Finite Element Modelling and Simulation Tools to Investigate the Process and Materials 3D-Printed by Selective Laser Melting

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INTRODUCTION: Selective Laser Melting (SLM), like many other additive manufacturing techniques, offers flexibility in design expected to bring a disruption to the manufacturing industry. The current cost of SLM process does not favor a try-and-error way of research; which gives more room for modelling and simulation in that field of engineering. Here we present a full model using Finite Elements Methods to solve a multi-scan SLM process problem using COMSOL Multiphysics Software. First, ray-tracing interface from Ray Optics Module is used to estimate the total laser energy deposited in powder bed then an analytical solution is used to define its distribution. Second, Temperature profile, cooling information and melt pool dynamics are simulated in a single or multi-scan process using coupling between heat transfer and laminar flow from heat transfer module. This model is conceived in a way to relate to experimental observations in printed parts.

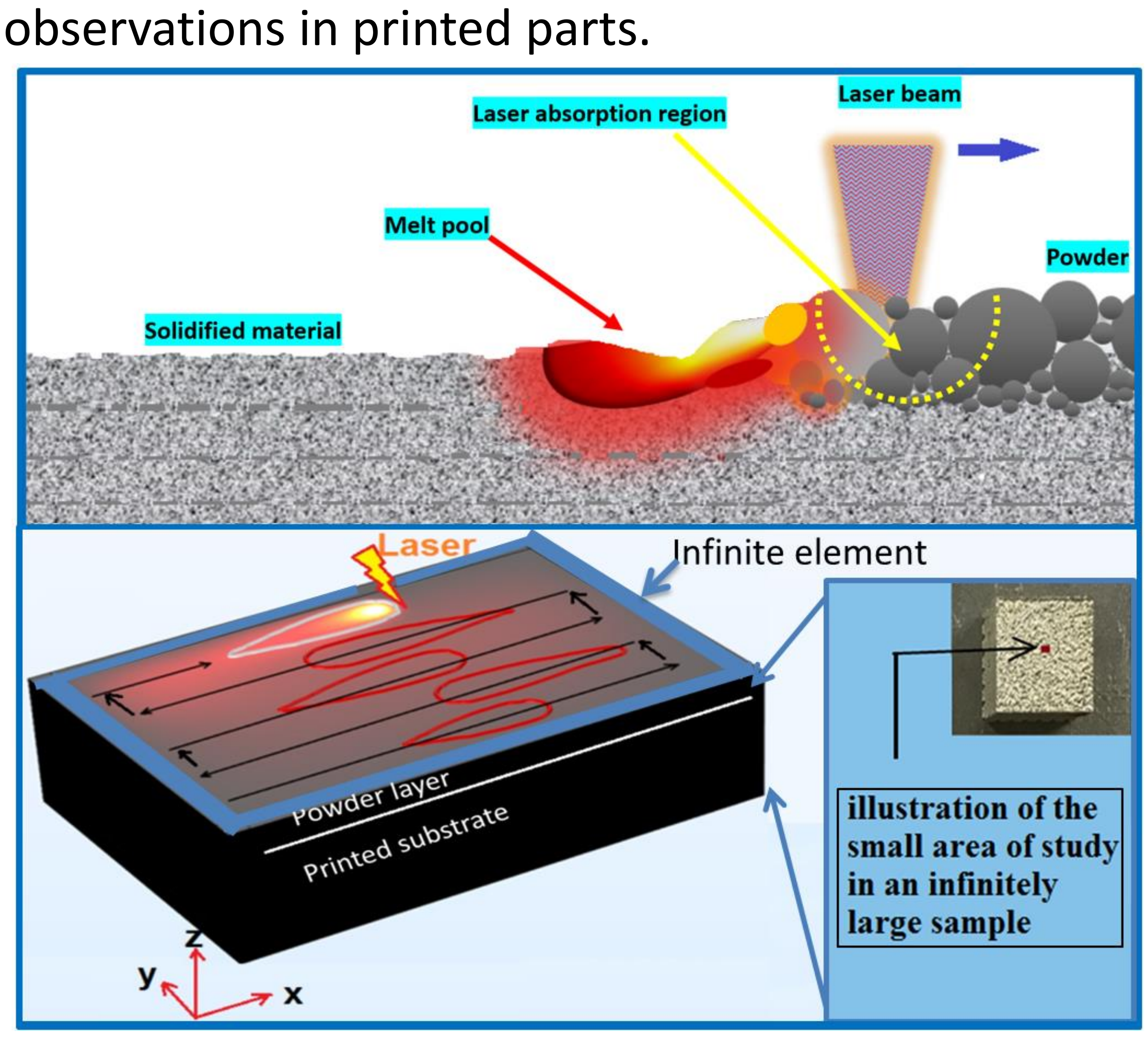

Figure 1. Illustration of SLM process (top) and a 5-scan simulation model setup (bottom)

COMPUTATIONAL METHODS:

Heat transfer

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u.\nabla T - \nabla(k\nabla T) = Q$$

$$k\left[\frac{\partial T}{\partial z}\right]_{z=H} = \varepsilon\sigma\left(T_o^4 - T^4(x,y,H,t)\right) + h\left(T_o - T(x,y,H,t)\right)$$

$$T(x,y,z,t)|_{t=0} = T_0$$

Mass transfer

$$\begin{cases} \rho\frac{\partial u}{\partial t} + \rho(u.\nabla)u = \nabla\left[-PI + \mu\left((\nabla u + (\nabla u)^T)\right)\right] + \rho g + F \\ \rho\nabla.(u) = 0. \end{cases}$$

Laser energy source from Ray-tracing and distribution

$$Q = (\alpha_A)\frac{2P}{\pi l(\alpha_r r)^2}\exp\left\{\frac{2[(x-p_1(t))^2 + (y-p_2(t))^2]}{(\alpha_r r)^2}\right\} \times u(z)$$

From Ray-tracing

- $F^{Marangoni} = \nabla_s\gamma, \quad \gamma = \gamma_0 + \frac{d\gamma}{dT}(T - T_{ref})$
- Recoil pressure during vaporization

RESULTS

Ray-tracing

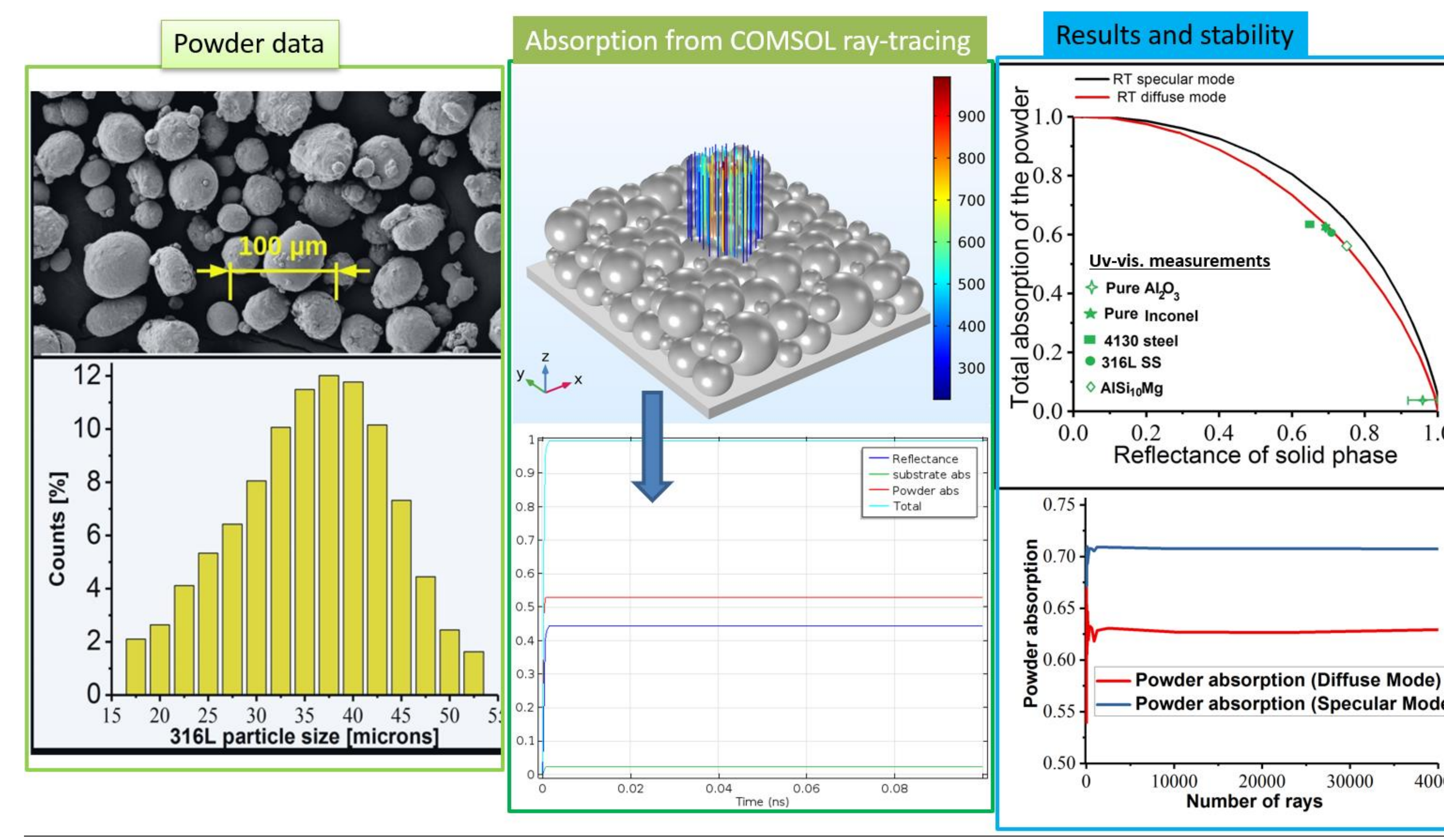

Figure 2. Collection of powder bed geometry parameters from experiment (left). Build powder-substrate geometry, generate the laser beam, trace rays, and compute the total absorption (middle). Comparison with experimental measurements and stability study of the solution vis-à-vis the number of rays.

T-profile, melt pool ad cooling information

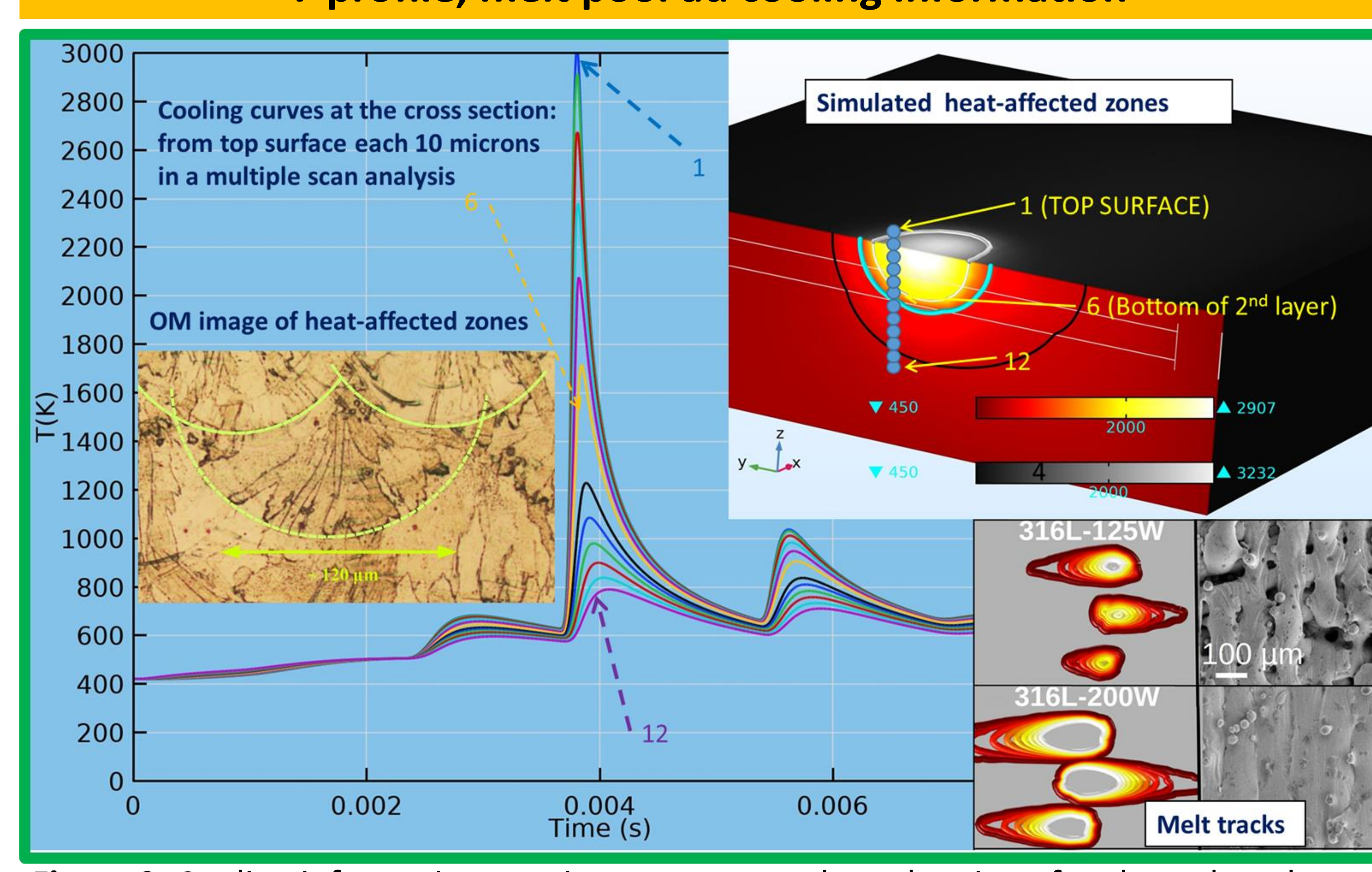

Figure 3. Cooling information vs microstructure and overlapping of melt pool track.

COMSOL Apps

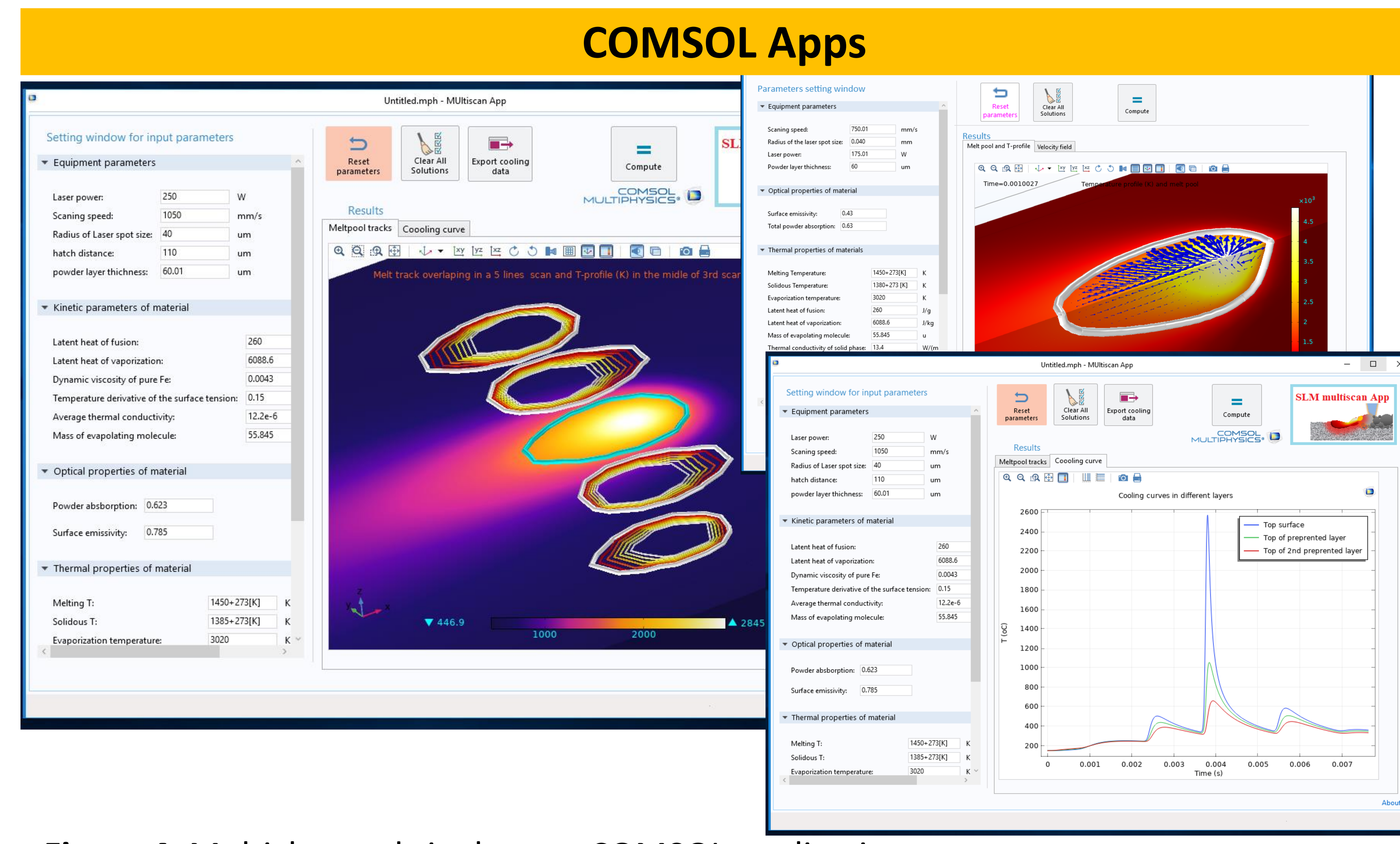

Figure 4. Multiclan and single scan COMSOL applications

CONCLUSIONS: Validated by experimental observations, the simulated T-profile and melt pool can predict the printing quality. The cooling information also helps to highlight microstructure of printed parts.

REFERENCES:

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