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Thermal Modeling and Benchmarking of Crystalline Laser Amplifiers

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Detailed thermal modeling of crystal amplifiers is a prerequisite for rapid improvement—higher pulse quality, higher average power at maximum achievable peak intensity, better repeatability, etc.—of high-intensity lasers (100 TW to multi-PW) with ultra-short pulse lengths ($<$ 100 fs). In recent work [1], we used the open-source, finite-element code FEniCS [2] to solve the linear partial differential equation for thermal transport across a cylindrical Ti:Sapphire crystal, assuming a $532\ \mathrm{nm}$ Gaussian pump laser illuminating the crystal from one side at $1\ \mathrm{kHz}$. From the experimentally measured thermal time scale of approximately $150\ \mathrm{ms}$, we inferred a room-temperature thermal diffusivity of about $0.29\ \mathrm{cm}^2/\mathrm{s}$. This value does not agree well with those calculated directly from thermal conductivity and specific heat capacity values found in the literature. Sources of uncertainty include (a) the pump laser power absorbed as heat by the crystal (which depends on both the absorption coefficient and the fractional thermal heat load), and (b) variations of the thermal conductivity and specific heat capacity (which vary with both temperature and details of the titanium doping). In order to address these uncertainties, we have generalized our FEniCS model to include nonlinearities associated with temperature variations of the thermal conductivity and specific heat capacity, across a wide range of temperatures. We will present recent work, comparing linear and nonlinear simulations, at cryogenic temperatures and also at room temperature.

[1] D.T. Abell *et al.*, Proc. IPAC'22, THPOTK062, https://jacow.org/ipac2022/papers/thpotk062.pdf.
[2] The FEniCS Computing Platform, https://fenicsproject.org.

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