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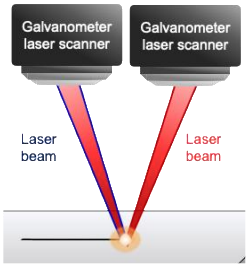
Dynamic Beam Shaping in Laser Material Processing

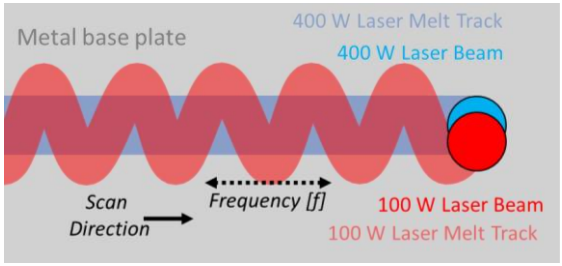
Challenge/Motivation:

- Laser manufacturing enables localized energy input to achieve precise processing of metals. However, the rapidly changing thermal and fluid interactions lead to instabilities and defects, making process control difficult.

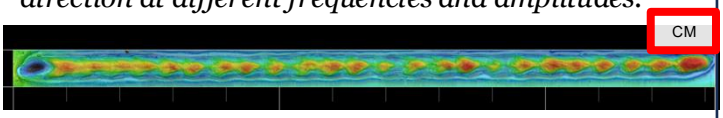
→ *Spatial and temporal laser beam energy modulation enables dynamic control of material response.*

Developed a self-built dual-laser beam setup to modulate the beam intensity spatially and temporally.





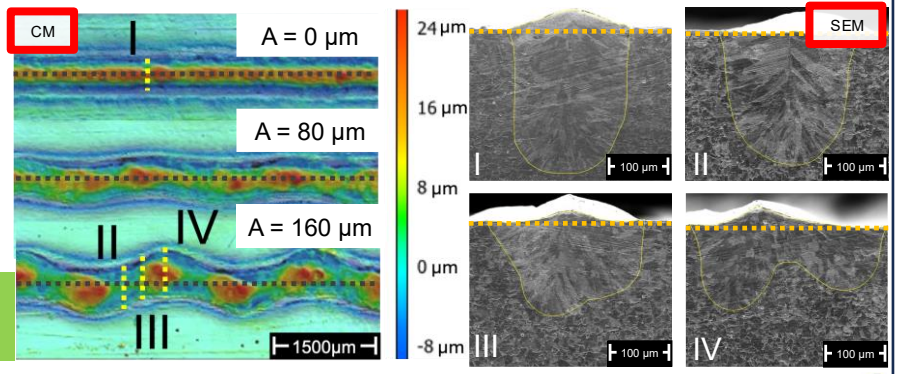
One laser beam was scanned without oscillation, while the other oscillated perpendicular to the scan direction at different frequencies and amplitudes.



Confocal images show evident periodic surface features.

Surface and Cross-sectional Analysis

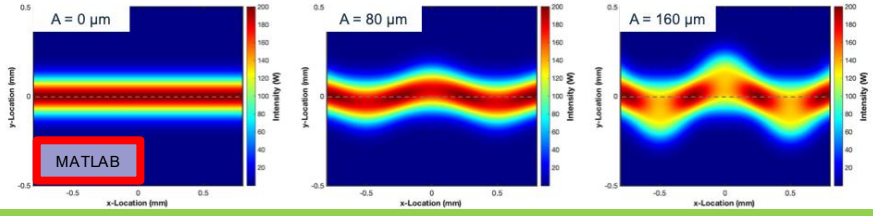
- Executed over 1000+ experiments across a broad parameter and material space
- Quantified melt track surfaces through various characterization techniques (*CM, SEM, EBSD)*
- Prepared, etched, and imaged melt track cross-sections to analyse microstructure and measure grain orientation

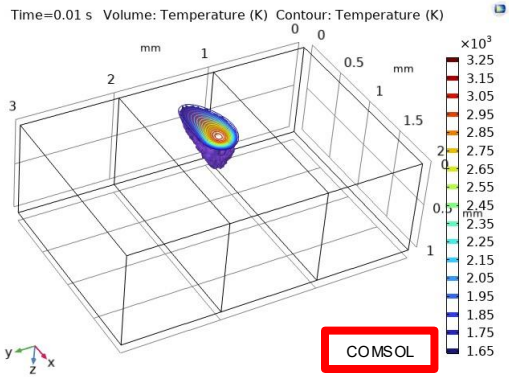


Correlated melt pool geometry and microstructure with beam parameters.

Modelling & Simulations

- Built a *MATLAB* models for dynamic beam superposition and motion
- Simulated spatiotemporal heat input and melt pool behavior in *COMSOL*
- Created a 3D melt duration space from *COMSOL* simulations results
- Validated simulations against experimental cross-sections

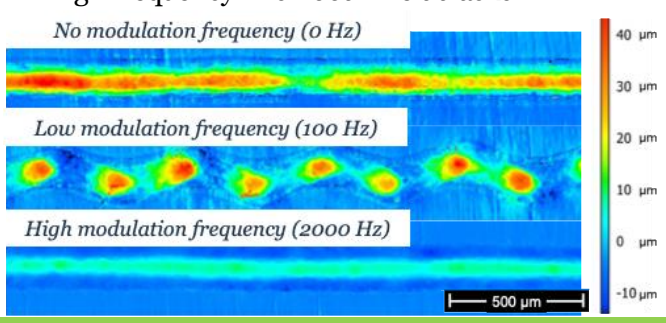




Captured melt pool behavior through 3D simulations and validated against experimental results.

Surface Processing

- Linked process parameters to surface morphology
- Low frequency → patterned melt tracks
- High frequency → smooth melt tracks

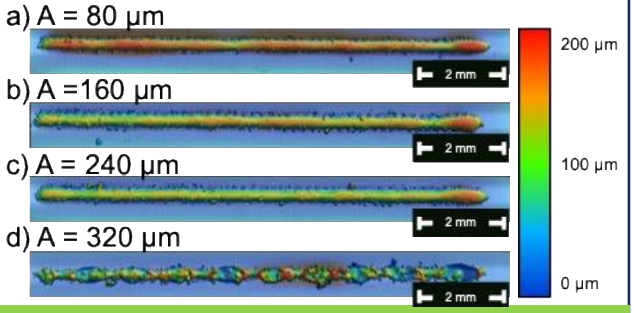


Powder Bed Fusion & External Fields

- Developed a *dynamic resonance model* for surface feature formation
- Probed the model by tuning surface tension via applied electric fields
- Achieved improved print quality and stability versus Gaussian beams

$$f_c = \frac{1}{2\pi}\sqrt{\frac{k}{\rho * V}} \approx 228Hz$$

for stainless steel 316L



Identified material-dependent resonance frequencies and developed a dynamic model, enabling a novel tuneable approach to control surface morphology and improve PBF.

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In-situ defect detection in PBF

Challenge/Motivation:

- In PBF, defects are often only identified after fabrication, making it difficult to prevent failures and ensure part quality

→ *By using optical and acoustic sensing, defects can be detected in real time during processing and 3D printing.*

Correlated in-situ and ex-situ data through machine learning to predict defect formation in PBF.

- Created an *in-situ sensing system* for continuous synchronized acoustic and optical data collection
- Designed *CAD geometries* and process conditions to induce controlled defects
- Performed *XCT* to identify and quantify defects
- Correlated in-situ signals with XCT-verified defects using machine learning for defect detection



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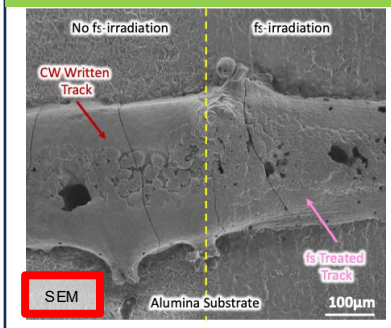
Photo-Metallurgy for Chemical Control in PBF

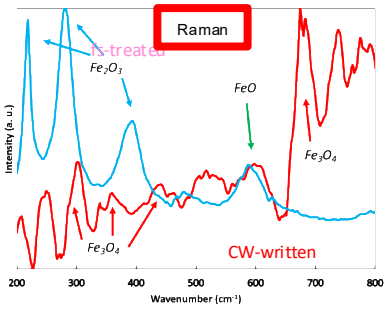
Challenge/Motivation:

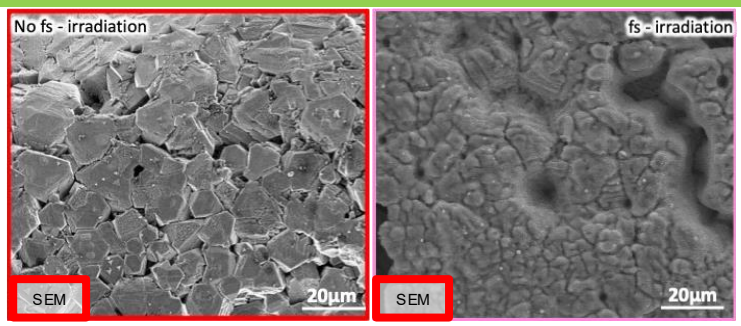
- Current processes rely on multi-step metallurgy for refinement prior to manufacturing, making it timely and costly.

→ *Highly ionizing laser sources can locally change the chemical composition with minimal structural effects.*

Developed a CW & fs-pulsed laser process to alter the chemical composition of printed Fe_3O_4 structures.







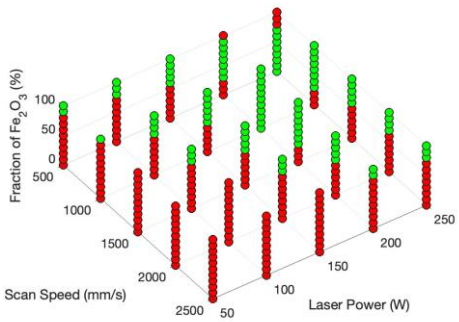
- Low-resolution SEM shows *no macroscopic structural change* between the fs-irradiated and non-fs-irradiated regions
- Raman spectroscopy confirms *localized chemical composition changes* after fs-irradiation
- High-resolution SEMs reveal *microstructural evolutions* from a grain-defined to a more homogenized morphology
- Morphological and Raman changes reveal *localized photo-metallurgy* from magnetite (Fe_3O_4) into hematite (Fe_2O_3)

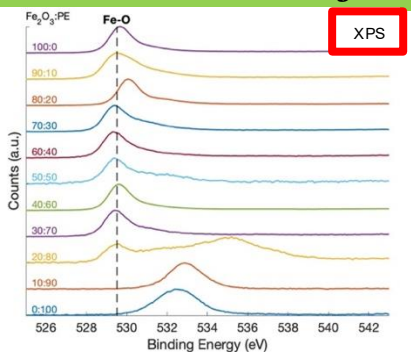
→ *By incorporating polymers, laser processing can enable in-situ chemical reduction via carbon and hydrogen.*

Developed a PBF process which enables in-situ reduction of Fe_2O_3 through laser-activated chemistry.

- Evaluated 10+ Fe2O3:PE mixtures across 25 processing conditions (power × speed)
- Identified a *processing window* enabling continuous, printable structures
- Characterized laser-processed materials via *XPS, Raman,* and *FTIR*
- Demonstrated *tunable reduction* via composition and processing parameters

$Fe^{3+} \rightarrow Fe^{2+} / Fe^{0}$





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Other Collaborations

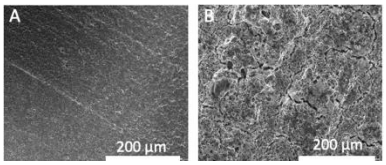
Laser Pyrolysis of Blood

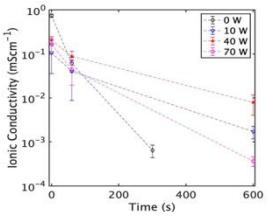
Laser scanning achieves graphene-synthesis concurrently with architecture-engineering through the localized graphitization of haemoglobin, enabling the direct preparation of engineered graphene aerogels.



Laser Annealing of Electrolytes

Laser treatment produces solid-state electrolytes with higher ionic conductivities than pristine counterparts after air exposure.





CHEMICAL AND BIOLOGICAL ENGINEERING

Laser Surface Functionalization of Cement

Engineered surface textures through controlled laser processing to achieve water-repellent behavior in cementitious materials while preserving its underlying structural properties.



CIVIL AND ENVIRONMENTAL ENGINEERING

Multi-modal Beam Shaping

Worked with Civan laser systems that dynamically reshape the beam by redistributing intensity within the spot in real time, allowing active control of energy input and processing outcomes.

FAU
Friedrich-Alexander-Universität Erlangen-Nürnberg



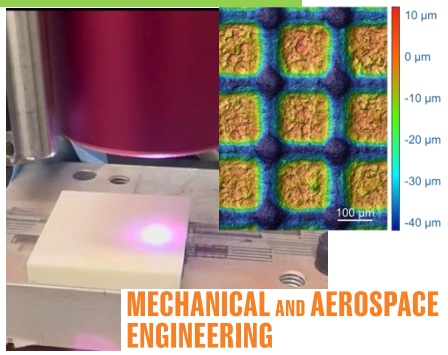
Laser Cutting of Click Beetle Joints

Employed fs-laser ablation to isolate and study the spring beetle's leg, preserving delicate biological structures by avoiding burning and heat-affected damage.



Laser Grooving of Ceramic Crucibles

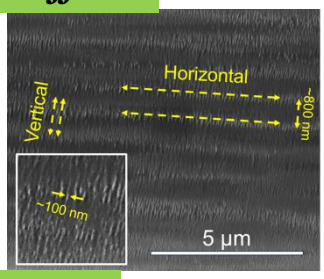
Engineered grid-patterned grooves on alumina substrates using fs-laser ablation, systematically tuning feature depth and width via multiple passes and objectives to precisely control bubble nucleation behavior.



MECHANICAL AND AEROSPACE ENGINEERING

Laser Texturing of Carbon Scaffolds

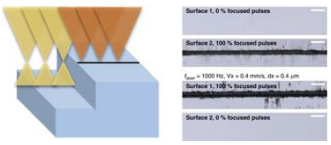
Used fs-laser processing to create three-dimensional carbon fiber networks with self-organizing nano-textures, enabling hierarchical surface structuring and controlled morphology across multiple length scales.



Tuneable Acoustic Gradient Lens

Implemented a TAG lens with a fs-laser to achieve high-frequency focal modulation, enabling rapid beam scanning and highly precise control of energy deposition in laser processing.

Mitutoyo



Non-Technical Projects

Crafted Awards for SPOTLIGHT 2025

Conceptualized, designed, and manufactures custom awards for Princeton's SPOTLIGHT event, recognizing individuals across multiple categories for the International Day of Light.



Laser Engraved Ice Hockey Blades

Designed and laser-engraved custom markings on ice hockey blades for the Princeton Women's varsity team, including player names, national flags, and the Princeton "P," enabling easy identification and tracking of primary and backup blades.

