Powder-scale Simulation and Experimental Characterization of Internal Pore Defects during Laser Powder Bed Fusion

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Introduction

What
- **Laser powder bed fusion (LPBF)** is an important sector of laser metal additive manufacturing. During LPBF, the laser is guided to selectively scan the surface of the powder bed to construct the three-dimensional (3D) part in a layer-by-layer manner.

Why
- The mechanical properties of the fabricated parts are affected by various **internal pore defects**, which are directly related to **laser-material interactions**, **heat transfer**, and **melt pool dynamics** during LPBF. Due to the high complexity of the process, the mechanism of pore formation has not been fully revealed.

How
- The present project attempts to understand the correlation between the process parameters and the pore formation by combining powder-scale **mechanistic modeling** and **in-situ characterization** of the LPBF process.
  - The experimental measurements are references to calibrate the mechanistic model.
  - The mechanistic model allows the quantitative investigation of the highly dynamic process, and it will guide the design of further experiments.

Mechanistic Modeling

1 DEM & CFD simulation of single-track LPBF with 316L by Aspherix® and FLOW-3D®

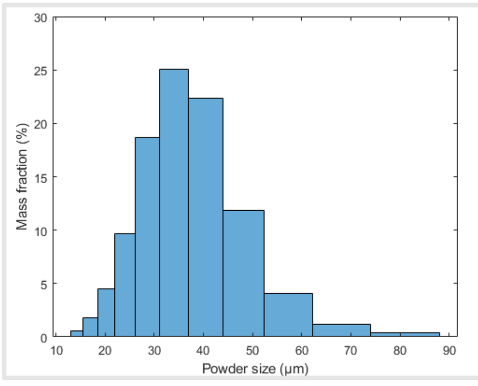


Fig. 1.1. Measured particle size distribution

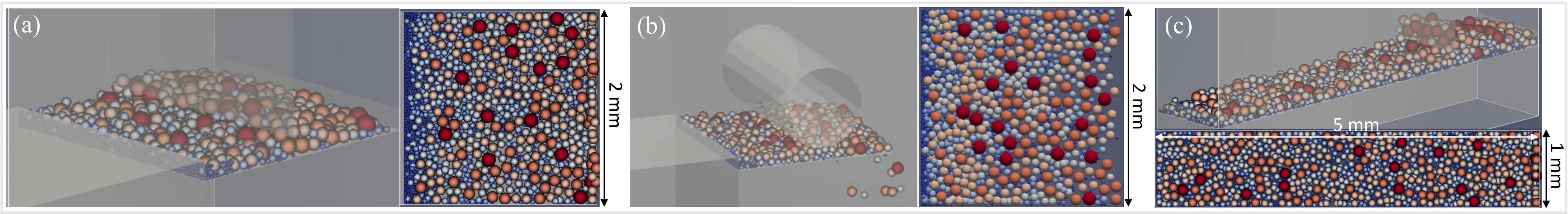
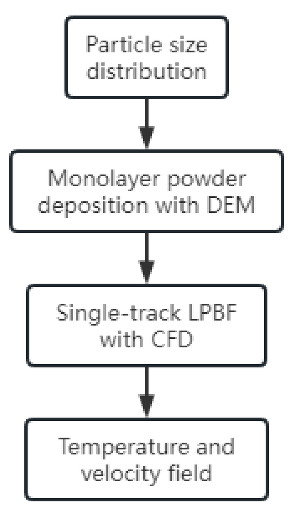


Fig. 1.2. Powder deposition process simulated by discrete element method (DEM): (a) sweep to lower stage by blade; (b) sweep to lower stage by roller; (c) free fall and sweep by blade



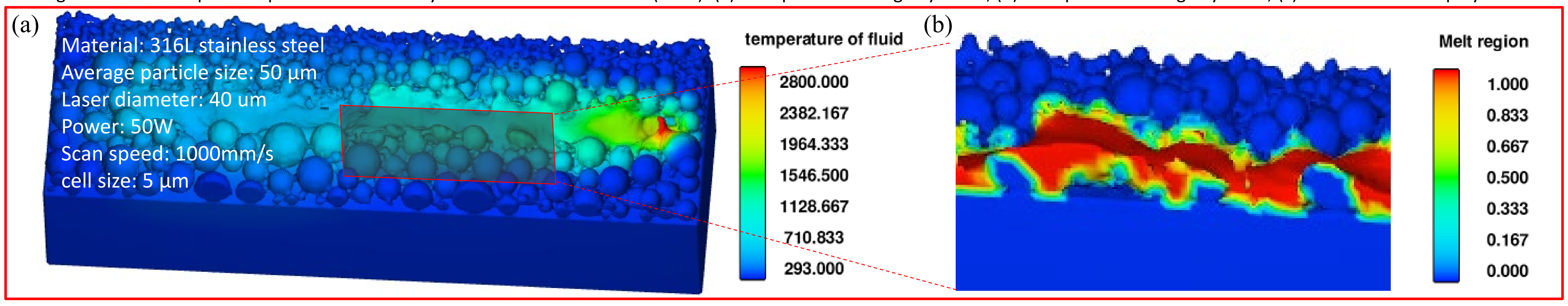


Fig. 1.3. Melt pool of LPBF process simulated by computational fluid dynamics (CFD): (a) temperature distribution; (b) cross-sectional view of lack of fusion defects

In-situ Characterization

2 In-situ synchrotron X-ray diffraction of single-track remelting with 316L at ID31, ESRF

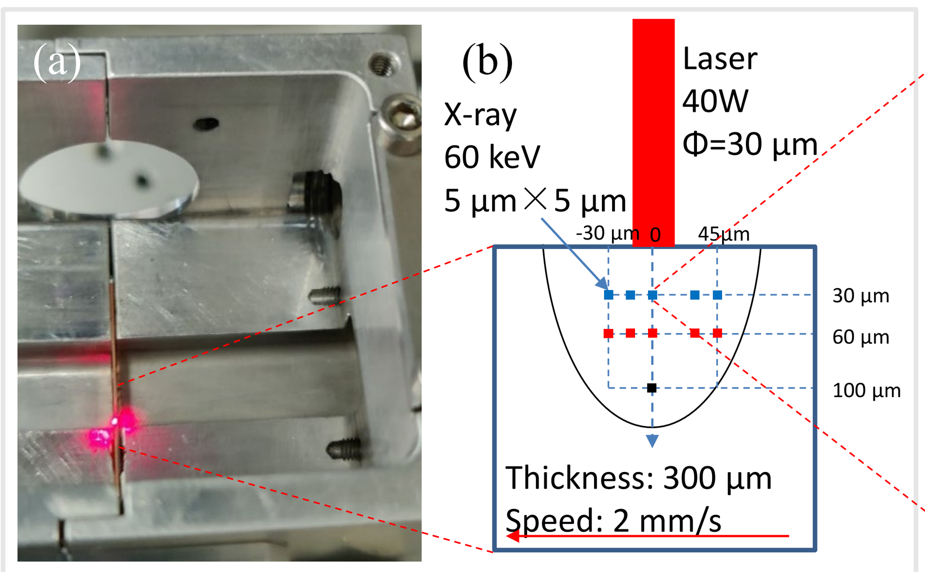


Fig. 2.1. Experimental setup: (a) build chamber; (b) scanning process

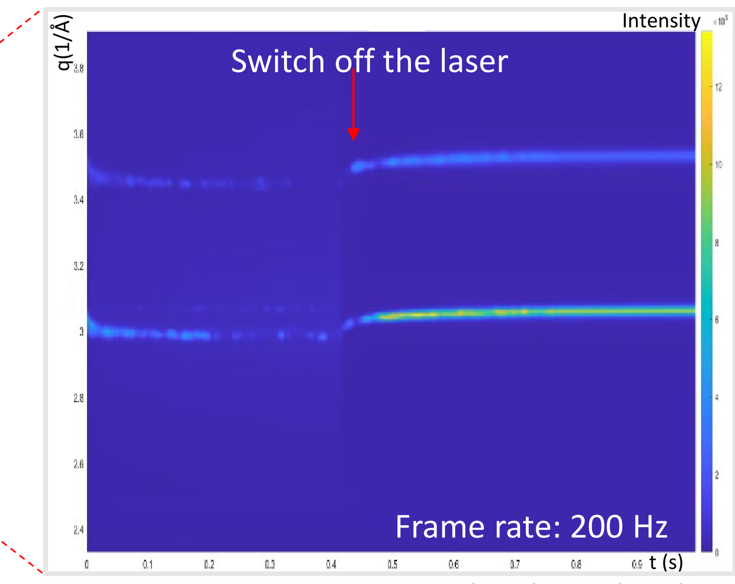


Fig. 2.2. Waterfall plot of (111) and (200)

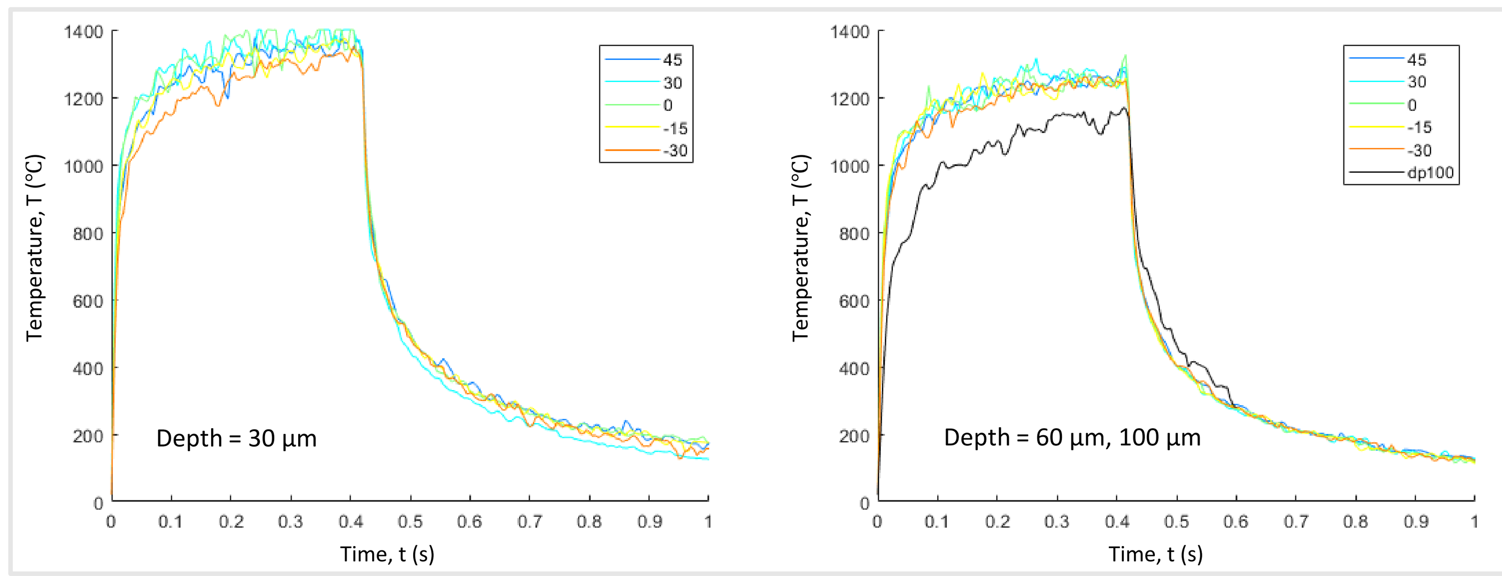


Fig. 2.3. Temperature evolution calculated based on peak shift and thermal expansion

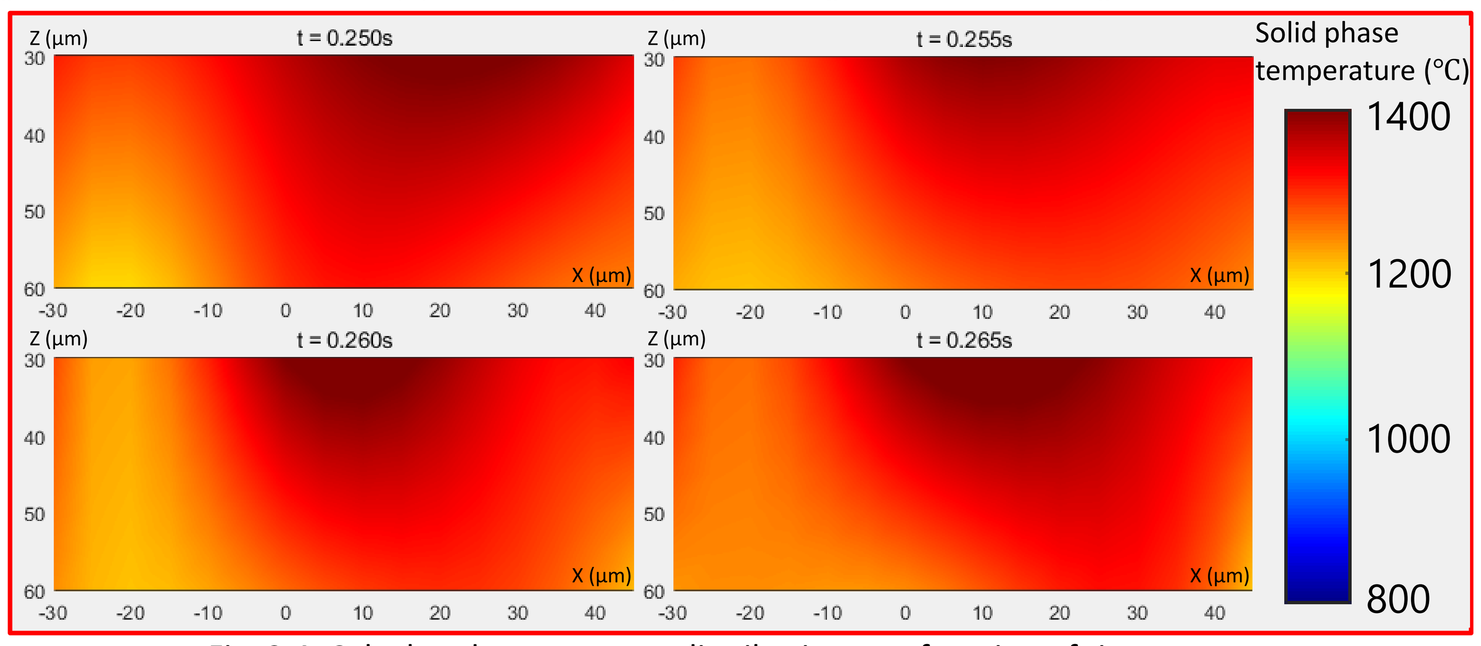


Fig. 2.4. Calculated temperature distribution as a function of time

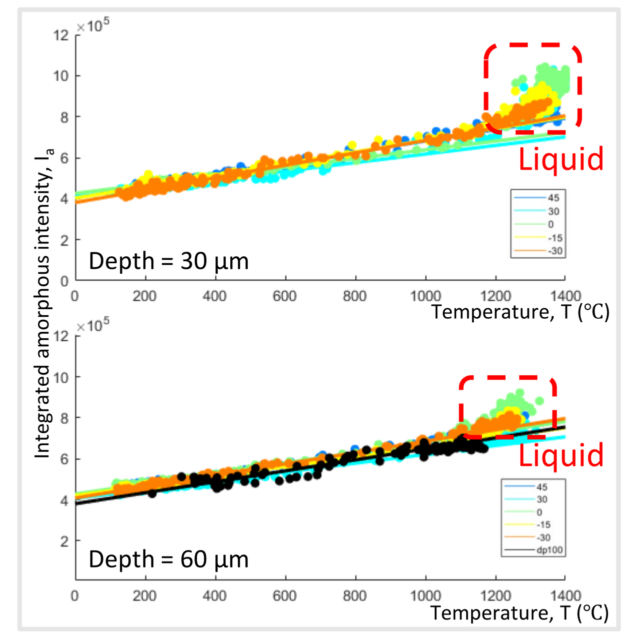


Fig. 2.5. Excluding thermal diffuse scattering

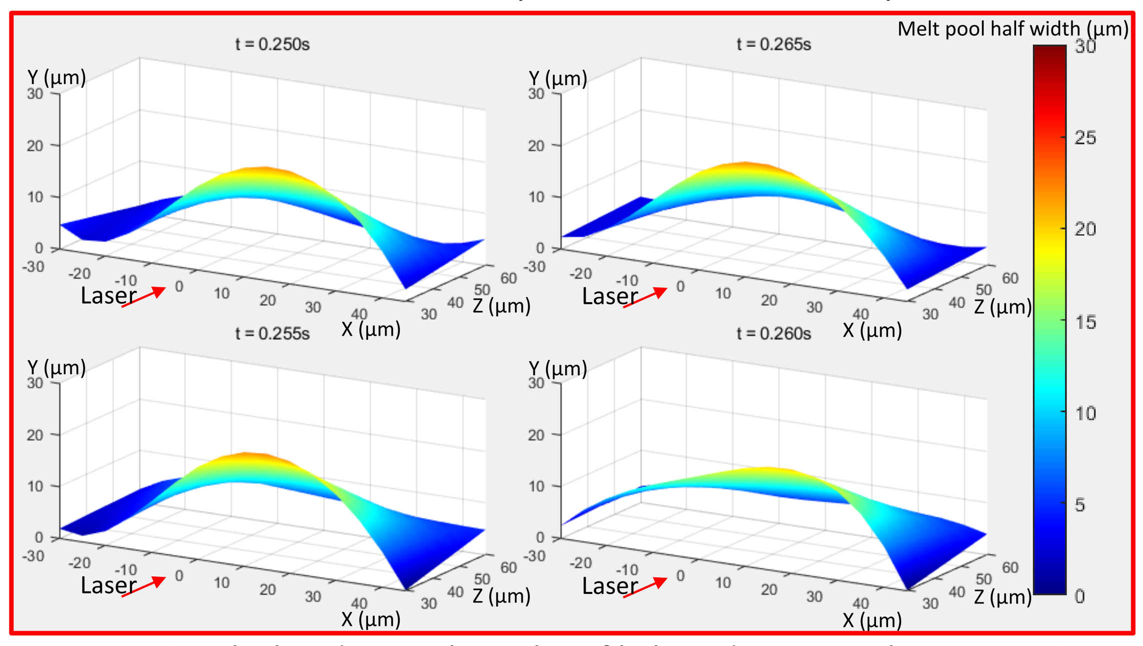


Fig. 2.6. Calculated 3D melt pool profile based on amorphous intensity

3 In-situ synchrotron X-ray imaging of single-track LPBF with 316L and 3 wt.% W Particles at TOMCAT, PSI

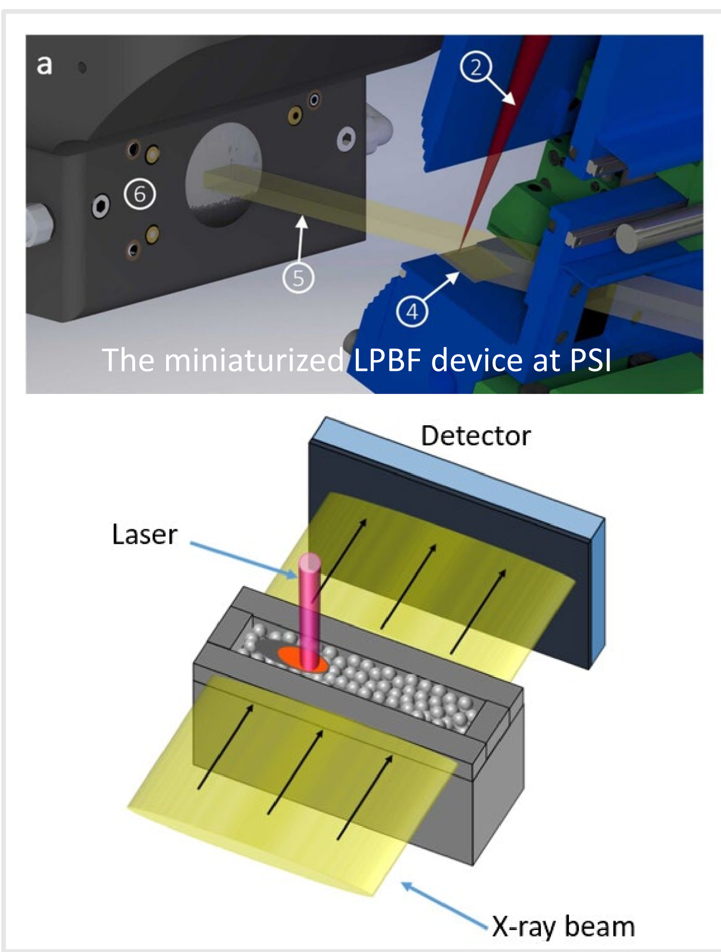


Fig. 3.1. Experimental setup

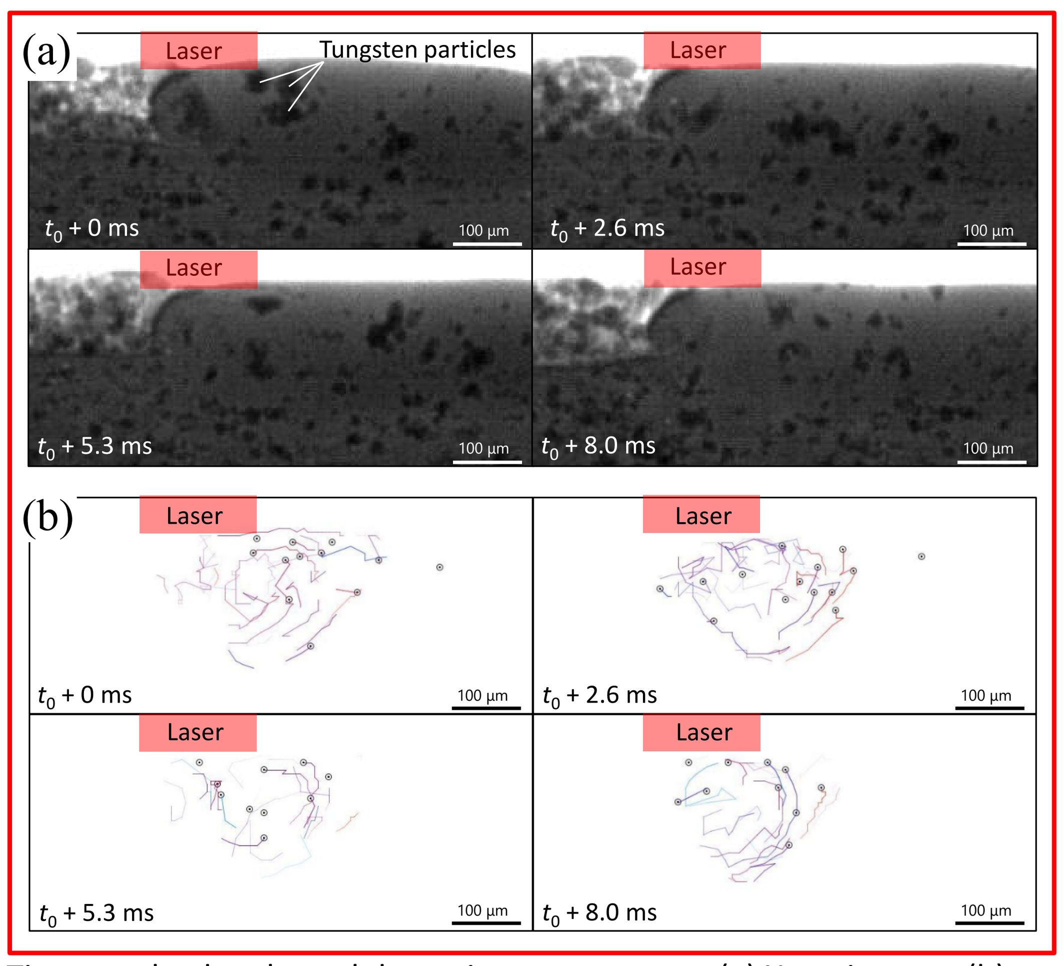


Fig. 3.2. Time-resolved melt pool dynamic measurement: (a) X-ray images; (b) particle tracing

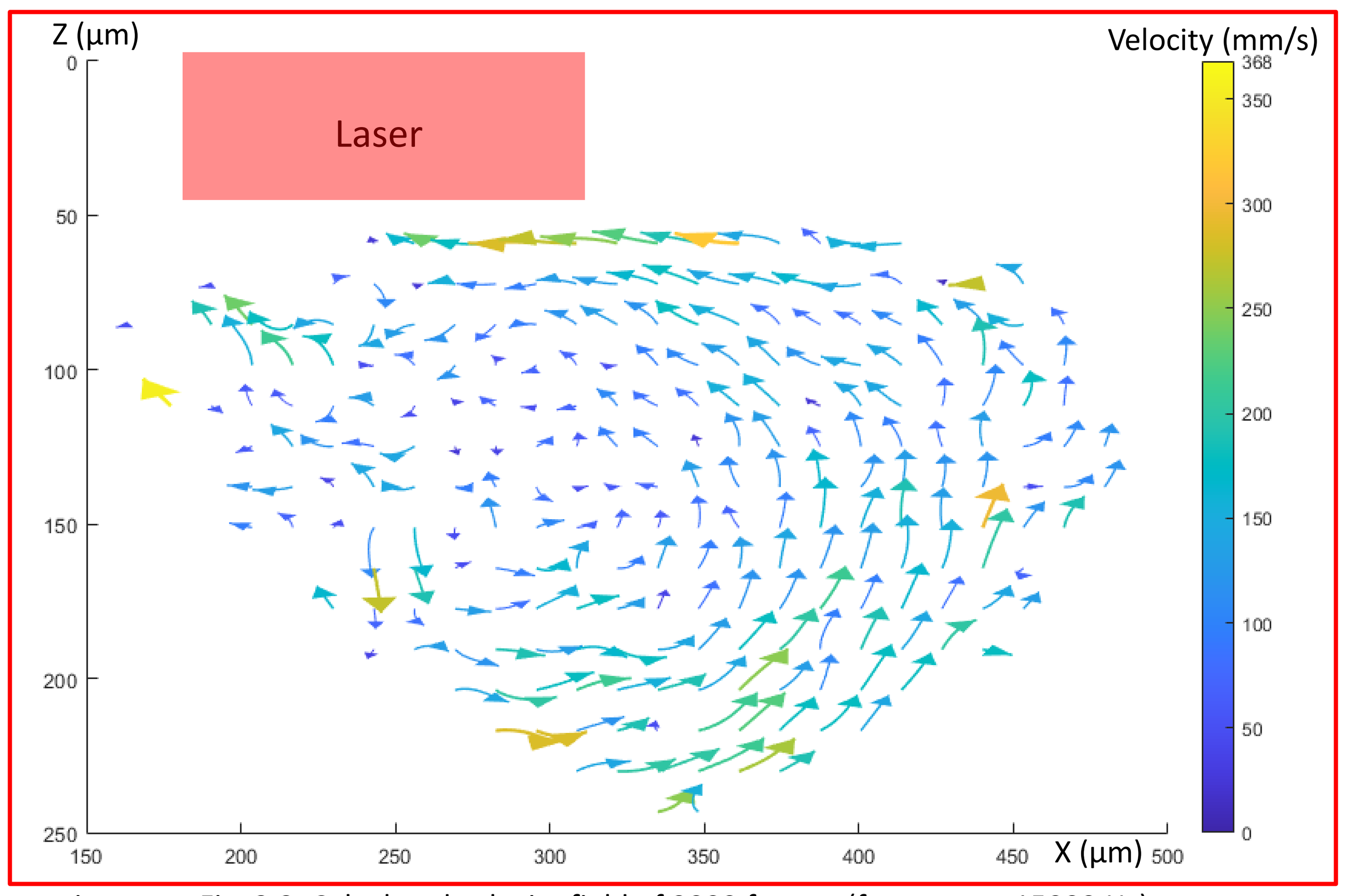


Fig. 3.3. Calculated velocity field of 2000 frames (frame rate: 15000 Hz)

Two year goals

- Calibrate CFD model with OpenFOAM using experimental data on temperature fields, velocity fields, melt pool shape, etc.
- Conduct hybrid in-situ experiments of LPBF with high-speed thermal camera and synchrotron X-ray imaging to measure simultaneously the surface temperature and melt pool dynamics.
- Build an empirical model to predict the probability of local occurrence of internal pore defects based on the simulation and experimental data.

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