Investigation of Laser Beam Attenuation and Energy Partitioning During Coaxial Laser Directed Energy Deposition Process

ID176

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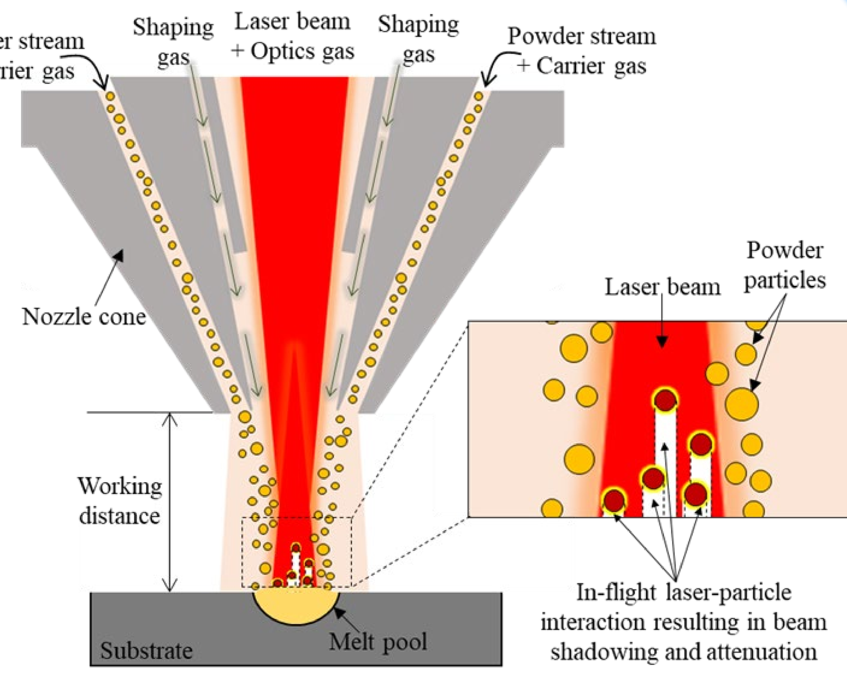
Aim and Objective

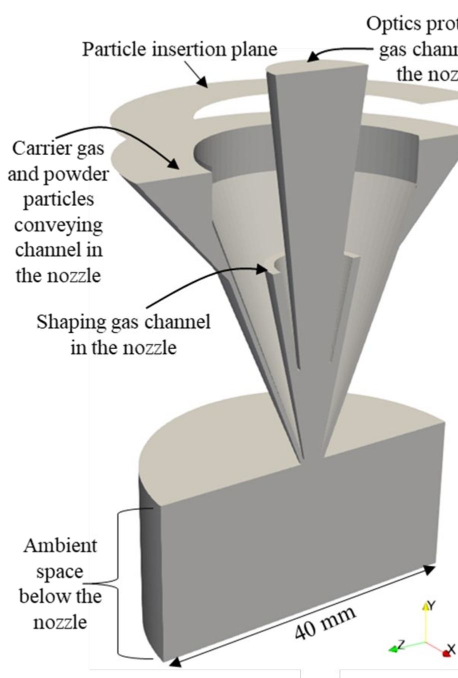
- High-fidelity CFD-DEM multiphysics modelling to understand the dynamics of the gas-powder stream and the laser-particle interaction.
- Focus on shadowing, attenuation, and scattering of the laser beam radiant energy.
- High-speed visible imaging of the powder stream, laser attenuation and shadowing measurements via a photo-diode system, and surface measurements of attenuated-laser interaction with the substrate to validate the CFD-DEM modeling.



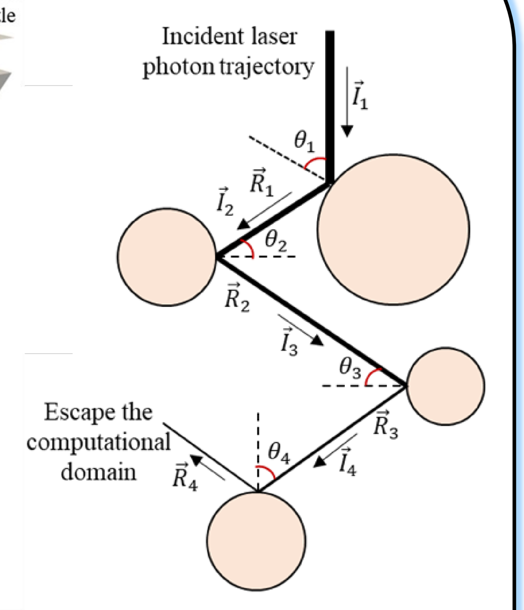
Schematic of the coaxial laser-based DED process

Modeling Methodology

- Gas-particle dynamics and laser-powder stream interaction have been modeled using a four-way coupled CFD-DEM approach, integrating Aspherix-6.1.4 and OpenFOAM 8.0.
- Laser beam photon discretization approach is also integrated for in-flight heating calculations of particles, taking into account multiple reflection phenomenon and laser beam attenuation and shadowing.
- Data exchange model (twoWaySocket) enables communication between DEM (Aspherix®) and CFD (OpenFOAM®) by transferring particle properties (position, radii, etc.) from DEM to CFD and drag force from CFD to DEM.
- In both the modeling and experiments, the inert gas (carrier, shaping, and optics) used is argon, while the powder material is commercially pure titanium.

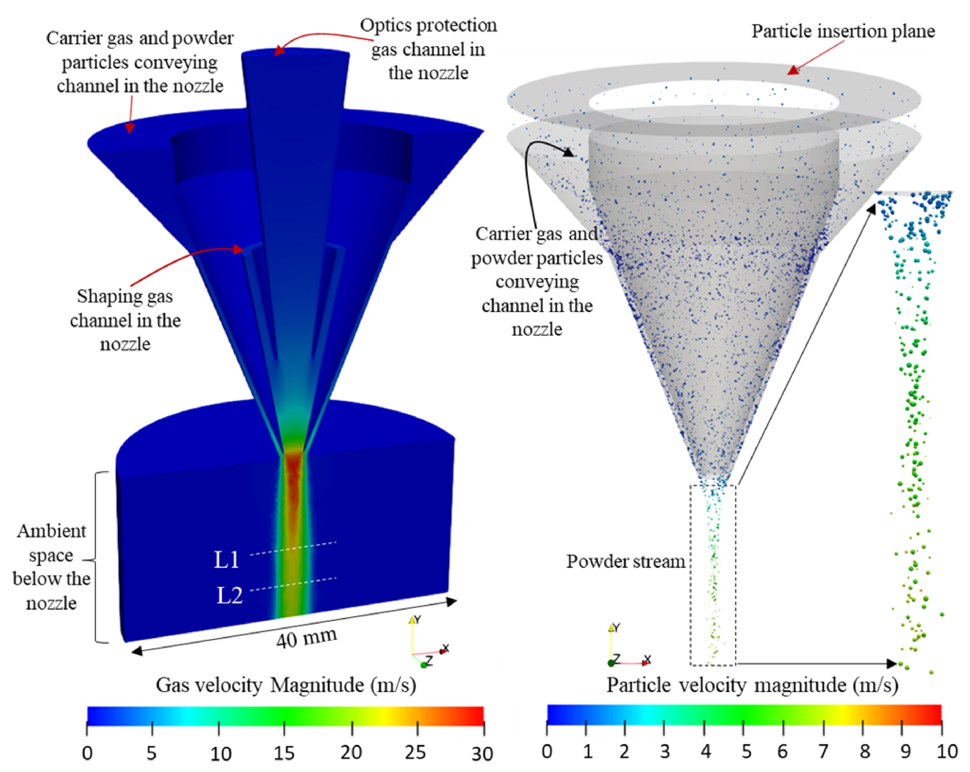


Computational domain for CFD-DEM



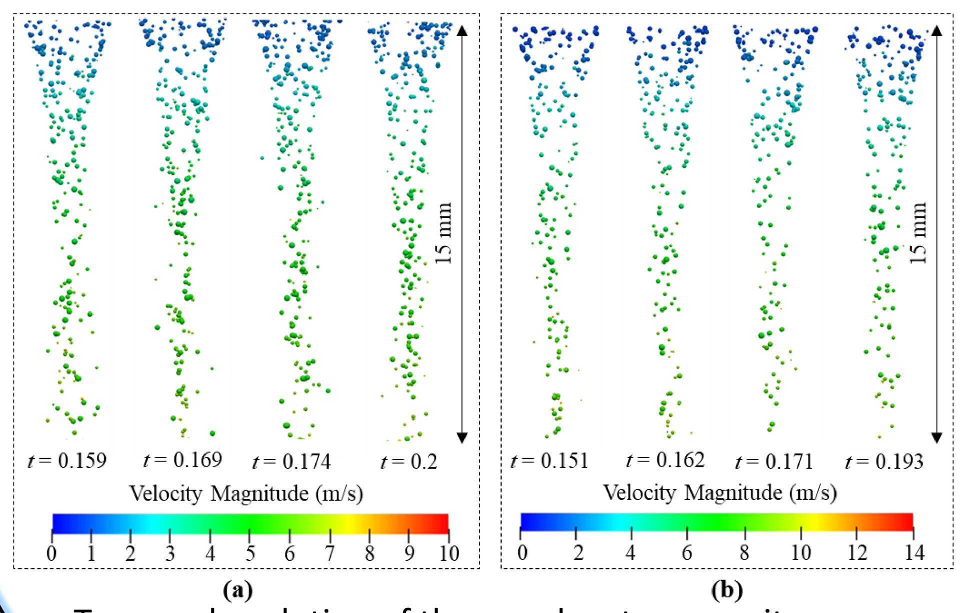
Schematic showing the multiple reflection of laser photon

CFD-DEM Modeling results: Gas-Powder Dynamics and Laser-Particle Interaction

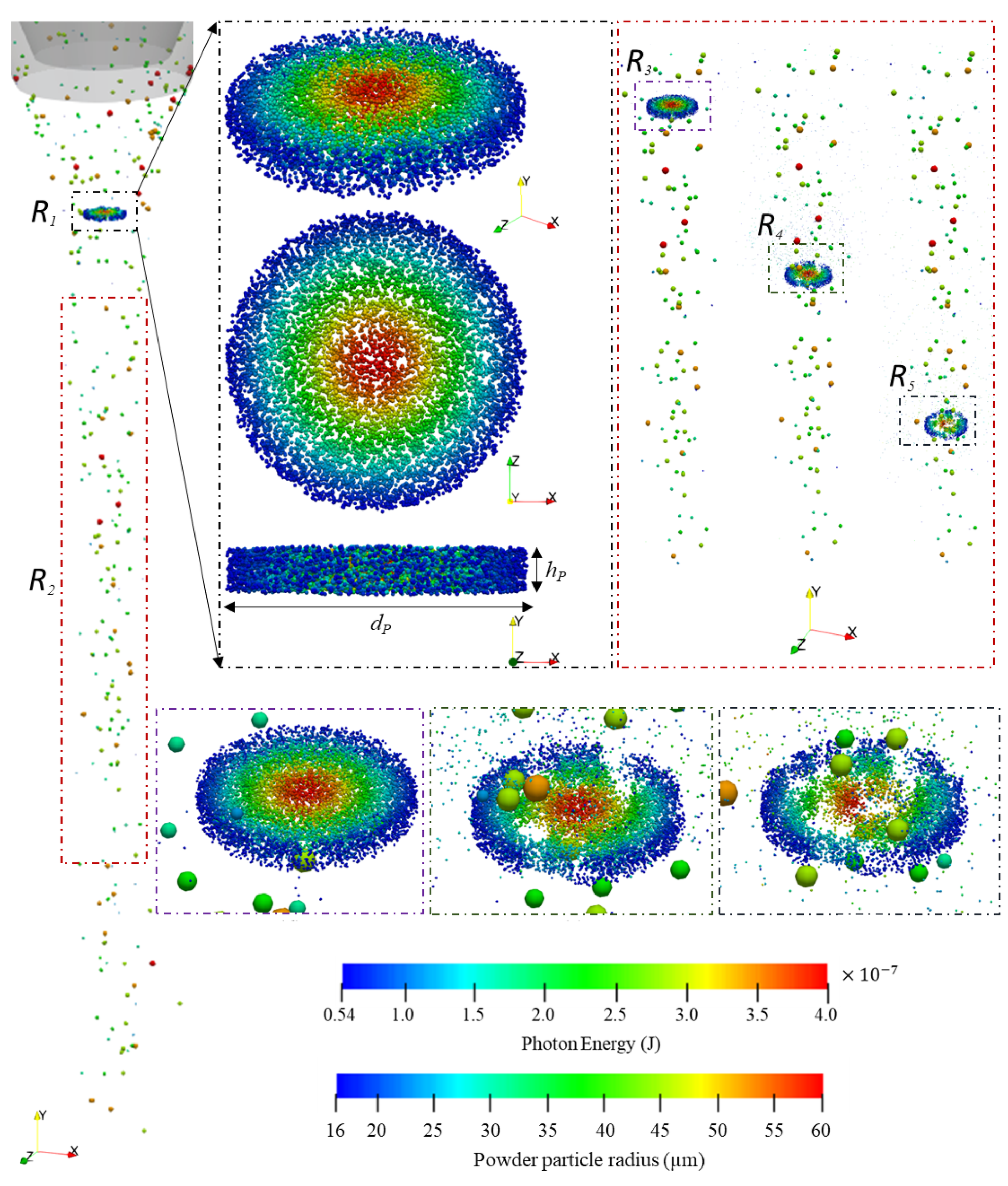


Gas velocity field

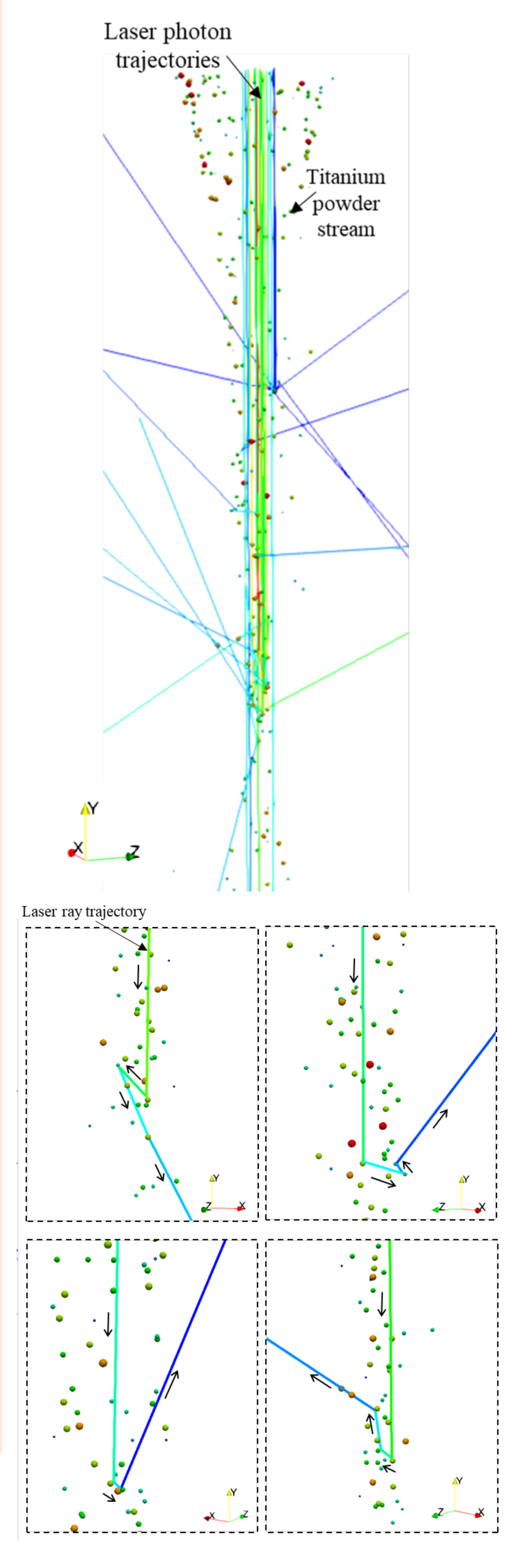
Predicted powder stream

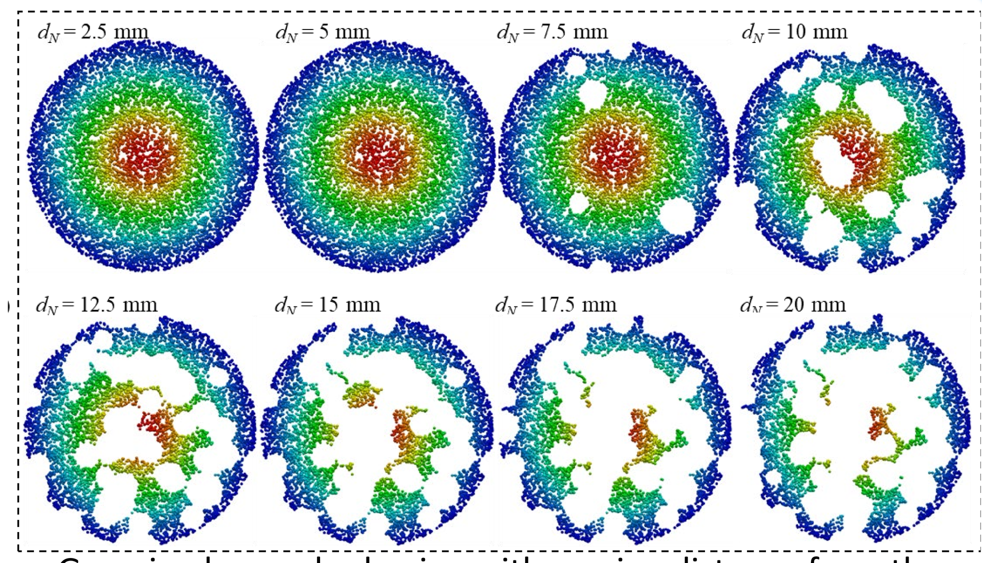


Temporal evolution of the powder stream as it emerges from the nozzle outlet predicted by four-way coupled CFD-DEM modeling (a) case *P2*, and (b) case *P3*

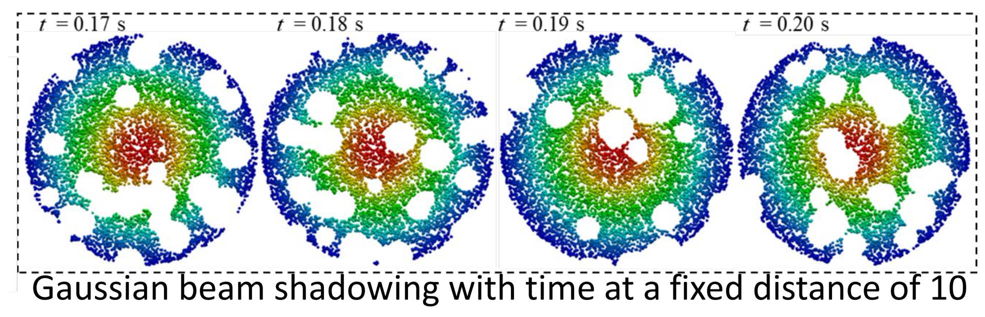


CFD-DEM modeling results of photon stream interaction with powder particles for case *P2* (shaping gas = 3 l/min, optics gas = 3 l/min, carrier gas = 3 l/min, and powder feed rate = 4 g/min).

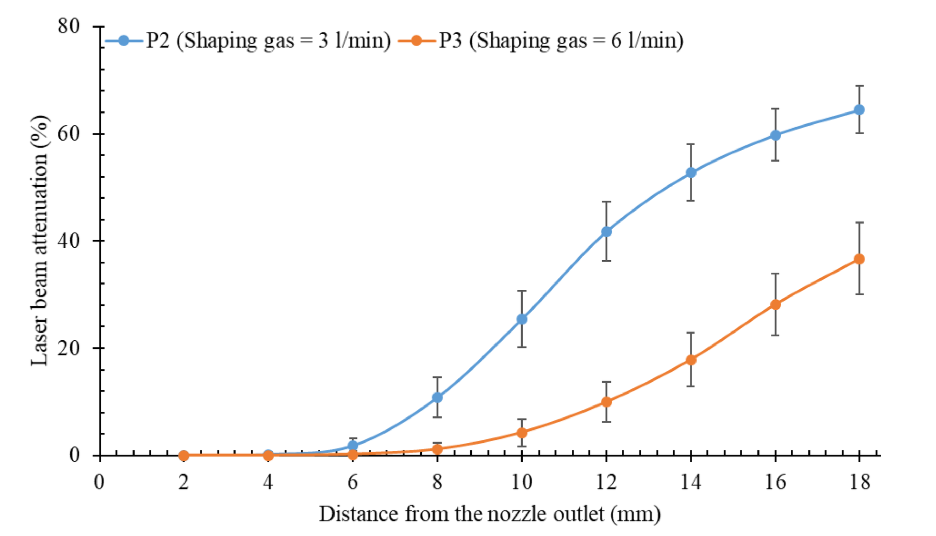




Gaussian beam shadowing with varying distance from the nozzle outlet for case *P2*



Gaussian beam shadowing with time at a fixed distance of 10 mm from the nozzle tip for case *P2*

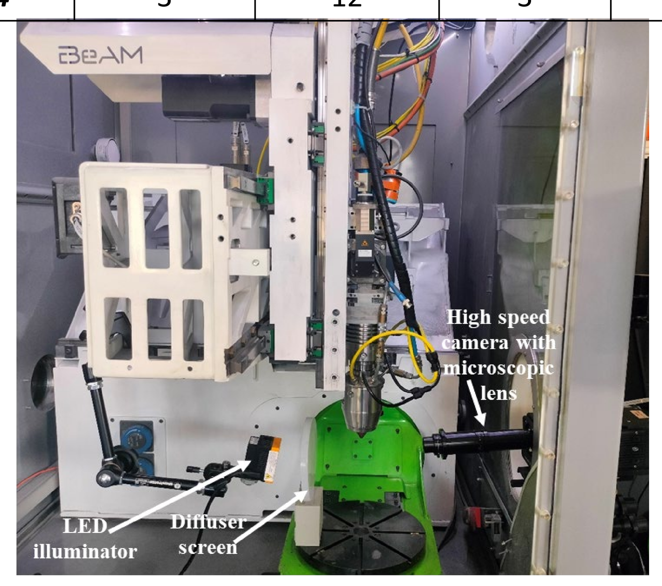


Laser beam attenuation for case *P2* and case *P3*

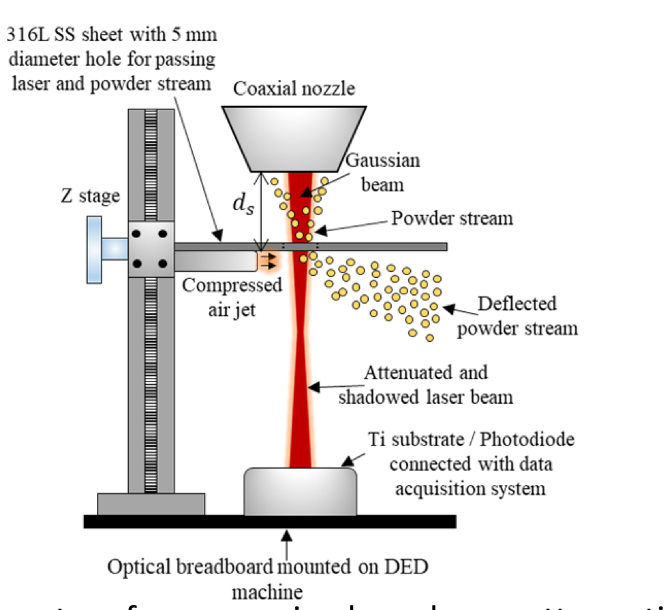
Experimental Methodology

- High-speed imaging of the laser-particle and particle-melt pool interaction
- High-temporal resolution measurements using photodiode to determine the attenuation of the laser beam by the powder stream.
- Measurement of attenuated beam influence on melt pool morphology.

Case ID	Carrier gas flow rate (l/min)	Shaping gas flow rate (l/min)	Optics gas flow rate (l/min)	Powder feed rate (g/min)
P1	3	0	0	4
P2	3	3	3	4
P3	3	6	3	4
P4	3	12	3	4

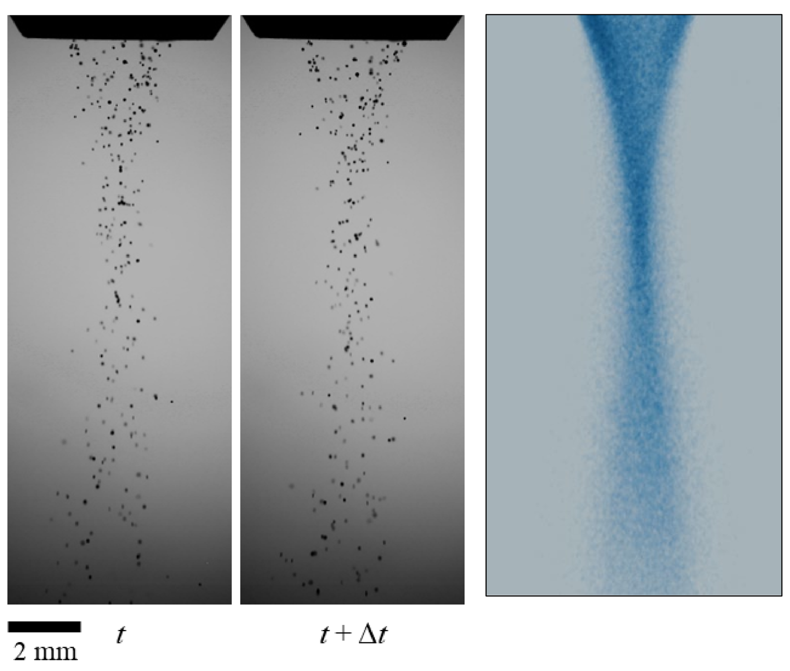


DED setup with high-speed imaging system

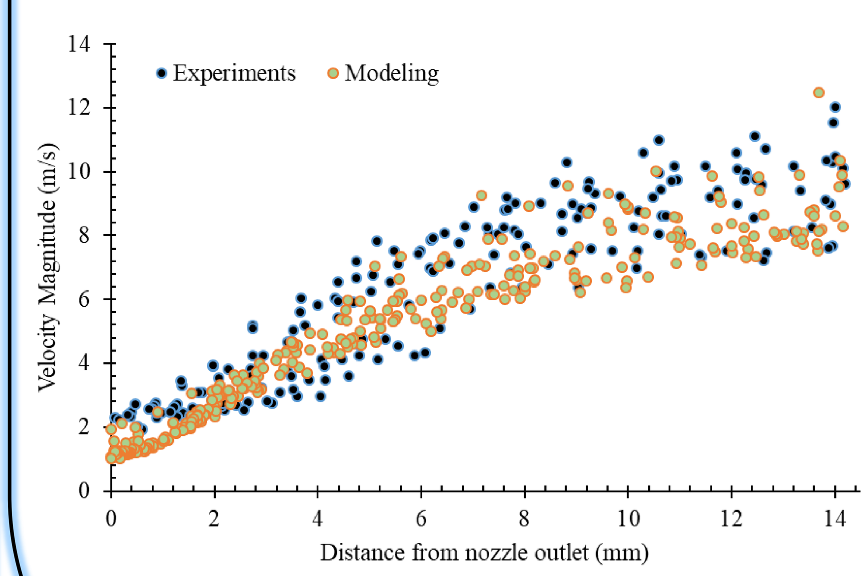


Z-stage system for measuring laser beam attenuation

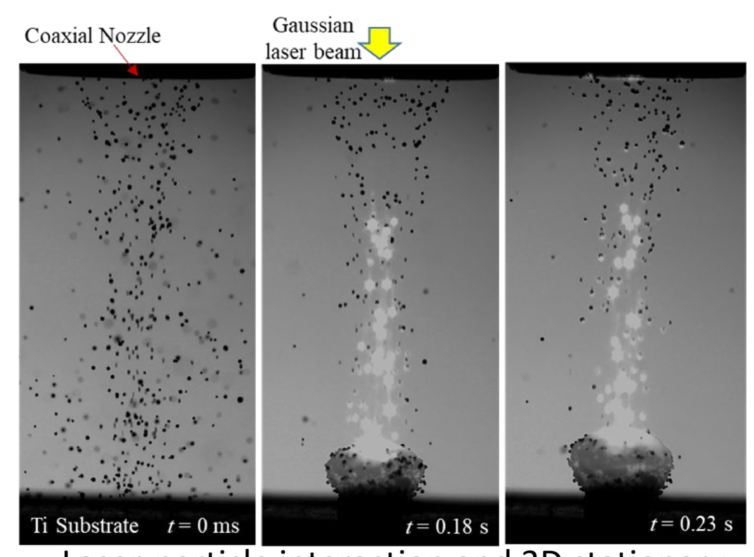
Experimental Results and Modeling Validation



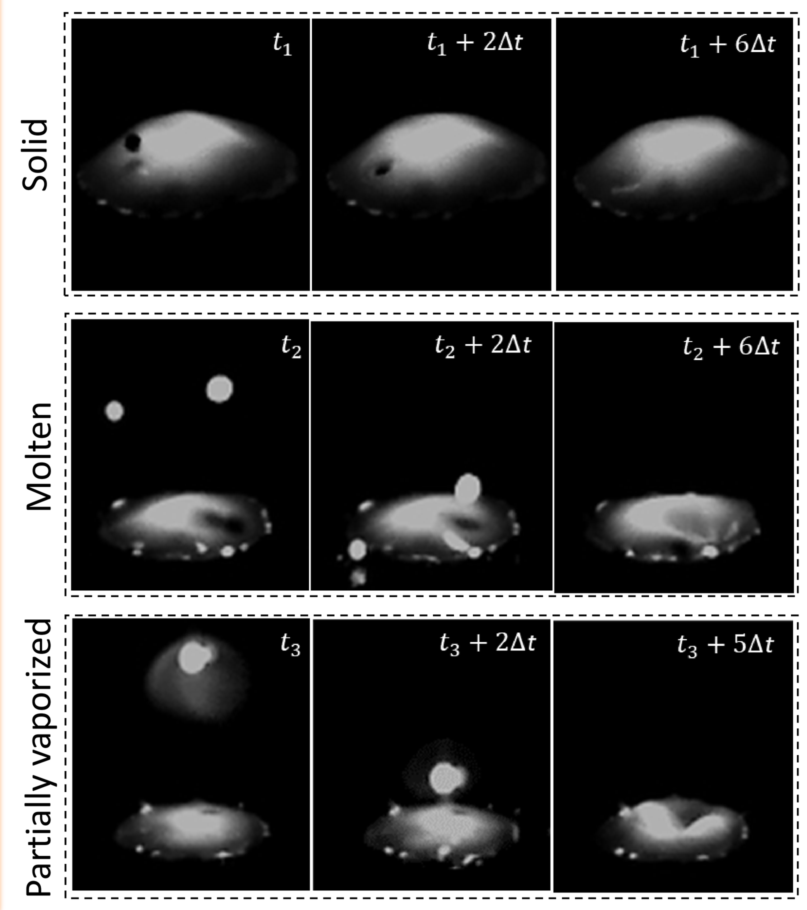
High speed images (5900 FPS) and superimposed image (shaping gas = 3 l/min, optics gas = 3 l/min, carrier gas = 3 l/min, and powder feed rate = 4 g/min)



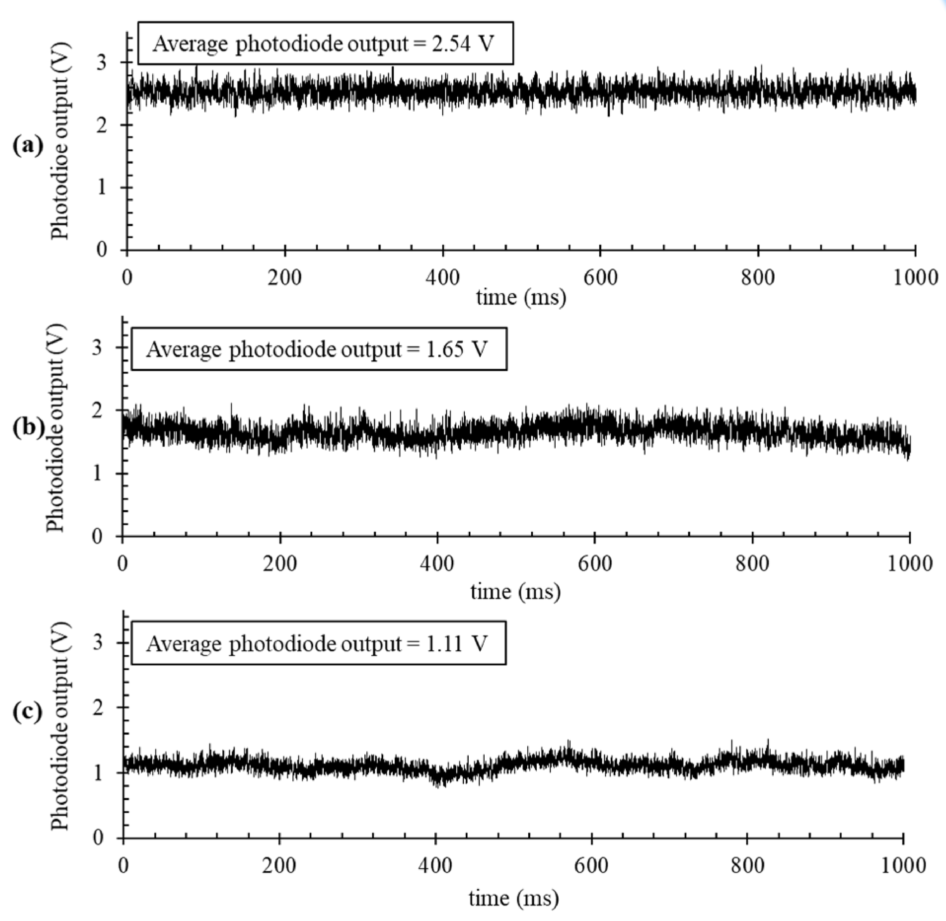
High-speed imaging and modeling results (shaping gas = 3 l/min, optics gas = 3 l/min, carrier gas = 3 l/min, and powder feed rate = 4 g/min)



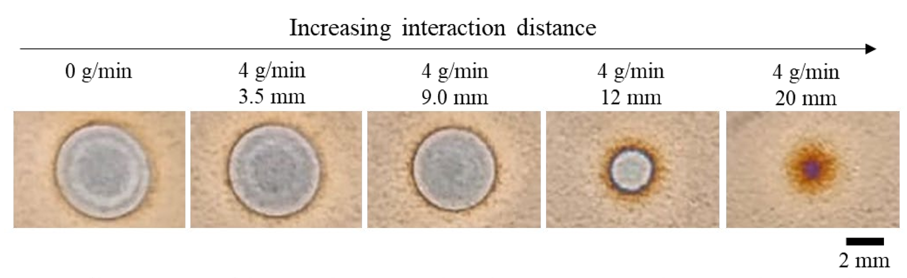
Laser-particle interaction and 3D stationary deposition



Particle-melt pool interaction



Transmitted intensity of the laser beam after interaction with the powder stream **(a)** Only laser (no powder stream), **(b)** 8 mm interaction length, and **(c)** 16 mm interaction length



Influence of laser beam shadowing on the melt pool morphology (Titanium substrate) for different laser-particle interaction length

Conclusions

- Due to the interaction of the laser beam with the in-flight powder stream, energy losses from shadowing and attenuation can reach up to 74%.
- Laser beam profile deviate significantly from its initial Gaussian profile, also displaying notable stochasticity and randomness over time.
- Laser beam's shadowing caused by the powder stream can notably influence the melt pool and the extent of shadowing by in-flight powder particles plays a vital role in the melt pool's formation and stability.

Acknowledgement

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