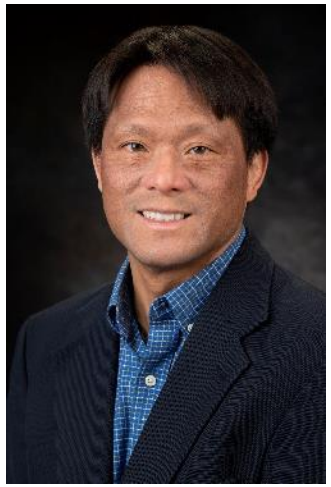
Melt Pool Imaging using a Configurable Architecture Additive Testbed System



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Outline

- Introduction/Motivation
- Configurable Architecture Additive Testbed (CAAT)
  - Overall Description
  - Calibration of Near Infrared (NIR) Camera
- Measurement Results
  - Melt Pool Imaging on Ti-6Al-4V Plate
  - Comparison to Optical Microscopy
  - Preliminary Modeling Results
- Conclusions

Introduction

Objectives

• Investigate the use of a low cost in-situ near infrared (NIR) sensor for real time measurement of the thermal history for improved additive manufactured builds.

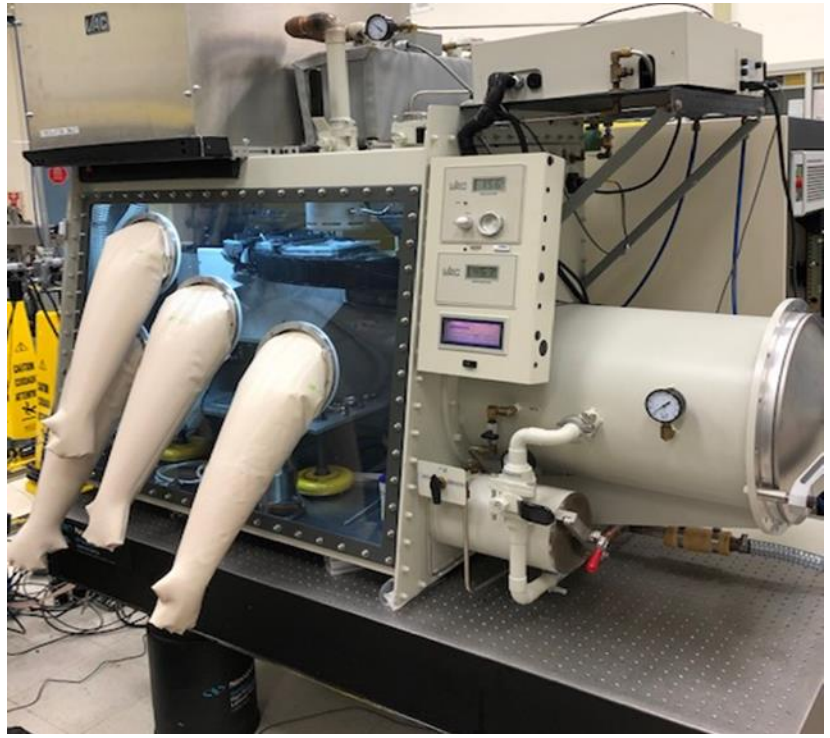
• Calibrate the NIR sensor and investigate the measured melt pool size based on varying process parameters.

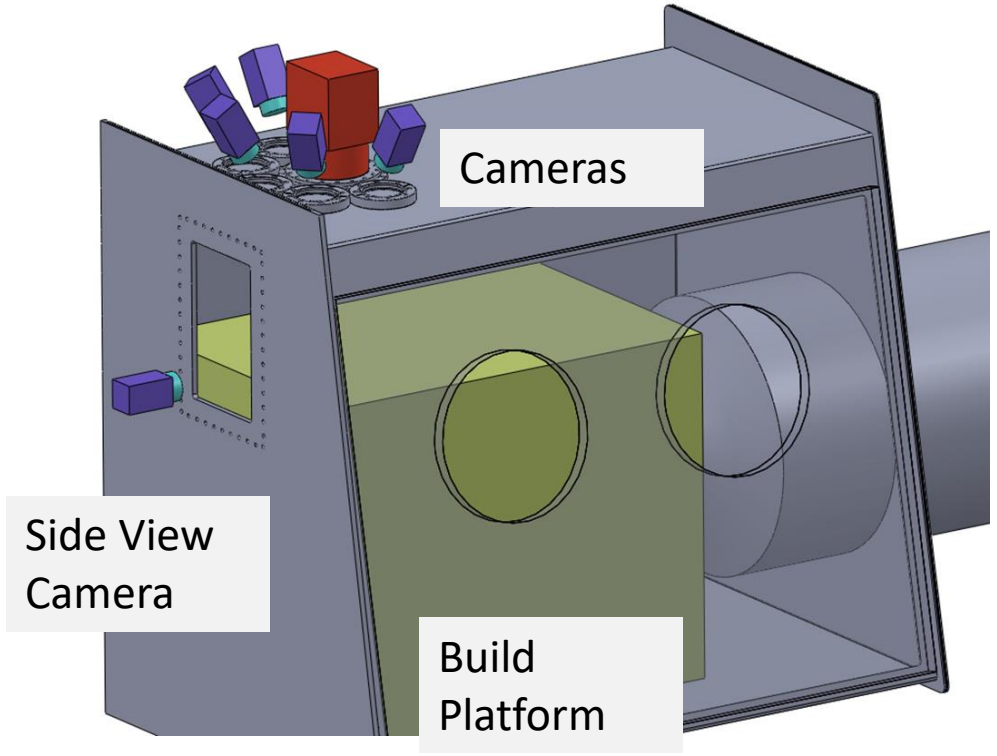
• Compare the melt pool width with optical microscopy measurements and perform initial comparison to modeling results.

Payoffs

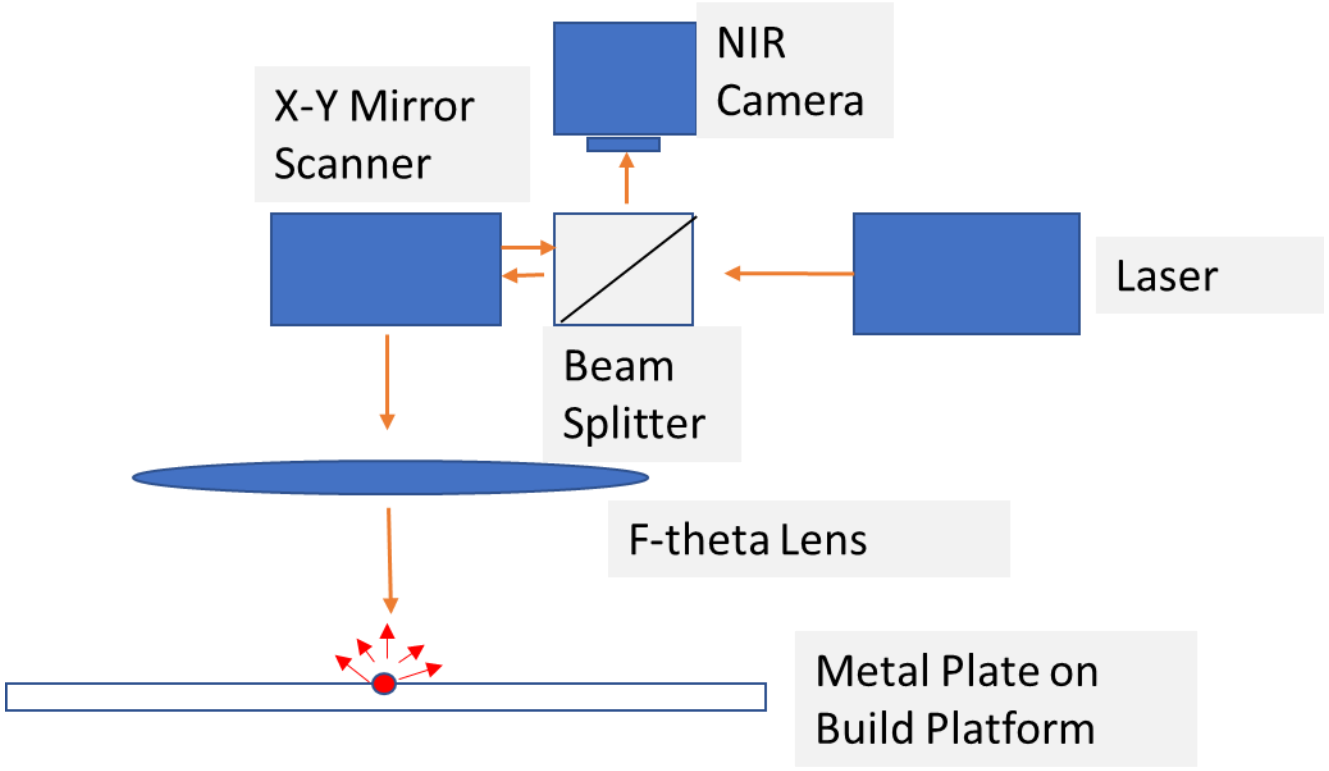
• Additively manufactured parts must be certified for broad application onto aircraft structures. By documenting the thermal history process parameters for microstructure can be evaluated and real time inspections can be performed during the AM build. These results can be used to validate thermal models.

Configurable Architecture Additive Testbed (CAAT)

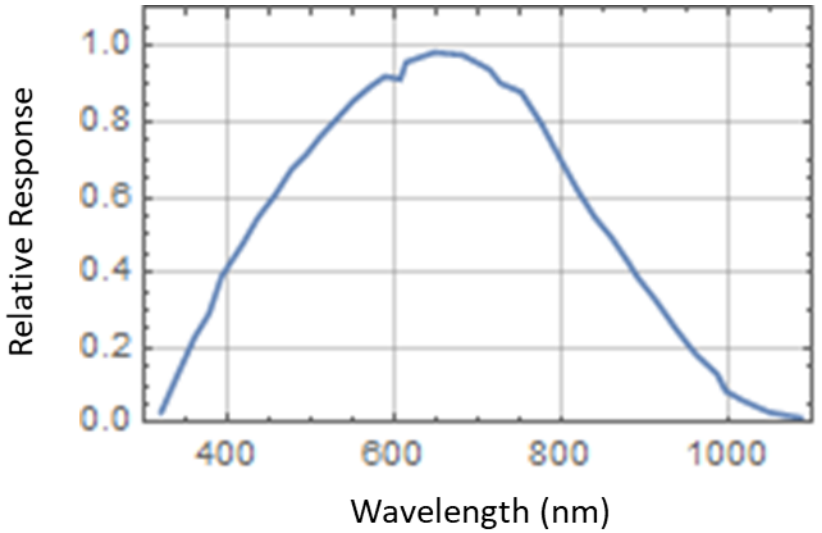




Co-axial NIR Optical Path



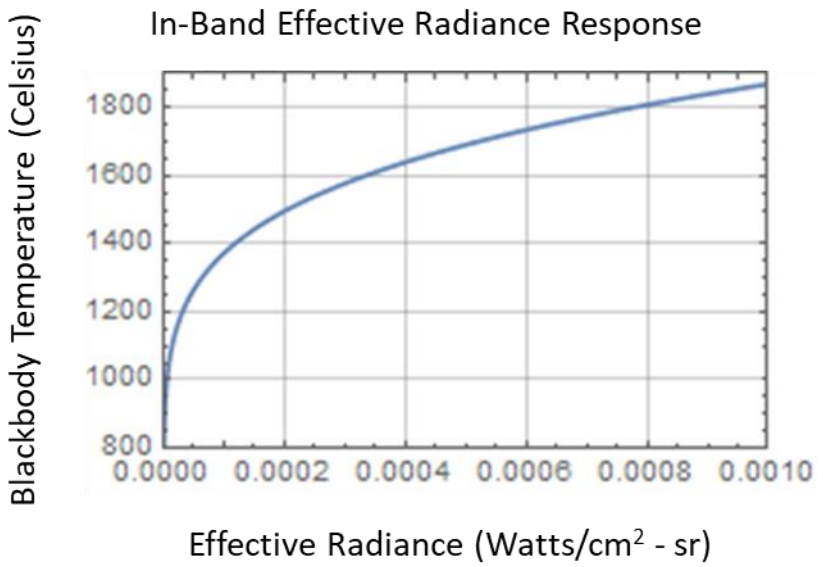
Basler acA640-750m



• NIR camera has 640 x 480 FPA, maximum frame rate = 751 Hz, pixel pitch is 4.8 x 4.8 um, configured with focusing optics and 880 nm narrow bandpass filter (875-884nm), resolution approximately 11 microns, ROI for images 144 x144, and provides frame rate of approximately 2,000 Hz.

Effective Radiance

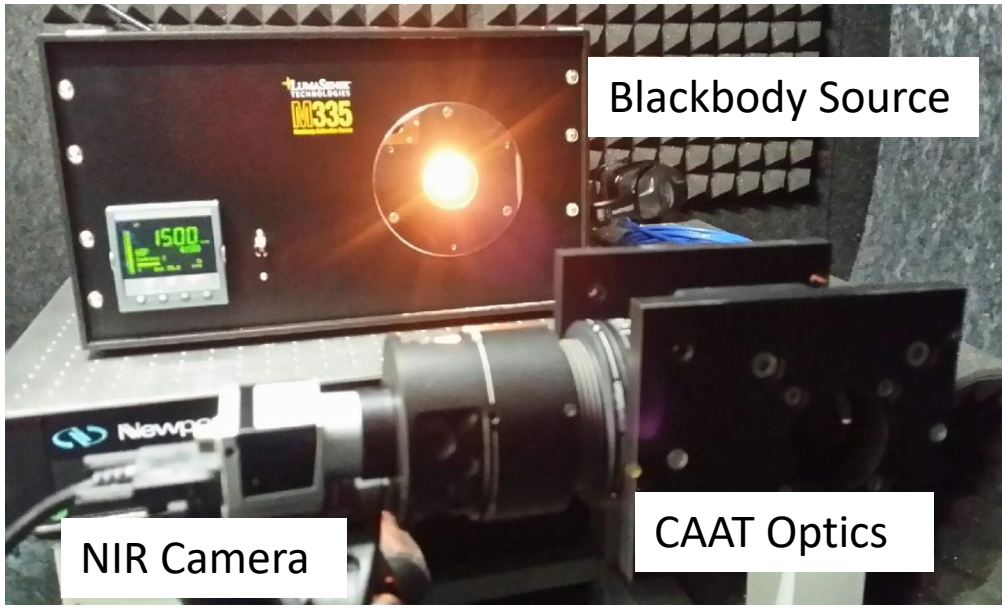
$$Radiance = \int_{\lambda_1}^{\lambda_2} \frac{c_1}{\lambda^5 \left(e^{\frac{c_2}{(\lambda\,(T+273.15))}}\right)} * sensor(\lambda) * filter(\lambda) * d\lambda \quad \text{where } c_1 = 2 * h * c^2 \quad \text{and} \quad c_2 = \frac{h * c}{k}$$



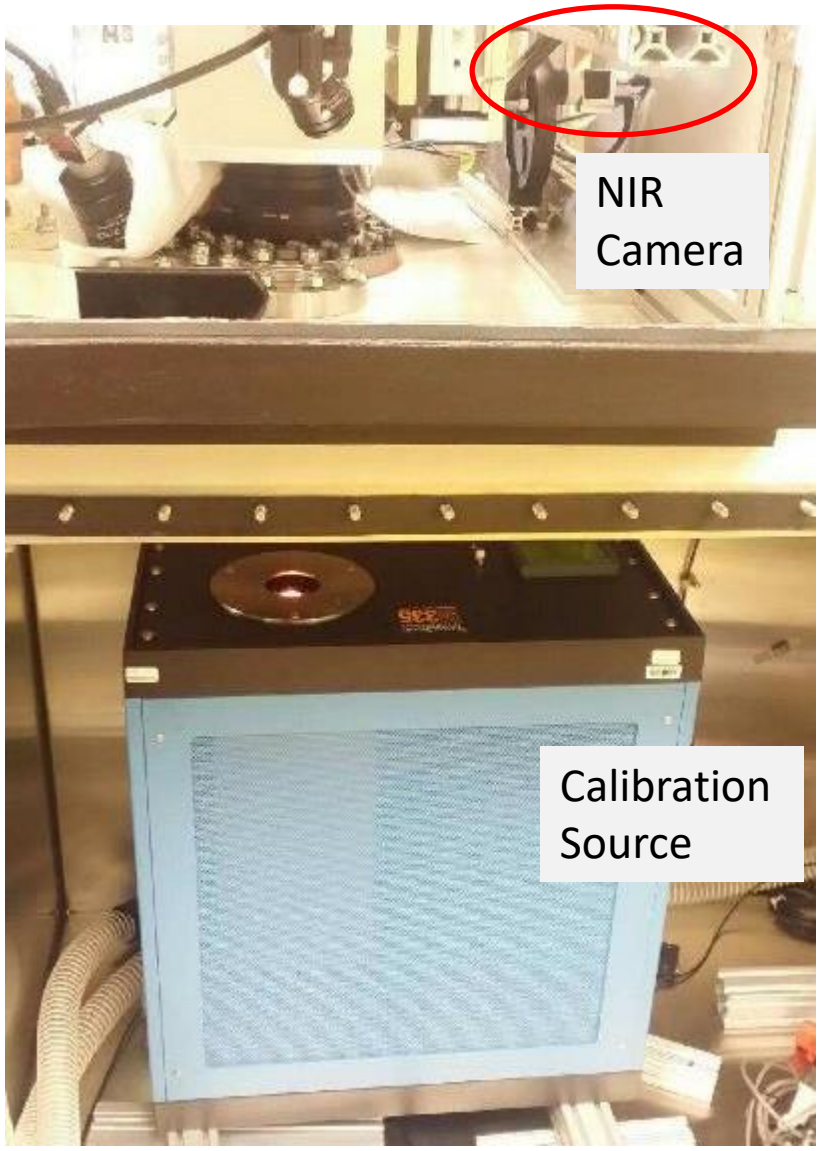
- Spectral band 875 to 884 nm defined by the 880 nm narrow bandpass filter.

Calibration of NIR Camera

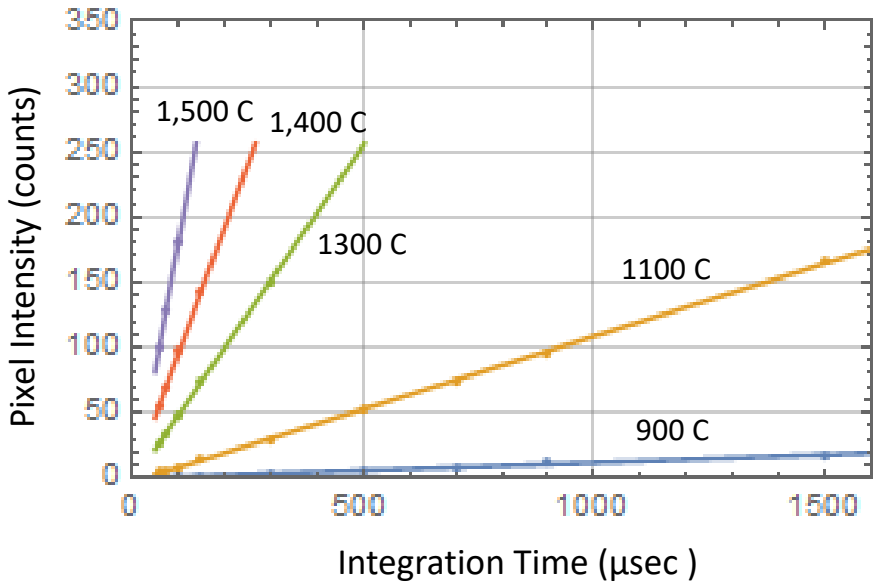
Primary Configuration

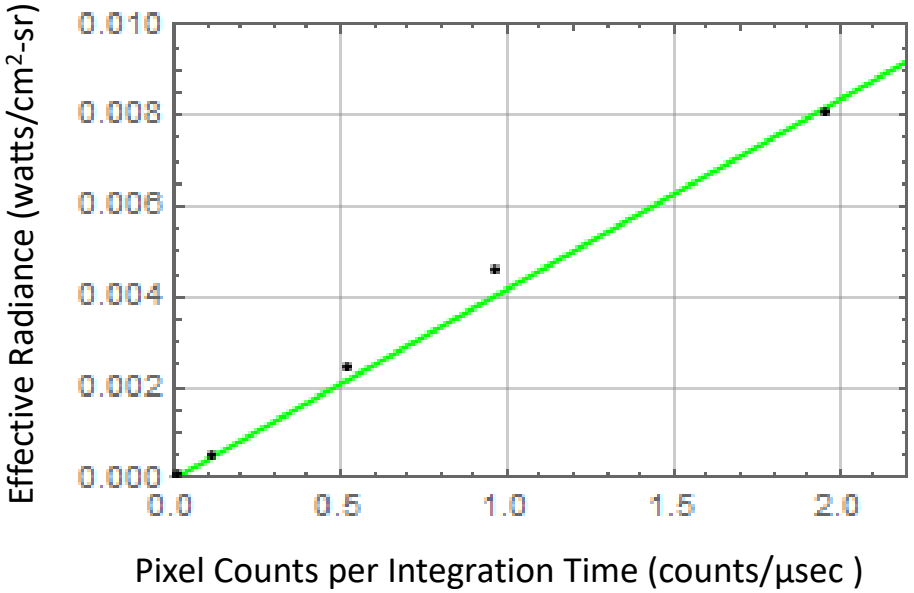


New Configuration



NIR Camera Calibration Results



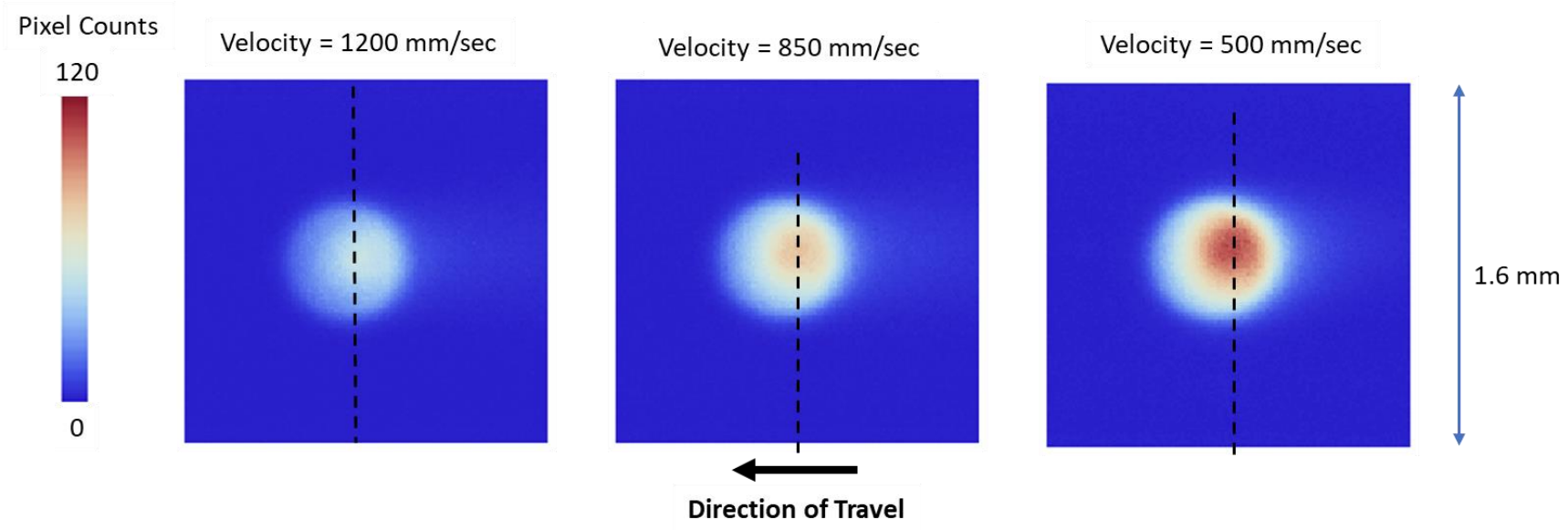


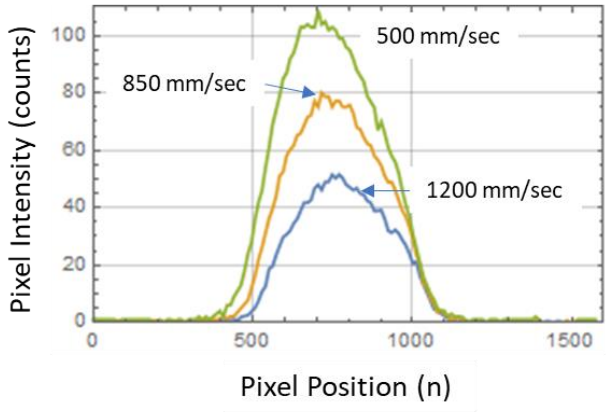
Ti-6Al-4V Plate for Laser Heating

2.5 cm

Analysis of images taken at center of scan track.

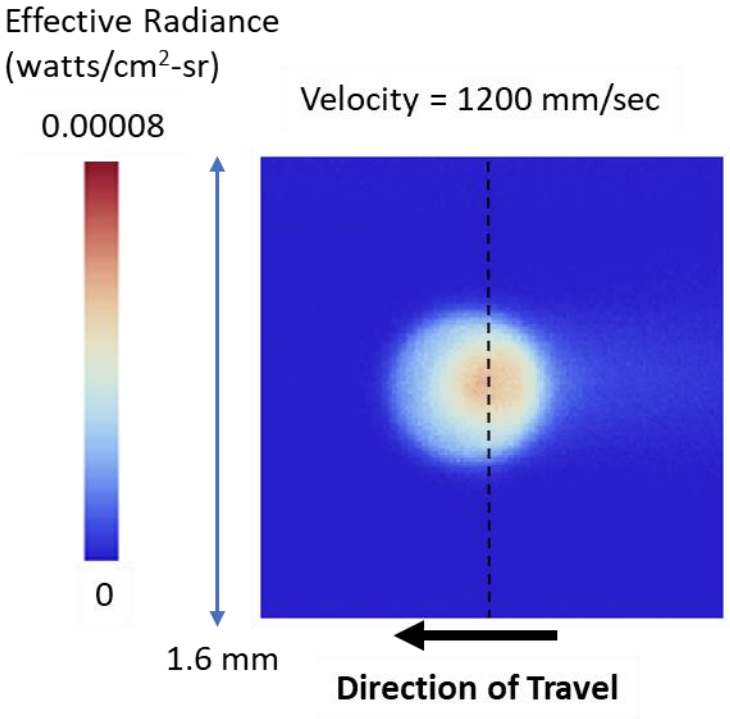
Melt Pool Imagery

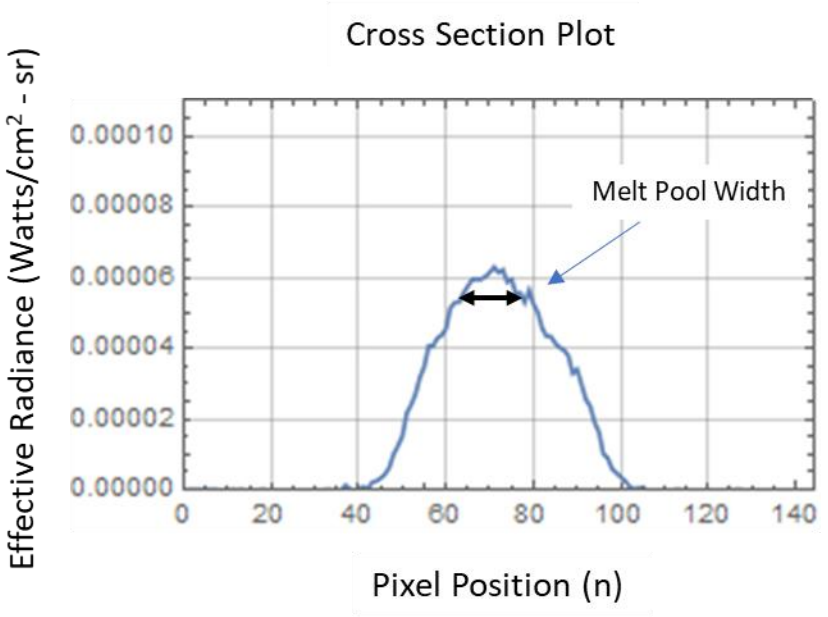


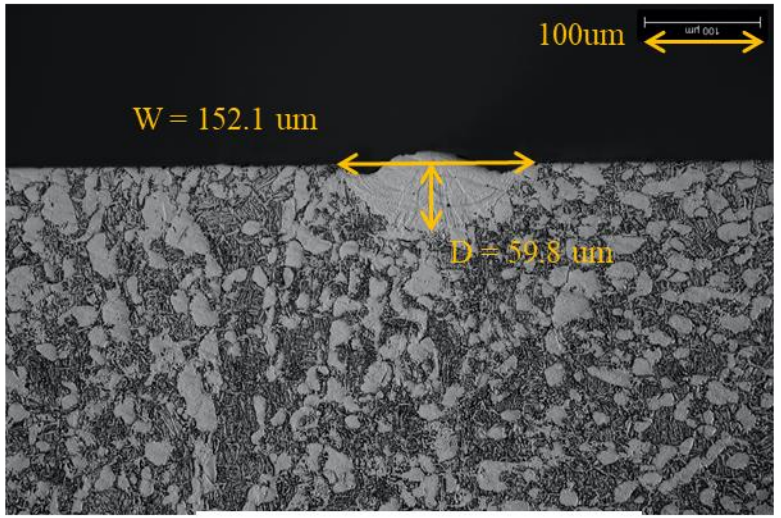


- Images were acquired at approximately 2,000 Hz with integration time of 100 us.
- Laser power was set to 280 Watts.

Counts to Radiance with Comparison to Optical Microscopy – 1200 mm/sec Velocity

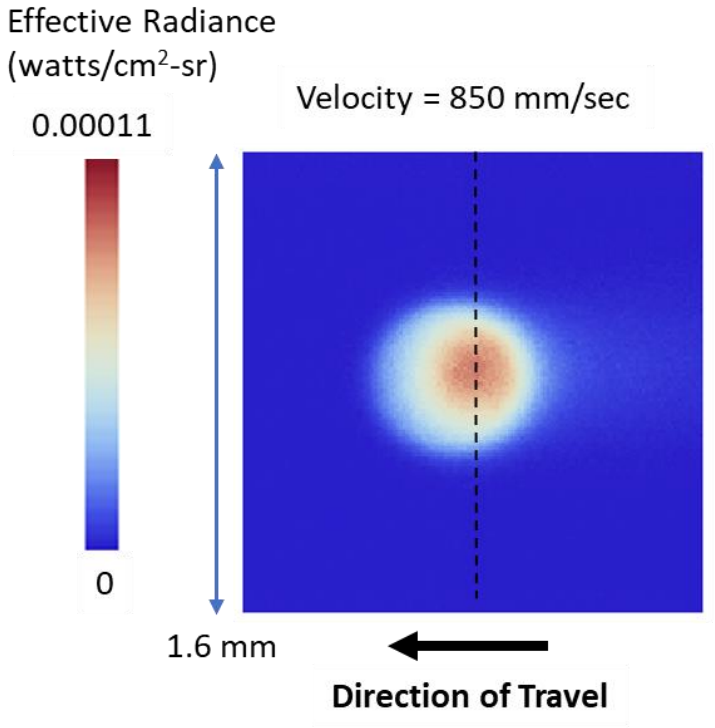


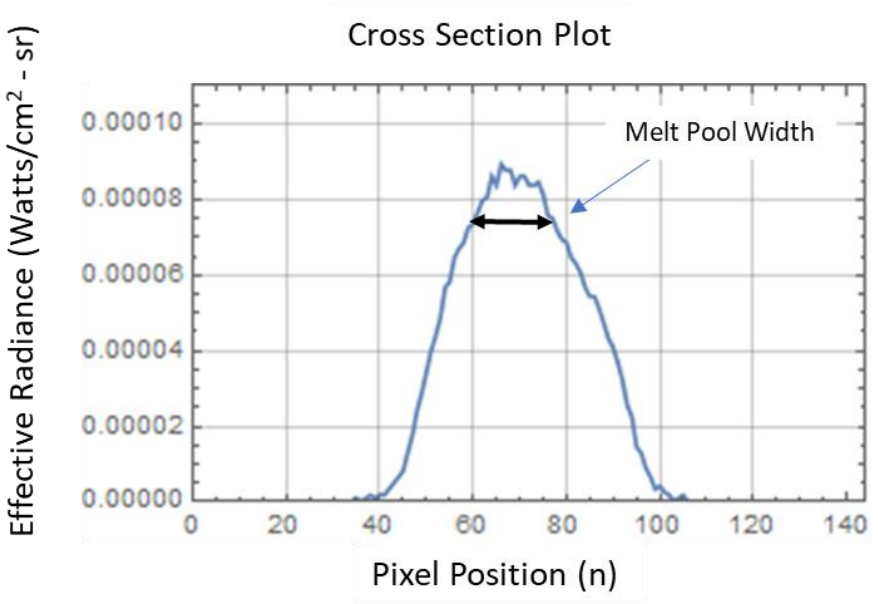


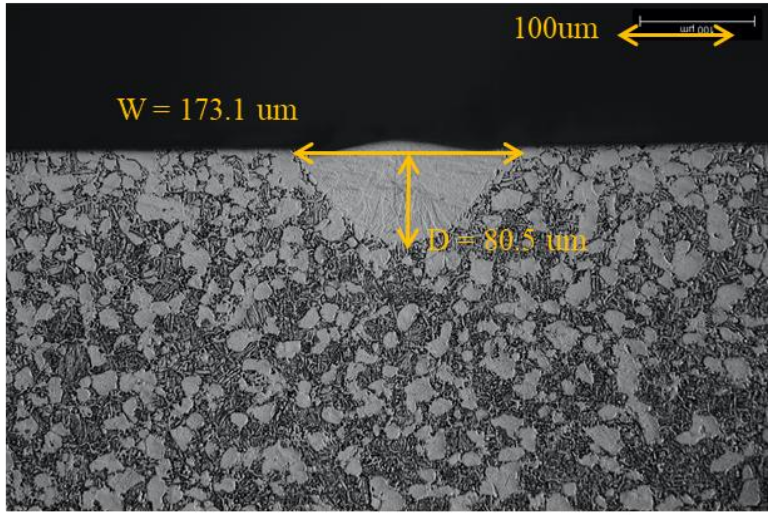


Cross Section Micrograph

Counts to Radiance with Comparison to Optical Microscopy – 850 mm/sec Velocity

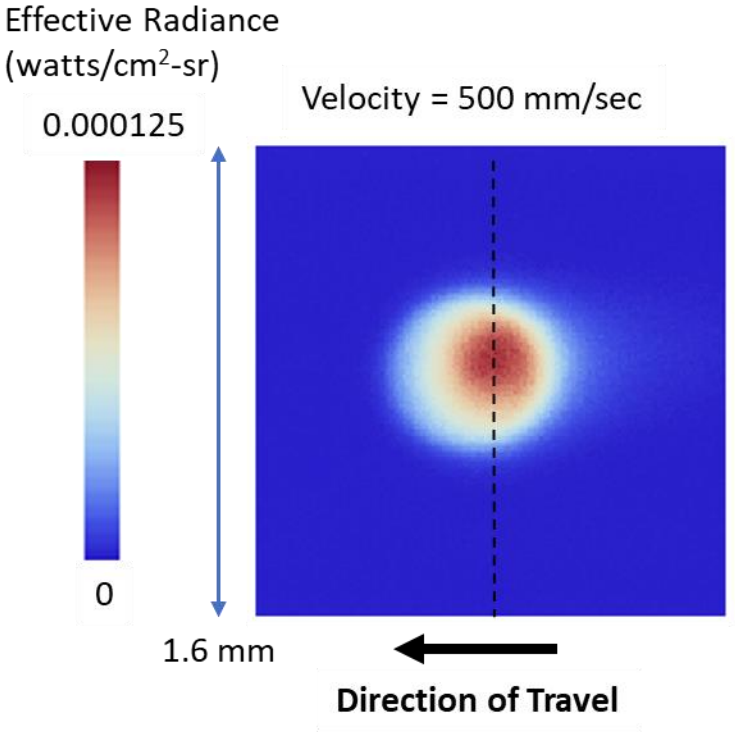


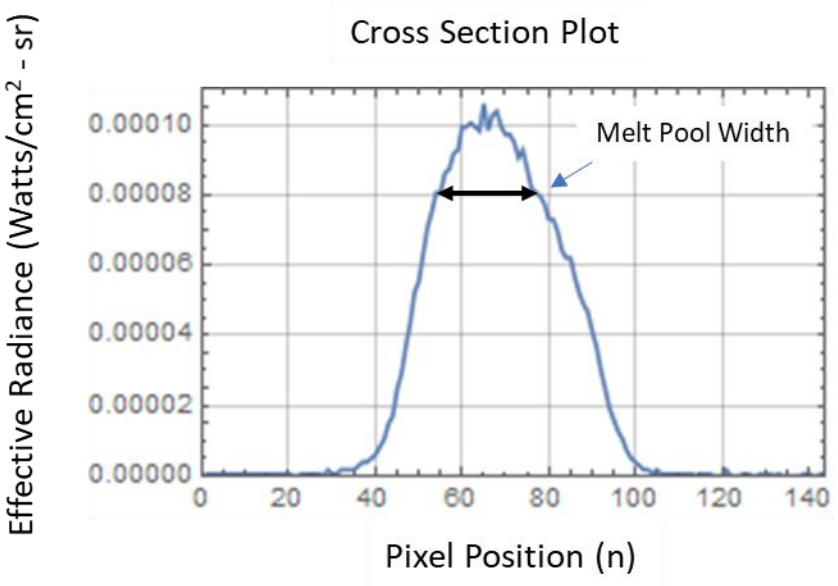


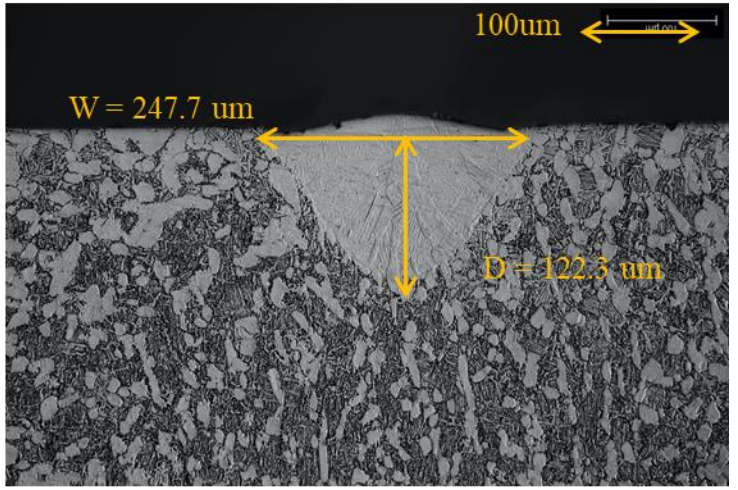


Cross Section Micrograph

Counts to Radiance with Comparison to Optical Microscopy – 500 mm/sec Velocity





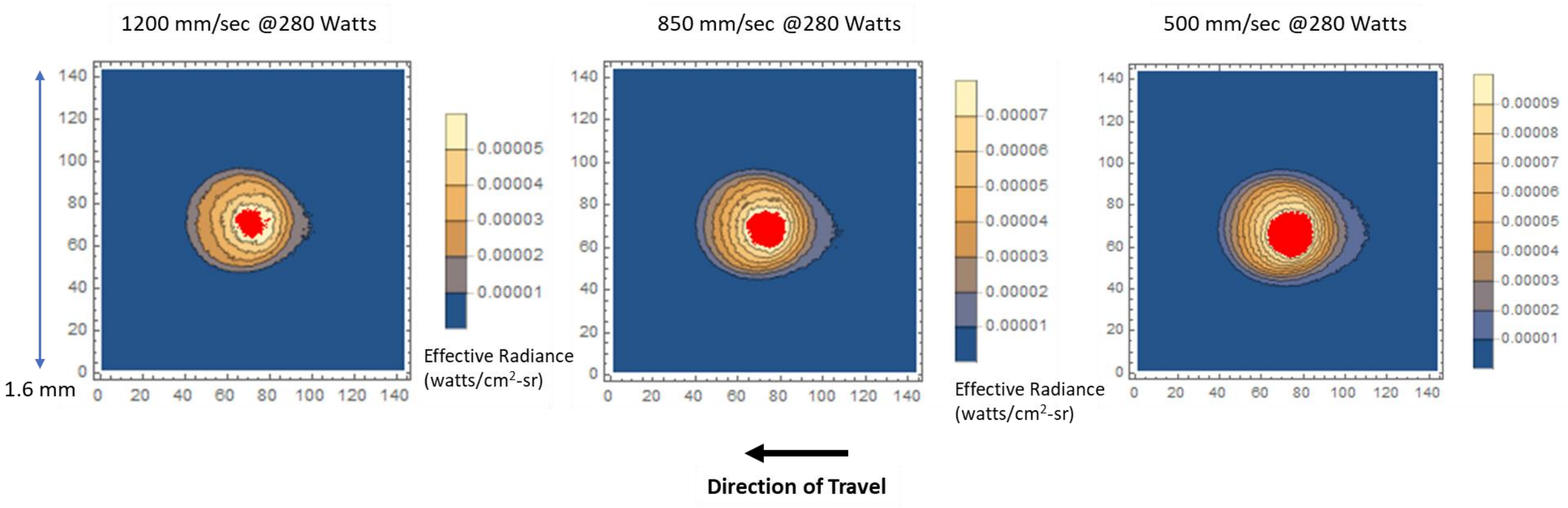


Cross Section Micrograph

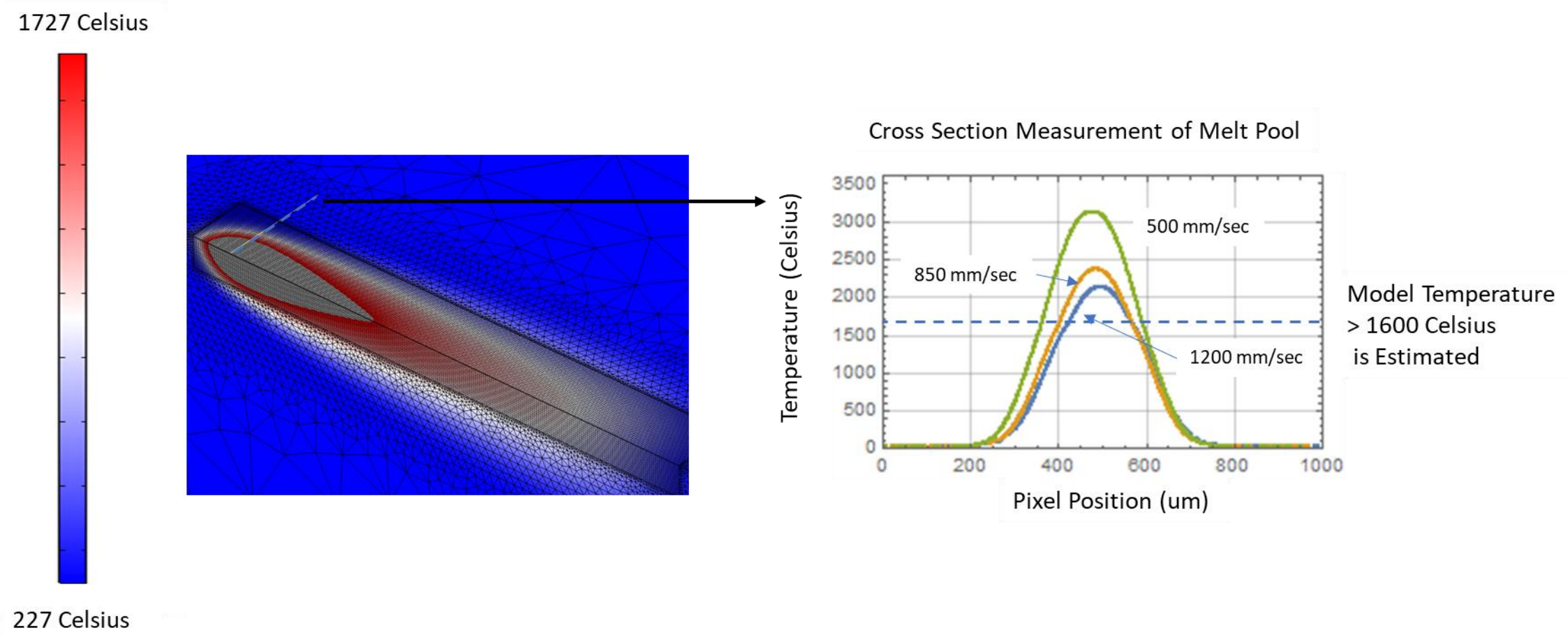
Conversion to Emissivity

Laser Scanning Speed (mm/sec)	Melt Pool Width (Pixels)	Thermal Radiance Value (Watts/cm² – sr)	Emissivity Value @ 1604 Degrees Celsius
1200	14 +/- 3	$5.2 \times 10^{-5} \pm 0.04 \times 10^{-5}$	0.15 +/- 0.005
850	16 +/- 3	$7.4 \times 10^{-5} \pm 0.04 \times 10^{-5}$	0.22 +/- 0.005
500	23 +/- 3	$8.1 \times 10^{-5} \pm 0.04 \times 10^{-5}$	0.24 +/- 0.005

Contour Plot of the Melt Pool

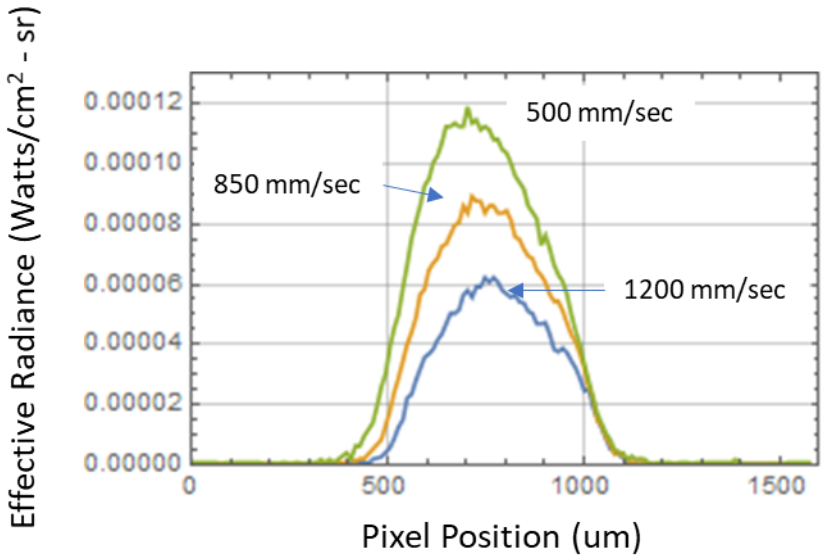


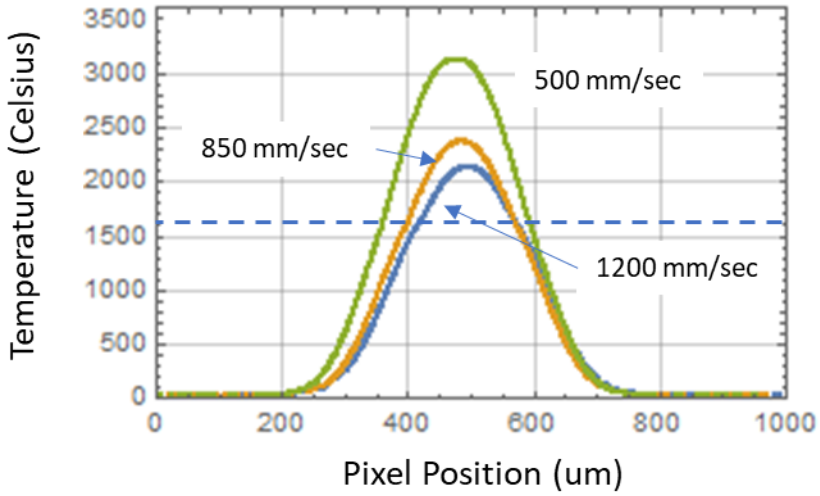
Finite Element Modeling of Surface Temperature



- The COMSOL model uses a volumetric heat source and was calibrated to the optical microscopy measurements. The gray center in the middle shows the melt pool and semi-solid regions.

Preliminary Comparison of Measured Radiance to Model for Melt Pool Width

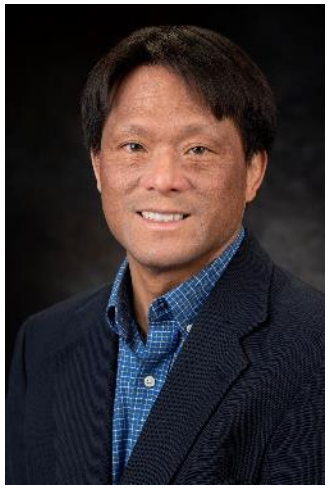




Model Temperature
> 1600 Celsius
is Estimated

Conclusions

- A low cost NIR camera was calibrated and used to measure the width of the melt pool on a Ti-6Al-4V plate.
- Optical microscopy measurements were used to calibrate the NIR melt pool width and was necessary to determine emissivity at the solidus boundary of the melt pool.
- The emissivity variation was not expected and may be due to geometry effects within the melt pool before solidification or perhaps reflection from the laser source.
- Future work will involve expanding the imaging band from 850 - 1000nm, investigate a dual camera pyrometry setup and the addition of a notch filter at the laser wavelength.



Thanks for your attention.

Questions?