Three Methods for Calculation of Thermally Induced Beam Distortions in Laser Ceramics

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Abstract—Methods for calculating thermally induced beam distortions in laser ceramics are discussed. The ranges of applicability and the quantities calculated are compared.

Keywords—laser ceramics; thermally induced beam distortions; beam quality; photoelastic effect; thermally induced birefringence

Ceramics are promising laser materials combining beneficial properties of single crystals and glasses. In the recent years ceramic lasers achieved average power level of several kilowatts [1,2].

Thermally induced beam distortions are one of the negative effects limiting the average power of solid-state lasers [3]. Thermal gradients are caused by quantum defect in active media and by parasitic absorption in supplementary optics. Due to thermal expansion, the gradients lead to elastic stresses that, in turn, due to photoelastic effect give rise to induced anisotropy of the medium. Being non-uniform in the cross-section, the latter causes phase and polarization distortions of the transmitting beam. The specificity of thermally induced beam distortions in ceramics comes from the randomness of crystallographic axes orientation in its grains [4].

About ten years ago a method for calculation of the thermally induced depolarization degree in ceramics in the plain wave approximation (and thus, for the case of grains much larger than the wavelength) using a matrix method similar to Mueller matrix approach was suggested [5]. We modified this technique in order to calculate statistics of the transmitted beam phase at weak birefringence. The overlapping integral of the input and the transmitted beams in the plain wave approximation which is based on the Jones matrix formalism and does not limit itself to the case of weak birefringence. We found out that the large-scale field intensity calculated using this technique coincides with the one obtained by combining the two methods described above.

Thus, there exist three methods for calculating thermally induced beam distortions. We have found out that, despite the differences in usability conditions and the ceramic medium models exploited, the quantities of distortions obtained by these techniques are identical. In the case of large grains the intensity of both large and small-scaled fields with both initial and transverse polarization was calculated. In the case of small grains the separation of the small-scale field into polarizations is yet to be made if necessary.

In the case of large grains it is proportional to the grain size and in the case of small grains to the size cubed. For large grains it is also possible to separate the scattered field up into initially polarized and transversely polarized (also called depolarized). Although Rayleigh-Debye scattering theory does not allow one to find the decay of intensity of initial (large-scale; non-scattered) field directly, it can be obtained from the intensity of the scattered field and the depolarization degree discussed earlier. However, the major difference in ceramic medium models implied by these two calculation methods calls the correctness of combining these solutions in question.

We suggested a method for calculating the overlapping integral of the input and the transmitted beams in the plain wave approximation which is based on the Jones matrix formalism and does not limit itself to the case of weak birefringence. We found out that the large-scale field intensity calculated using this technique coincides with the one obtained by combining the two methods described above.

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