Simulation of Polarization Effects in Solid State Lasers and Amplifiers

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***Abstract*—Polarization effects in laser crystals like Nd:YAG have a strong influence on output power and beam quality of laser resonators and laser amplifiers. Simulation techniques to analyze these effects are presented.**

I. Introduction

Nd:YAG and Yb:YAG are widely used crystals in high power/pulse energy laser applications. These crystals are used in both laser resonators and amplifiers. One important property of Nd:YAG crystal is its high gain efficiency for a relatively small bandwidth. In normal room temperature, these crystals produce no birefringence effect. Higher power pumping of the laser crystal leads to a strong inhomogeneous temperature field and a stress induced birefringence effect, which decreases beam quality of the output beam (see Figure 2). Therefore, reducing the influence of birefringence is important for both laser resonators and amplifiers [3]. Popular approaches used to decrease birefringence effects include adding different types of polarizers, as well as suitable adjusting of one or several crystals as gain medium. The drawback of these techniques is that strenuous efforts are needed to optimize laser resonators and amplifiers, because they add new parameters to the optical system. In practice, several resonator and amplifier parameters are ignored to simplify the optimization process. For example, the rotation of crystals and different cut directions are not studied in an optimization process. Therefore, numerical simulation is essential for an accurate optimization of resonators and amplifiers.

II. Numerical Method

In this paper, two approaches to analyze polarization effects in laser crystals are presented. Both methods are based on a detailed finite element analysis (FEA) of temperature and mechanical stress in lasers crystals. Pump light absorption is accurately calculated using ray tracing method. The result of the FEA is used to calculate the refractive index change:

$$n_{ij} = n_0 + \frac{\partial n_0}{\partial T}(T - T_0) - \frac{1}{2} n_0^3 p_{ijkl} \epsilon_{kl}.$$

Here, p_{ijkl} are the photoelastic constants, n_0 the refractive index at room temperature, ϵ_{kl} the mechanical strain, and $\frac{\partial n_0}{\partial T}$ the temperature dependence of the refractive index. The refractive index n_{ij} leads to the indicatrix

$$B_{11} x_1^2 + 2 B_{12} x_1 x_2 + B_{22} x_2^2 = 1,$$

where B_{ij} is the dielectric impermeability. Using this indicatrix one can calculate the birefringence:

$$\triangle n_{bire} = \frac{n_0^3}{2} \sqrt{(B_{11} - B_{22})^2 + 4 B_{12}}$$

Figure 2 depicts this birefringence for a laser crystal pumped at both end faces.

The indicatrix is the main input for the two approaches for analyzing polarization effects in laser crystals. The first approach uses the Jones matrix method on a 2-dimensional transversal plane (see [1]). This method can be applied to both resonators and amplifiers. For example, this analysis allows us to calculate the polarization eigenvectors in a laser resonator. The corresponding eigenvalues describe the damping of these modes per round trip. This simulation approach can be used to study the effect of a polarizer inside a laser cavity on the laser output power and beam quality. Specially, it can be shown that inserting a suitable polarizer increases beam quality and reduces output power. Beam quality calculation is performed by dynamic mode analysis (DMA) method (see [4]). The second approach implements a vectorial beam propagation method (VBPM) (see [2]). This method calculates the rotation of a beam inside a laser crystal.

III. Numerical Method

As an example let us consider a laser amplifier based on a side pumped Nd:YAG crystal. Using a vectorial beam propagation method (VBPM), we analyze polarization distortion in the laser crystal caused by birefringence. Figure 1 show typical simulation results. Assuming an x-polarized TEM00 wave is incident to a laser amplifier crystal, the birefringence inside the crystal rotates the polarization. Consequently, the output beam will not be x-polarized. An interesting observation is that the output beam is not symmetric with respect to the x-axis. The reason is that birefringence is not rotational symmetric for a [111]-cut crystal. However, it has a three folded symmetry caused by the crystal structure. These symmetry properties and birefringence have to be considered, in order to optimize the laser beam quality more efficiently.

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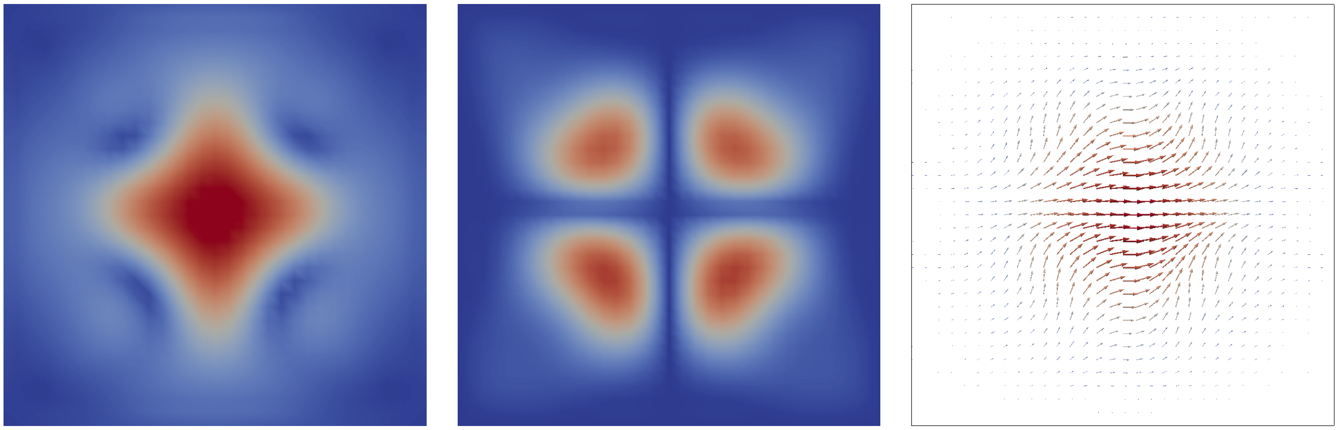

(a) x-component (b) y-component (c) vector field

Fig. 1: Output beam of a laser amplifier. The input beam is a TEM00 x-polarized Gauss mode.

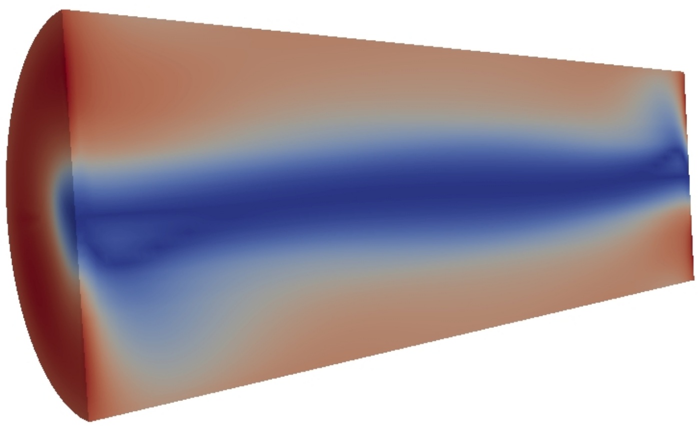

Fig. 2: Birefringence in a two end face pumped [111]-cut Nd:YAG crystal.

IV. Conclusion

Using 3-dimensional finite element analysis and vectorial beam propagation method one can analyze polarization effects in solid state lasers and amplifiers in detail. Further investigations and simulations will help to reduce birefringence effects. This will improve beam quality and output power of laser amplifiers.

References

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