Highlight

Next generation multiphysics models of laser powder bed fusion

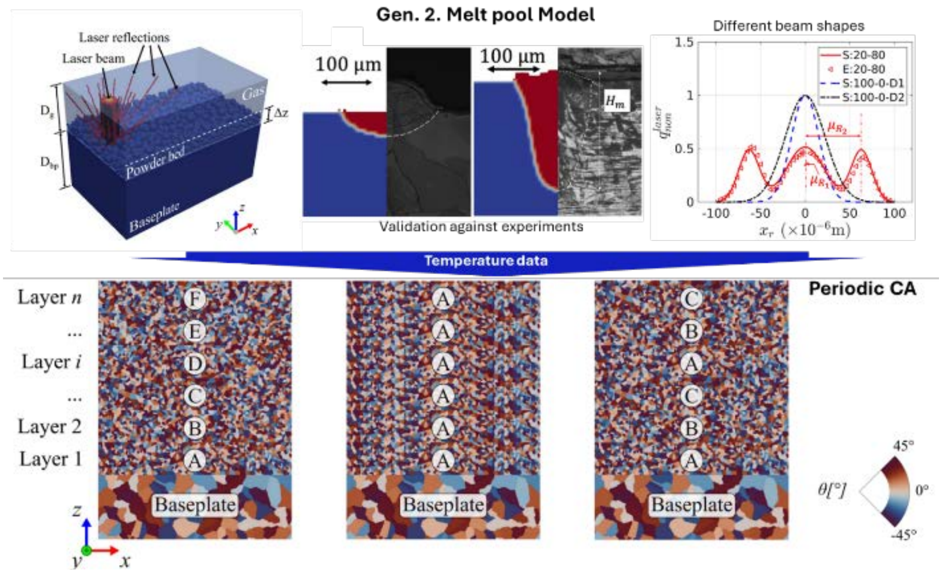

Illustration of the Gen. 2. melt pool dynamics simulation with validation against different laser beam profile as well as the periodic CA model describing the grain orientations across several layers. The Gen 2. melt pool dynamics model incorporates ray-tracing and accounts for gas dynamics in the vicinity of the melt pool, as a new feature. The upper right corner shows the different beam shapes incorporated in the model for validation, shown in the upper middle section. The bottom row shows different strategies for enforcing out-of-plane periodicity, where, from left to right, are: Standard approach, alternative approach, and finally repetition of predefined patterns for periodic CA.

Laser powder bed fusion (LPBF) is an inherently multi-scale process in which multiple physical phenomena occur simultaneously over extremely short timescales and across different length scales. The resulting microstructure and porosity strongly govern the mechanical performance of printed parts, making an accurate description of microstructural evolution and pore formation essential for understanding, and for example exploiting, the effects of laser beam shaping.

To address this, a computationally efficient microstructure simulation framework based on cellular automata (CA) was developed. The model incorporates periodic boundary conditions, enabling seamless coupling with fast Fourier transform (FFT)-based crystal plasticity (CP) solvers. This new CA implementation enables rapid simulation of entire LPBF builds, facilitating virtual process optimization. Temperature fields used to determine grain growth kinetics were obtained from the recently developed second-generation (Gen.2) melt-pool dynamics model implemented in the open-source CFD platform OpenFOAM.

The Gen. 2 melt-pool model includes vapor-plume capture and predicts thermal and fluid-flow conditions for a range of laser beam profiles, from conventional Gaussian spots to ring-spot and full ring beams. Built on the diffused-interface-capturing interFOAM solver, the framework can be further enhanced by incorporating sharp-interface methods, such as isoAdvector, to enable even more accurate temperature and phase-boundary predictions in future developments.

For further reading, please see:

Santi A, Zinovieva O, Zhou B, Pan Z, Poulios K, Hattel J & Bayat M (2025), “Tailoring Cellular Automata for Physically-Based Generation of Periodic Microstructures in Powder Bed Fusion Processes”, SSRN.