Controlled Molten Metal Deposition: Toward Low-Cost, High Value Additive Manufacturing

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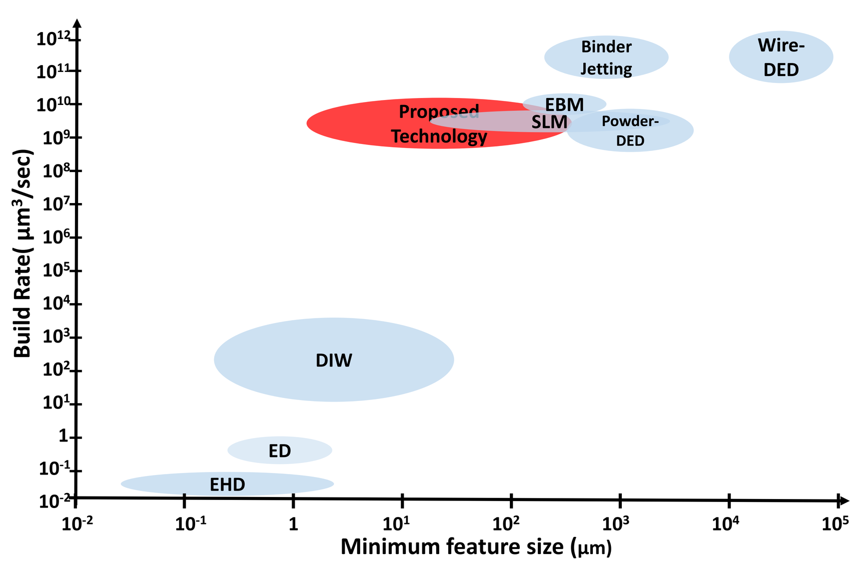
Introduction and Objective

Controlled Molten Metal Deposition (CMMD) is a proposed Metal Additive Manufacturing technology that has the potential to revolutionize the 3D printing industry. CMMD has the ability to break the print resolution vs build rate trade-off due to its on-the-fly tunability while also avoiding the use of metal powders as feedstock.

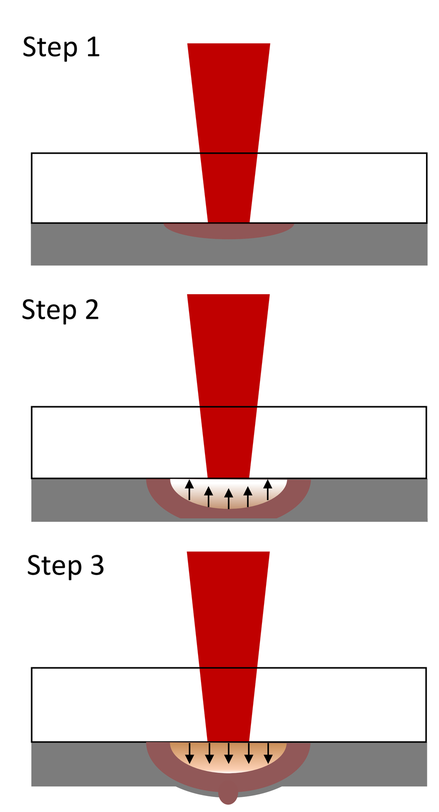
The objective of this project is to develop a proof of concept for the CMMD process and design an experimental prototype for further investigation.



Background

CMMD is a molten droplet ejection process that uses a nanosecond-pulsed laser as an energy source. The laser is focused on a metal foil, kick-starting a three step process that leads to high-velocity ejection:

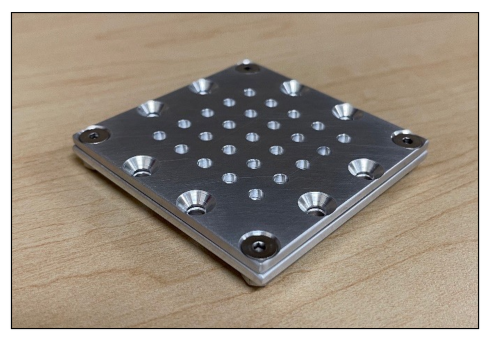
- **Step One:** The laser irradiates the feedstock foil and heats the incident side past melting.
- **Step Two:** The laser vaporizes the incident material and generates a pressure wave due to the phase change.
- **Step Three:** Due to the enclosed environment, the pressure wave is redirected downwards, propelling molten droplets toward an acceptor substrate.

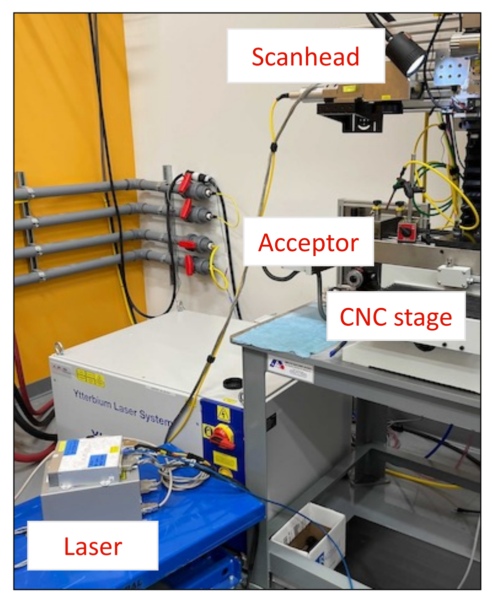


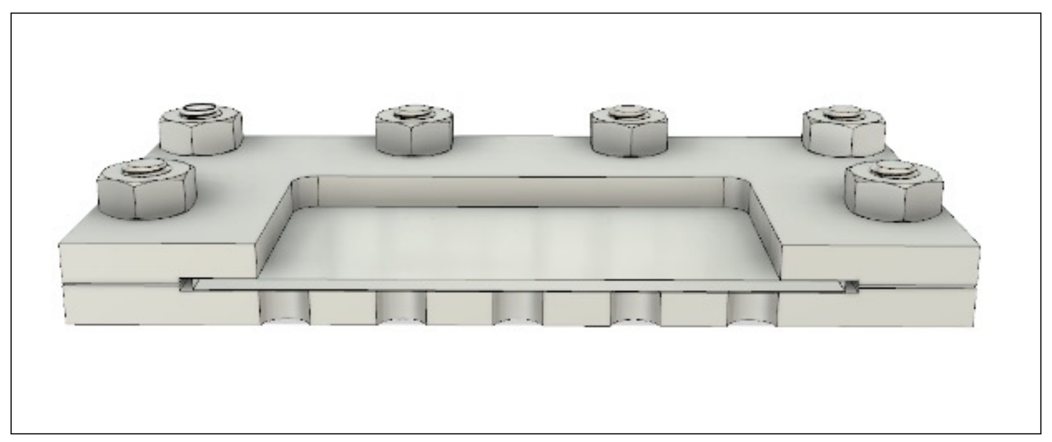
Materials and Methods

The proof of concept experiments were performed at IPG Photonics in Novi, MI. The goals of these experiments were to investigate how laser and feedstock properties affect droplet characteristics. The following properties were to be investigated:

- Laser fluence (energy density)
- Pulse duration
- Feedstock Thickness
- Raster Speed

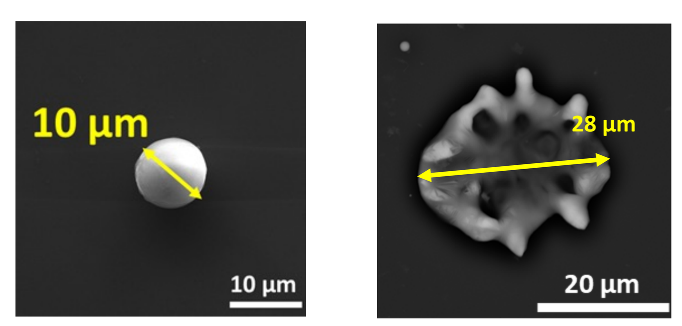






Results

The results of the experiments show that the ejection mechanism is directly dependent on laser fluence. Ejection was observed at fluences between 1.4 and 8.0 J/cm^2, with droplet size increasing with fluence. At fluences of 2.3 J/cm^2 and higher, multiple droplets were observed per pulse, and at fluences of 2.4 J/cm^2 and higher, droplets took an irregular splatter shape.

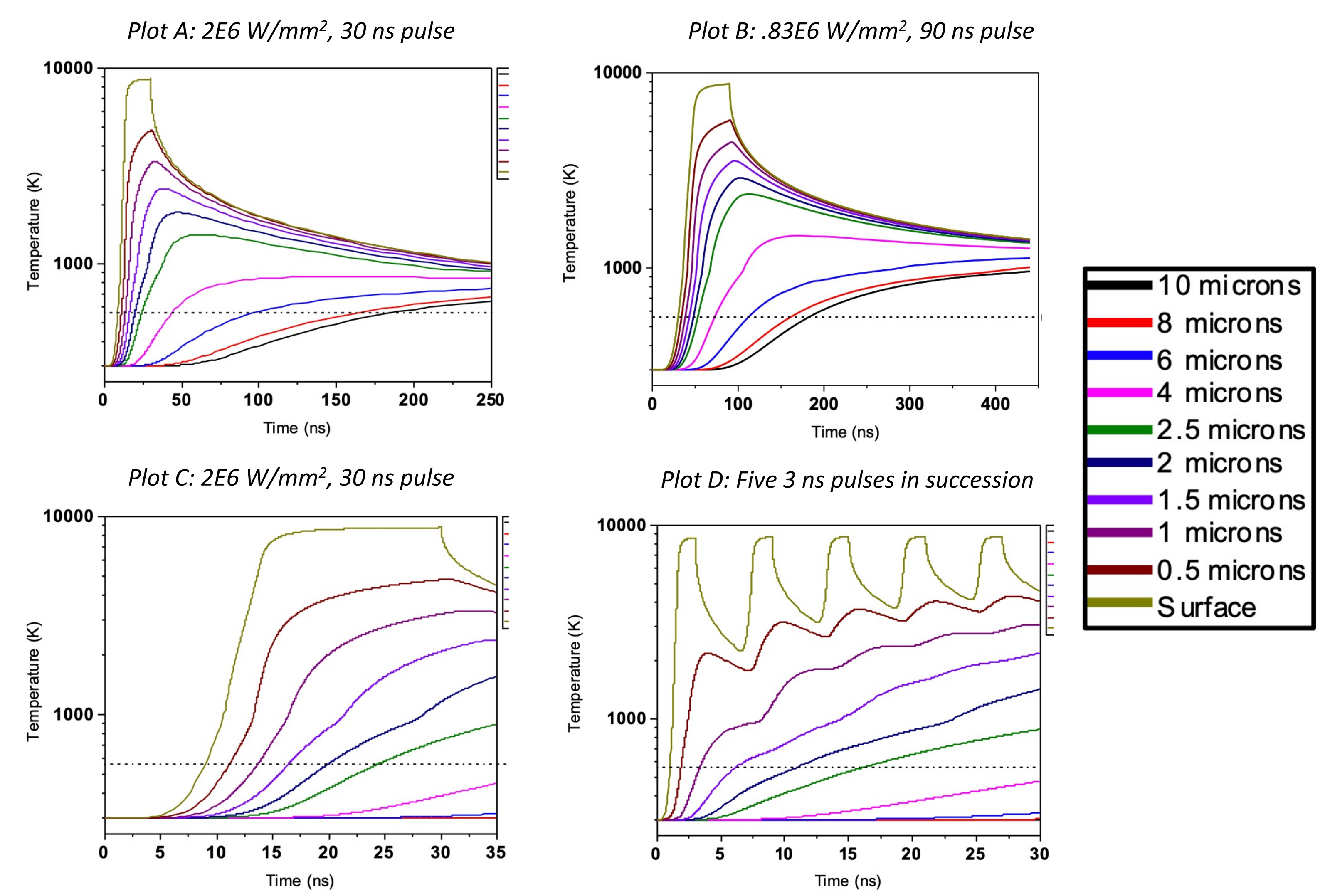


Left: An isolated droplet from a 1.4 J/cm^2 experiment.
Right: a splatter from a 8 J/cm^2 line scan experiment.

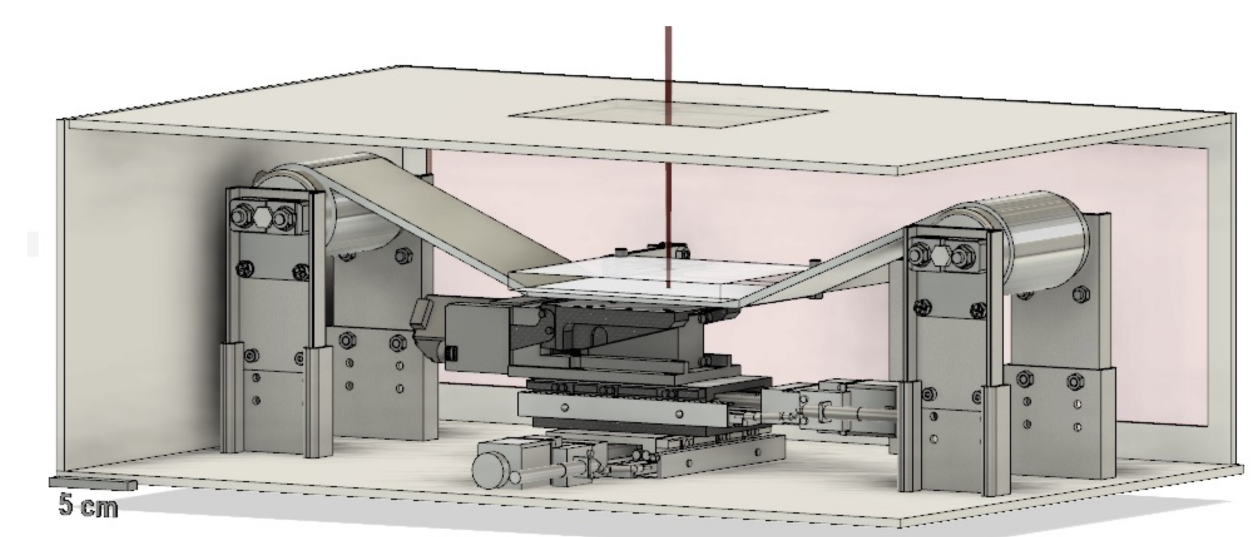
Current Work: Simulation

Currently, finite element analysis simulations are being carried out to supplement the results from the proof of concept experiments. We are simulating a variety of laser parameters to understand how they affect the thermal history of the feedstock in order to inform our prototype design. Some examples of these simulations include:

- Effect of pulse duration (plots A and B).
- Effect of multiple pulses (plots C and C).
- Effect of spot size.
- Effect of laser fluence.
- Effect of duty cycle with multiple pulses.



Current Work: Experimental Prototype



A full-scale prototype is currently in development. Features of the design include:

- Conveyor roller feedstock refreshing system with adjustable height for reloading and tensioning feedstock.
- XYZ translational stage system for fast experiments and multi-layer prints.
- Kapton windows for experiments at CHESS.
- Oxygen sensors and valves for inert gases to create an inert atmosphere.
- Removable housing to facilitate easy internal adjustments.
- Full automation.

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Zoom Link: https://cornell.zoom.us/j/9045528791?pwd=OXlJNng3TmVZcVJMWmQyYmduOHpqZz09