Iterative 3D modeling of thermal effects in end-pumped continuous-wave Ho^{3+}:YAG lasers

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High power lasers operating at around 2 µm can be used for a variety of applications, ranging from medical treatments and countermeasures to the pumping of mid infrared optical parametric oscillators (OPOs). Especially for the latter application, pulsed crystal lasers have shown great potential. Ho^{3+}-doped media like Ho^{3+}:YAG are efficient for emitting at wavelengths greater 2 µm, where OPOs can be pumped more efficiently due to lower parasitic absorption. To optimize Ho^{3+}:YAG resonator setups for high power, efficiency and a good M², a simulation model can greatly assist with the development and understanding of such setups. The model we present in this work aims to simulate a real resonator setup with high accuracy, therefore many properties of the resonator and the laser gain medium need to be taken into consideration.

The fundamental propagation model is based on a split-step fast Fourier transform beam propagation method, similar to the one developed by Fleck et al. [1]. By adding additional calculation modules in between the propagation steps, a resonator with a variety of components can be simulated. For example, mirror surface components are necessary to calculate the replicating field in a resonator. Another essential component of the model is the laser crystal, the gain of which is calculated by solving the temporal rate equations of the material, in this case Ho^{3+}:YAG. The rate equations are based on a 2D model for Er^{3+}:YAG described by Eichhorn [2] and include upconversion, cross-relaxation and quenching effects to model the laser gain as accurately as possible. The laser crystal component also takes into account thermal effects like thermal lensing and stress-induced birefringence. This is achieved by iteratively calculating the temperature distribution and the thermal expansion in the crystal based on finite-difference methods solving the respective differential equations [3].

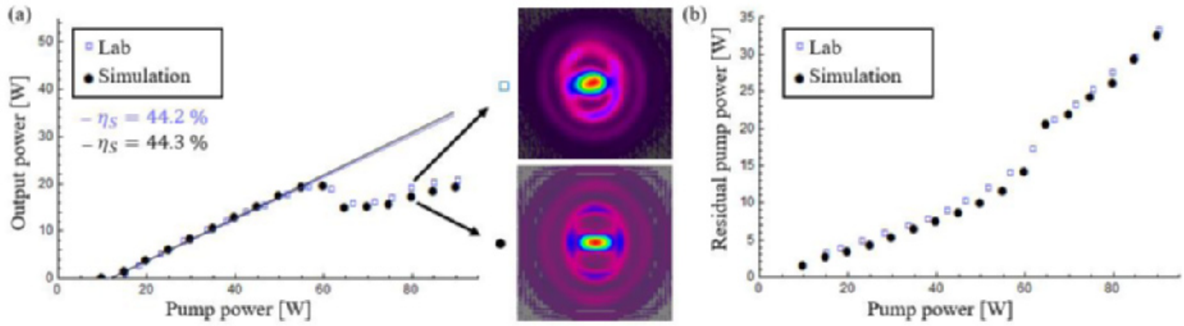

Figure 1. Comparison of an experimental Ho^{3+}:YAG resonator setup with the model. In (a), the laser output power is compared, in (b) the residual pump power.

The combination of the aforementioned algorithms allows the modeling of Ho^{3+}:YAG resonator setups with an accurate representation of laser output power, resulting M² and output field distribution. Fig. 1 shows a comparison of the model with a simple single pass, Tm^{3+} fiber end-pumped Z-resonator that was not optimized in order to test the model at suboptimal beam qualities due to thermal distortions. The output Ho^{3+}:YAG laser power (a) as well as the residual pump power after the single pass through the crystal (b) is in excellent agreement throughout the whole pumping range. The model is also capable of reproducing the beam distortions in the output field with very good accuracy, which is shown in Fig. 1 for a pump power of 80 W. The validation with this resonator setup proves the model to be a powerful tool to investigate and optimize Ho^{3+}:YAG resonators, which will be put to the test and improved upon in further research work.

References

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