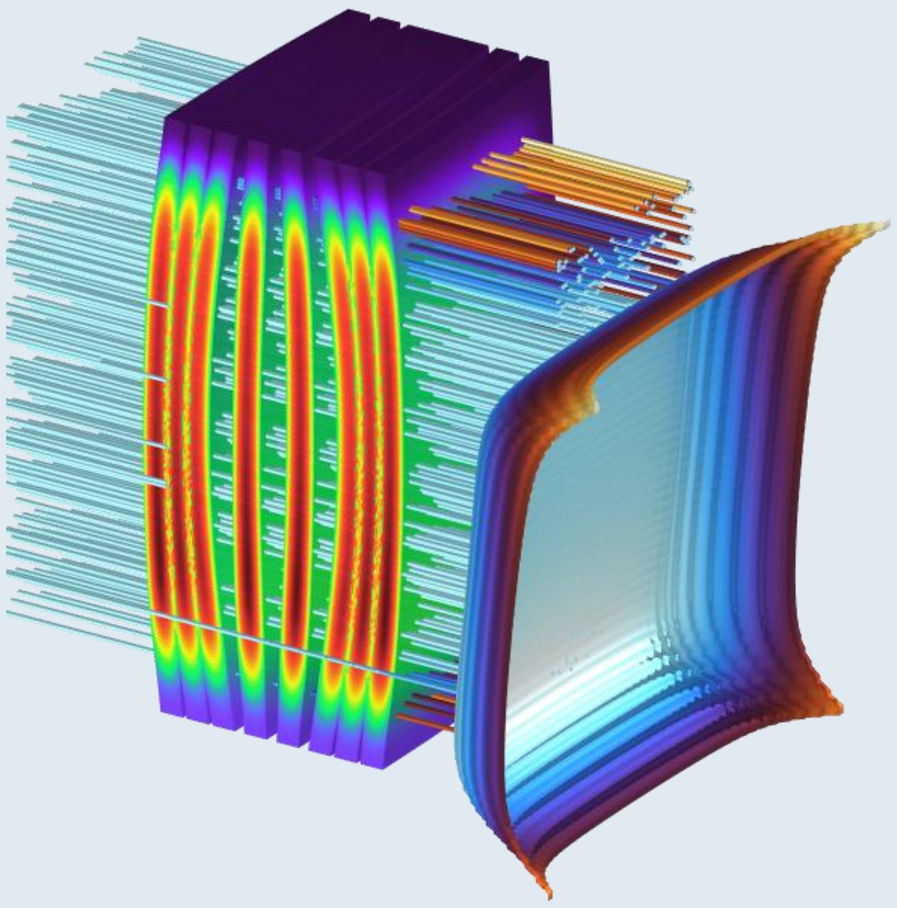

Thermo-optics of a Diode-Pumped High Energy Laser Amplifier for Inertial Confinement Fusion

Parametric study of the sources of optical phase distortions for next-generation fusion-class laser amplifiers

G Friedman[1], G LeTouze[1], B LeGarrec[1], D Hammond[1], C Paradis[1]
1:Focused Energy GmbH - Darmstadt, Germany + NorCal, USA

Abstract

High average power lasers with increased efficiency are a crucial development required for achieving inertial confinement fusion as a viable energy source. For high average power, the thermal management and its influence on laser beam quality strongly affect the final focusability on the target of fusible material. A thermo-mechanical-optical model of such a diode-driven laser amplifier in COMSOL® is presented. A holistic model tracks inputs from illumination-driven heat to ion energy storage dynamics to a customized optical propagation model yielding final output optical maps of phase and polarization as influenced by local thermal and stress. Cross-validation efforts from in-house code bases and published empirical results have been evaluated for canonical test cases. The final model outputs enable studies of the influence of architecture and design choices on optical metrics that indicate how to best manage the laser beam lines in a future fusion power plant.

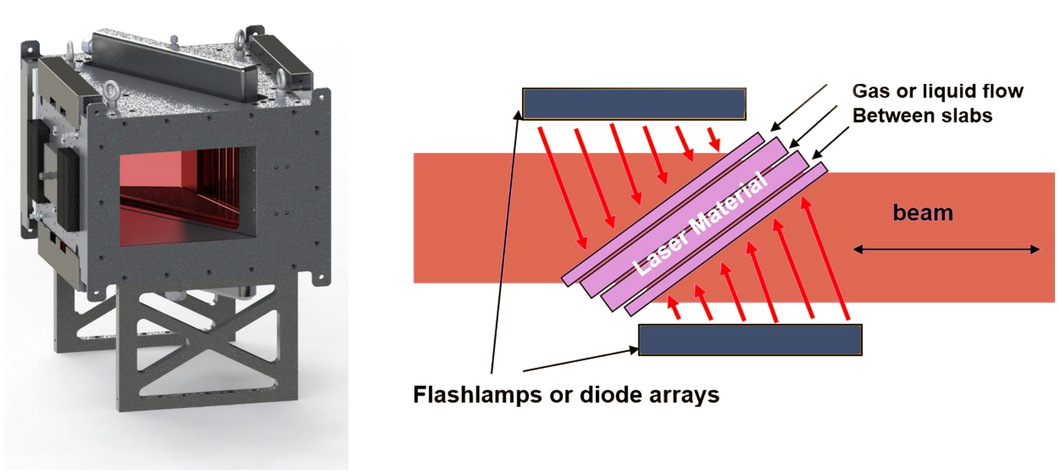

Figure 1: Left: Typical IFE Laser Amplifier Right: Horizontal Cross-Section of simplified amplifier used in the simulation.

Methodology

A Laser Amplifier is modelled including all optics and coolant channels. Optical material models for the complex refractive index are evaluated using tensor transformations from crystal material axes to propagation axes. The local refractive index ellipsoids are then evaluated relative to local polarization to capture birefringence. Birefringence is critical to performance since most laser fusion amplifiers and downstream frequency conversion are optimized at one polarization.

$$\boldsymbol{n_{ij} = n_0 + \frac{\partial n}{\partial T} * \Delta T(\vec{r}) + \sum \left(\frac{\partial n_{ij}}{\partial \sigma_{kl}}\right)_{ijkl} * \sigma_{kl}(\vec{r})^1}$$

Results

A refractive index tensor material model has been added to COMSOL®'s scalar treatment of the refractive index. A canonical test case has been cross-validated with in-house high power laser code and experimental data sets. 1st order match has been seen. Cross-validation performed for three key phenomena relevant for coupling laser light to fusion targets:

- R(z): Self-Focusing induced by Refractive Index Gradients.
- $I_x(x,y)$: Intensity losses due to radial stress-induced misalignment of polarization along diagonals.
- OPD(x,y,z): Wavefront Distortions that will diffract laser light out of the focus on target.

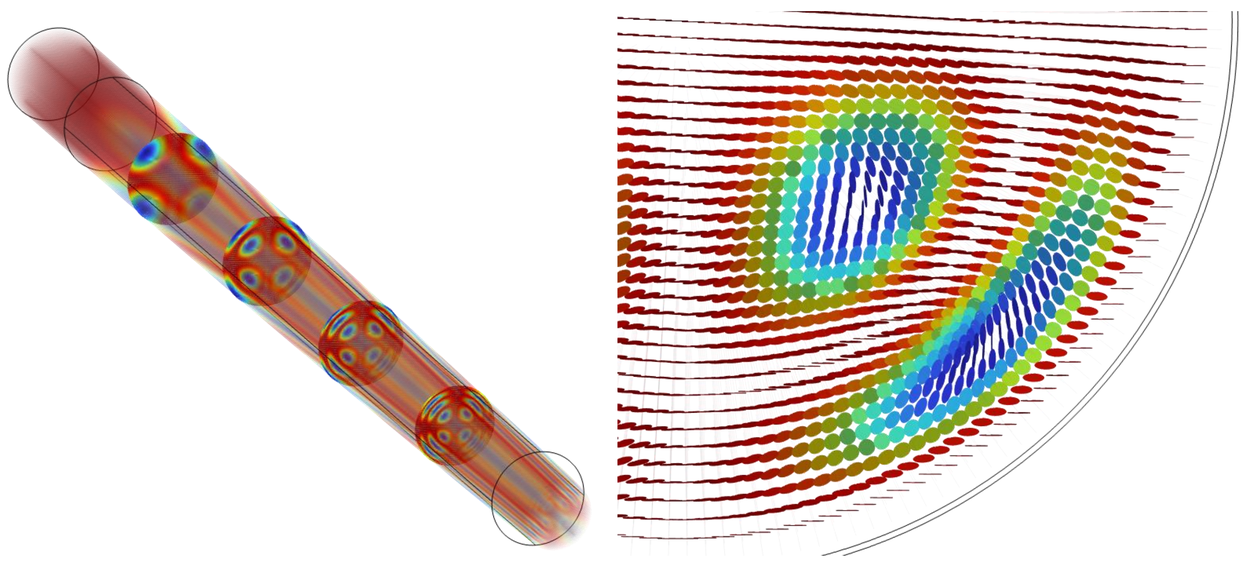

Figure 2: Left: Simultaneous self-focusing and birefringence of a high power Nd:YAG laser rod amplifier. Right: Local Polarization directional distribution from stress-induced birefringence.

REFERENCES

[1]Eggleston, J. M., Kane, T. J., Kuhn, K., Unterharer, J., & Byer, R. L. (1984). The Slab Geometry Laser-Part I: Theory. IEEE JOURNAL OF QUANTUM ELECTRONICS, QE-20(3).

FOCUSED

Excerpt from the Proceedings of the COMSOL Conference 2025 Amsterdam