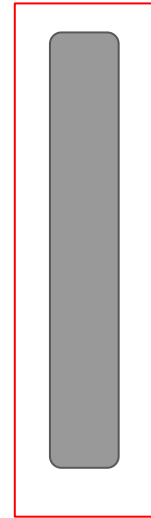
# Experimental Outline - Builds

## First Round of Data

### Side view



3 Builds, different number of layers in each build (allows us to assess how thermal cycling impacts phase fraction, texture).



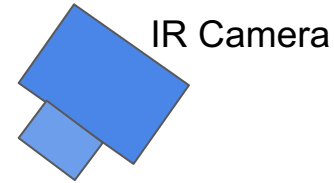
### Top view

# Experimental Outline - Monitoring

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3 conduction modes:

- absorption
- reflection
- transmission



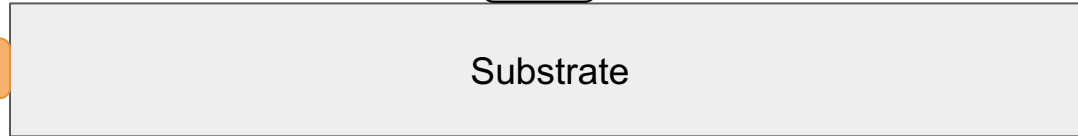
IR Camera

Record reflected and transmitted temperature, obtain qualitative idea of local energy density



Substrate

Thermocouple



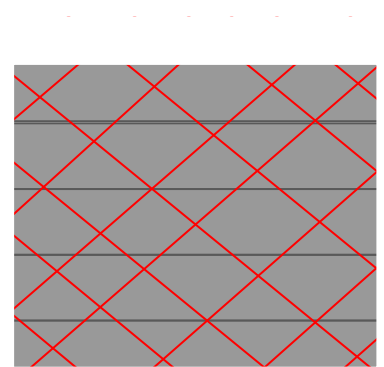
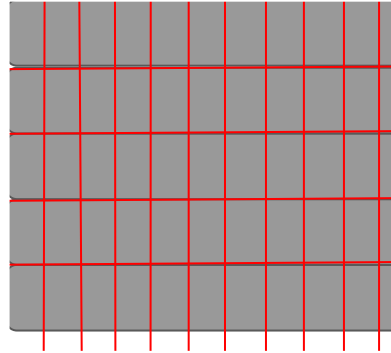
# Experimental Outline - Post Measurements

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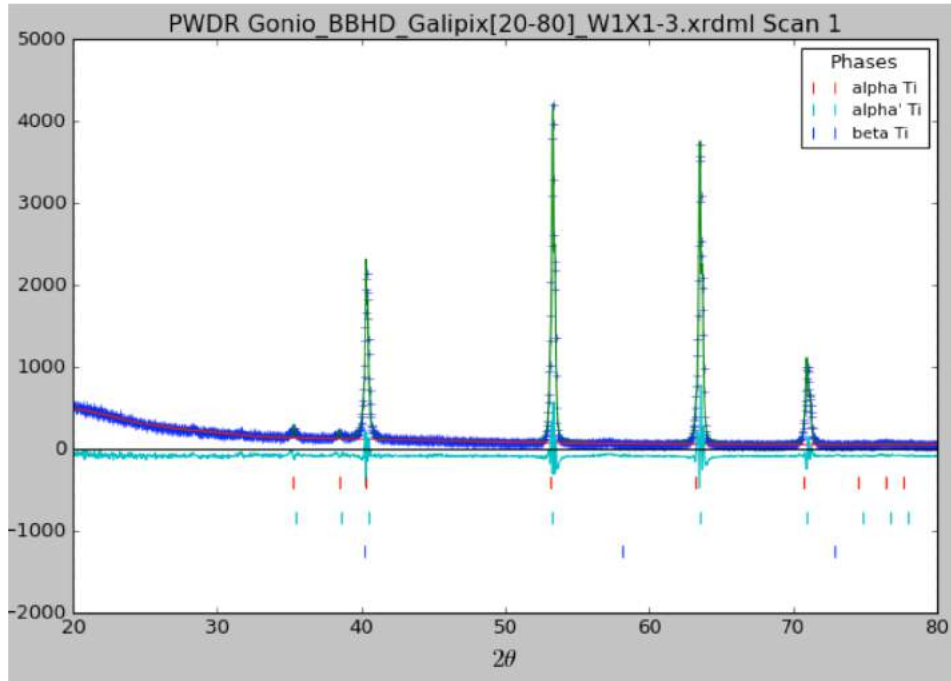
- Chop builds in grid
- XRD to obtain phase fraction, texture

Train a Citrination model on sample location, phase fraction, majority orientation, integrated thermal history\*, time between deposition, manufacturing parameters (bead size, deposition rate).

Use model to suggest deposition locations, deposition rate, time between deposition, and laser energy.



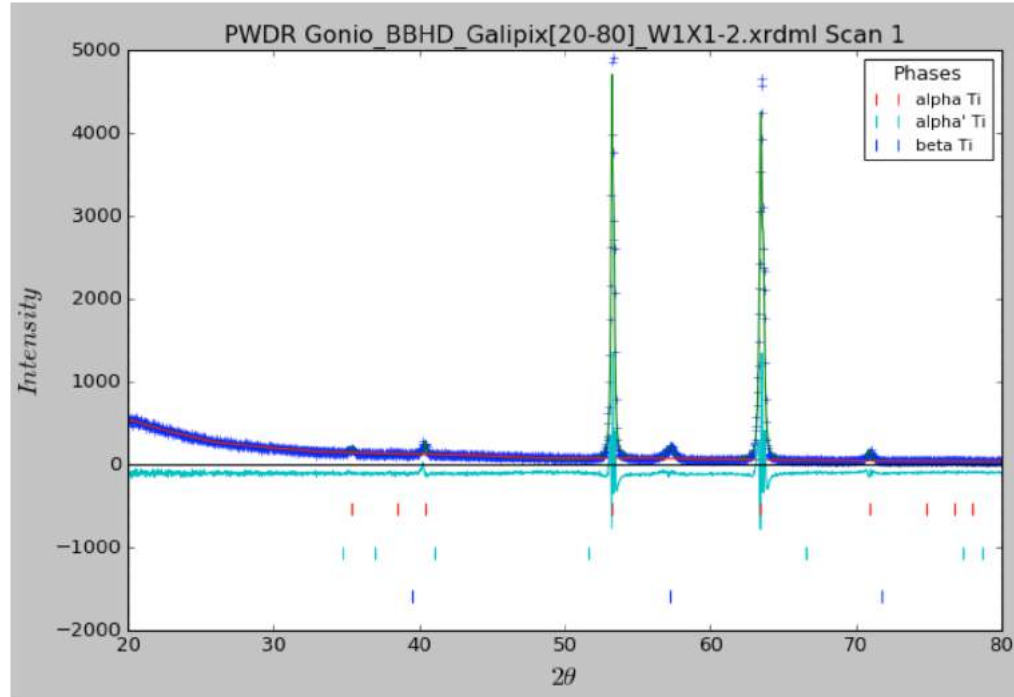
# Thermal History in AM: Phase formation



Scan parameters:  
20-80° 2θ  
0.028° step size  
150s dwell time  
Cu  $k\alpha$  radiation

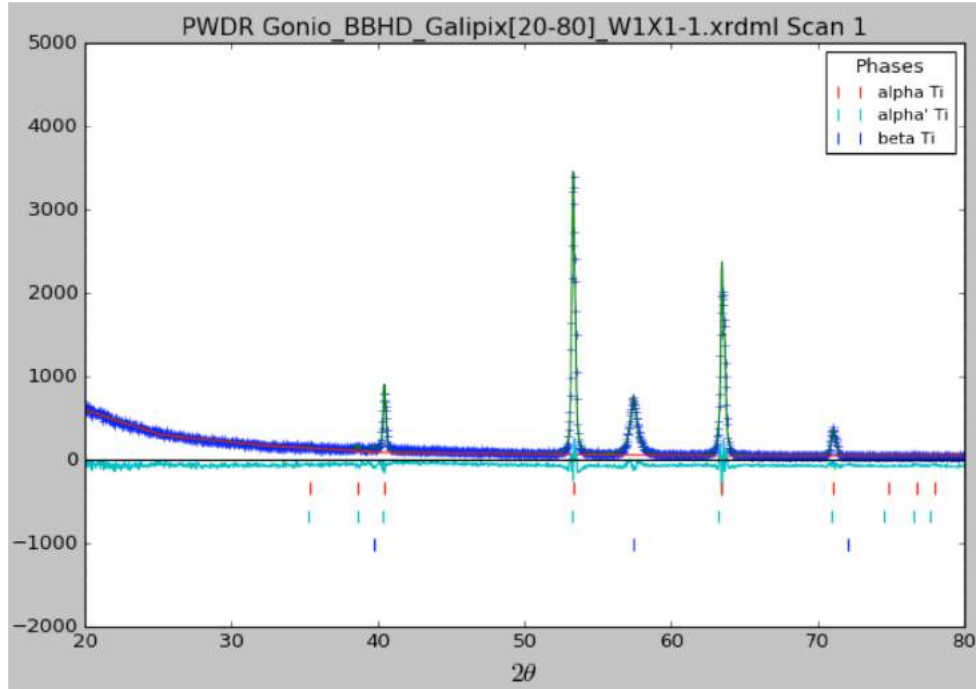


# Thermal History in AM: Phase formation



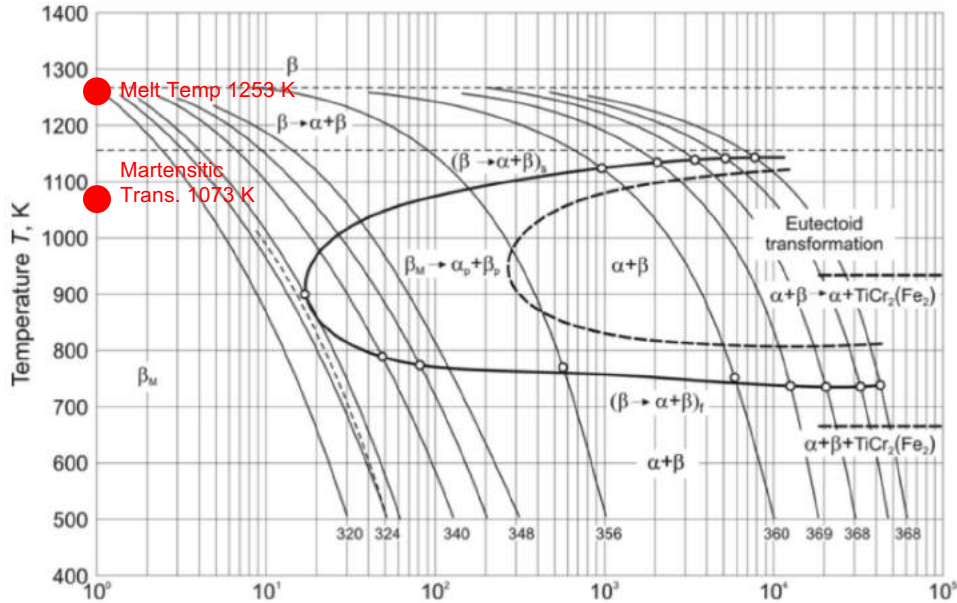
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# Thermal History in AM: Phase formation



Scan parameters:  
20-80°  $2\theta$   
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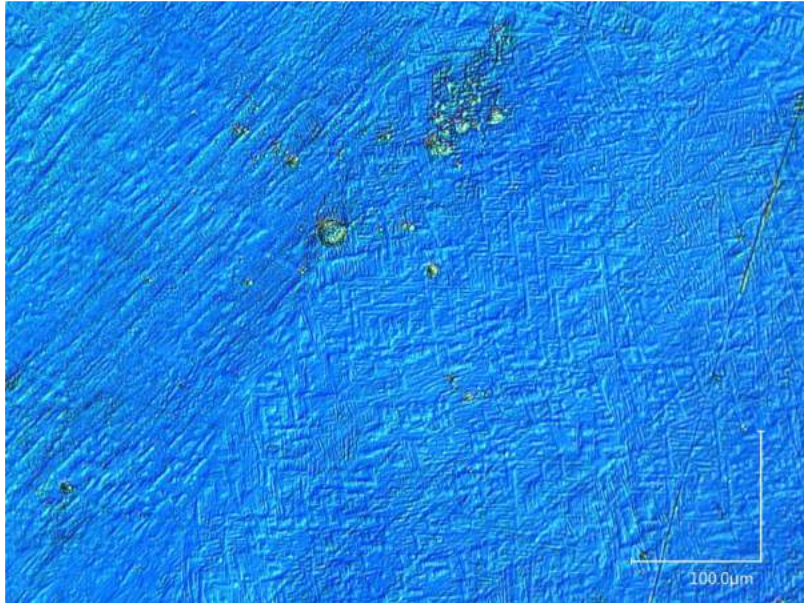
# Thermal History in AM - Phase Formation



Hypotheses:

- Continual heating and re-heating of previous layers causes  $\beta \rightarrow \alpha/\beta$  transition
- Martensite fraction increases with build height due to lack of thermal cycling

# Thermal History in AM - CET



Top



Bottom

IN718

