Finite Element Model Of Floating Zone In Laser-Heated Pedestal Growth Of Sapphire For Fiber Optics

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Abstract

Laser-Heated Pedestal Growth (LHPG) is a crystal growth technique that employs a focused laser beam to melt a source material, creating a molten zone that is precisely controlled to produce high-quality single crystals. This method is particularly advantageous for growing crystals with high melting points and for materials that require a clean, contamination-free environment. LHPG allows for the growth of crystals with tailored properties by adjusting the growth parameters, making it suitable for applications in electronics, photonics, and materials science. The process also enables the production of fibers and rods with uniform composition and superior structural integrity.

In this work, we present a Finite Element (FE) model to analyze the steady state of the sapphire molten zone generated by the Laser-Heated Pedestal Growth (LHPG) technique. We employ an incompressible fluid flow coupled with a heat transfer model to simulate the floating (molten) zone, while a heat transfer model is applied to the seed and solidified sections. The model incorporates phase change and mass transfer across the melting and solidification interfaces, buoyancy effects within the molten zone, and the Marangoni effect on the free surface. The solid sections are treated as rigid bodies moving at a uniform velocity. The boundaries of the molten zone (melting line, solidification line, and free surface) are tracked using an arbitrary Eulerian-Lagrangian approach. Heat input to the molten zone is provided by a far-field Gaussian temperature profile optimized to match our operating conditions. The numerical results closely align with experimental data, demonstrating excellent agreement in the shape and size of the molten zone.

The LHPG apparatus used in this work features a CO_2 laser as the heat source, an optical setup with a reflaxicon for generating an annular beam, and a system of mirrors to focus the beam onto the feed rod. The diameter of the growing crystal is controlled by adjusting the feed rod and seed speeds during growth.

Reference

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C-W. Lan, K. Sindo, Heat transfer, fluid flow and interface shapes in floating-zone crystal growth, Journal of crystal growth, 108.1-2, 351-366(1991).
M. Fejer, Single crystal fibers: Growth dynamics and nonlinear optical interactions, Stanford University, (1986).

Figures used in the abstract

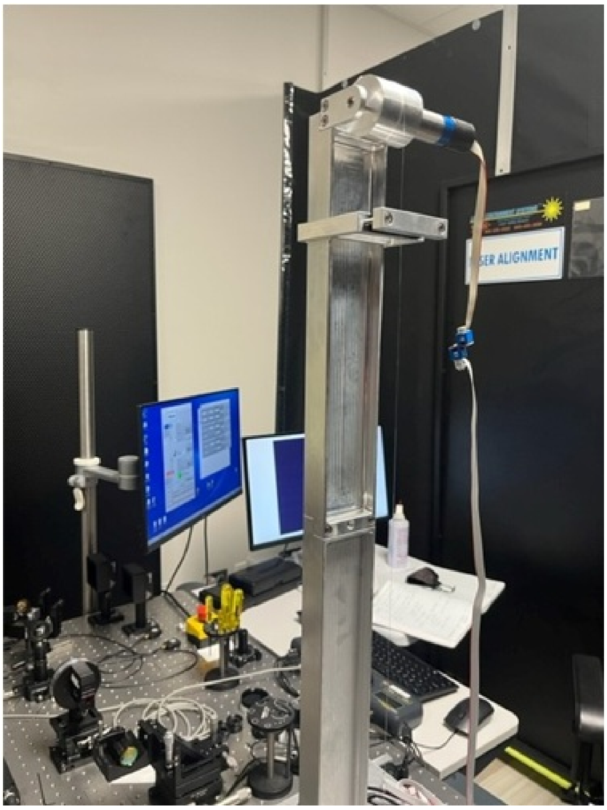

Figure 1 : Sapphire Growth Apparatus

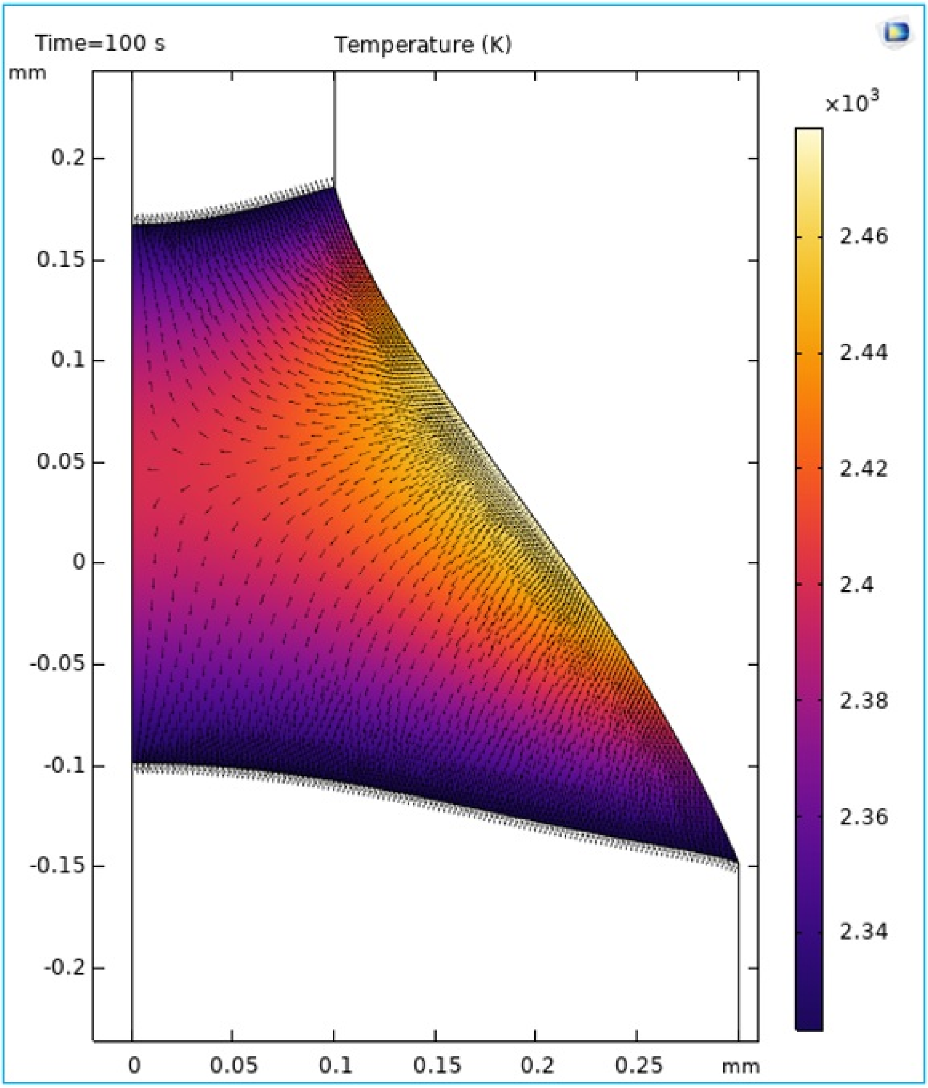

Figure 2 : Steady state temperature and heat flux inside the molten zone

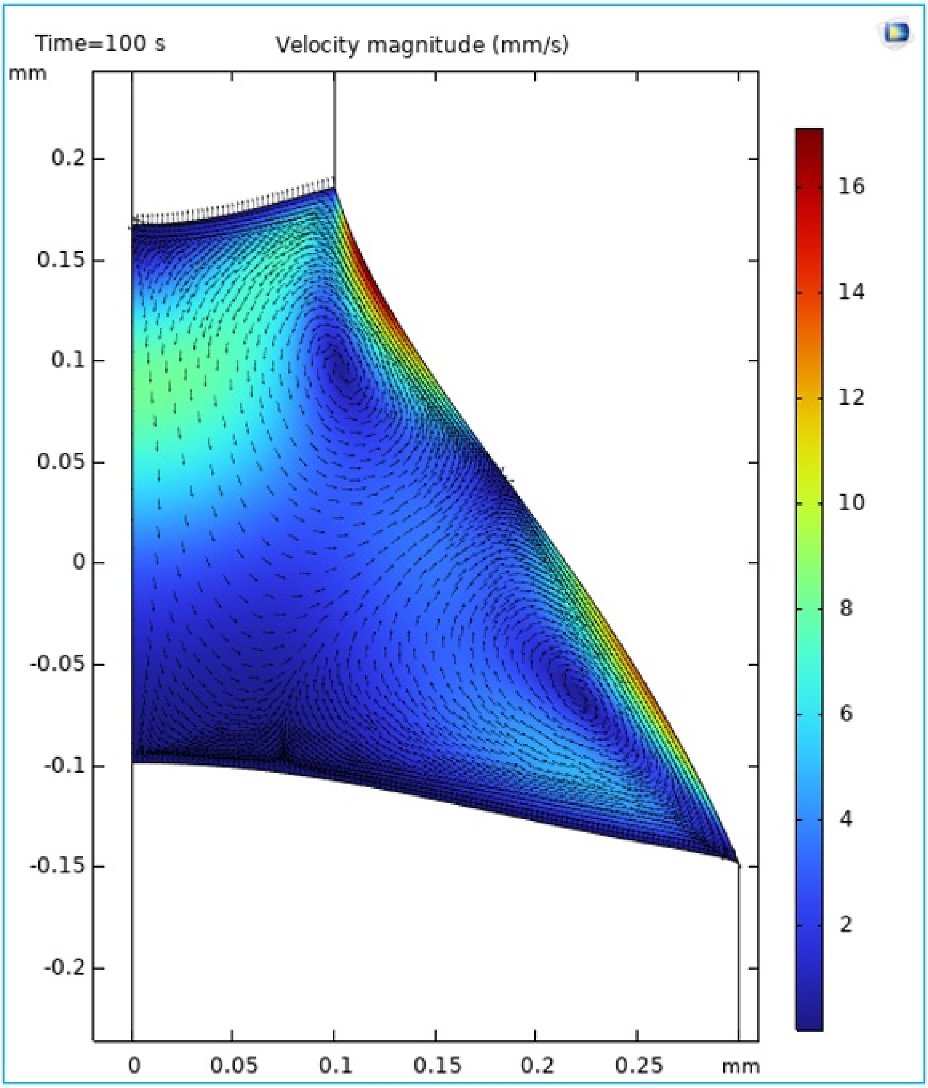

Figure 3 : Steady state velocity magnitude and direction inside the molten zone

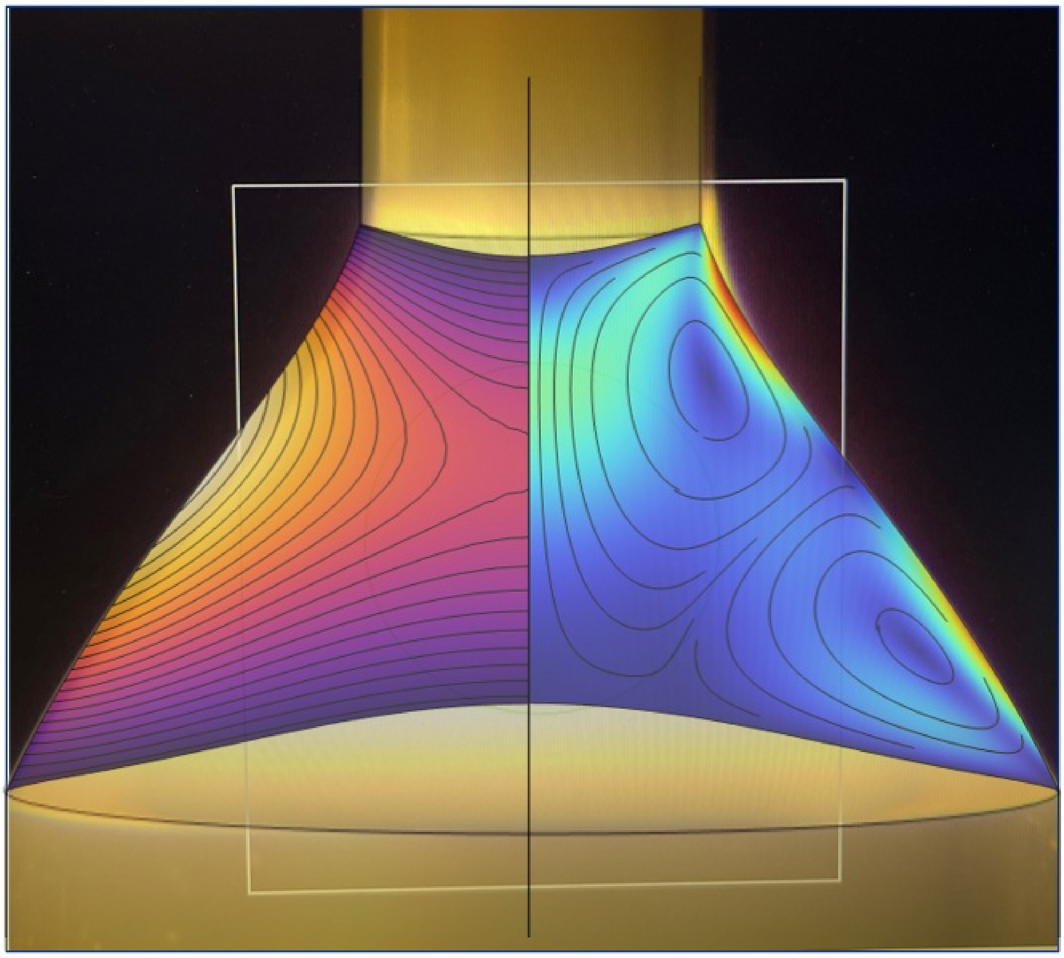

Figure 4 : Comparison of the molten zone shape with experimental results