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Gauss-BPM: An accurate Beam Propagation Method for Gaussian Beam Amplification

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Here, a novel method called the Gauss-BPM is presented for the amplification of laser beams in solid-state amplifiers and resonators. This modified version of the classical beam propagation method exhibits a significant improvement in accuracy. In detail, the Gauss-BPM is obtained by introducing the analytical solution for pure Gaussian beam propagation into the differential equation of the classical BPM. This leads to a transformation of the Helmholtz equation to the following partial differential equation:

$$-\frac{\partial^2 \Xi}{\partial x^2} - \frac{\partial^2 \Xi}{\partial y^2} + 2ik_0 \frac{1}{q+z}\left(x\frac{\partial \Xi}{\partial x} + y\frac{\partial \Xi}{\partial y}\right) + 2ik_0\frac{\partial \Xi}{\partial z} + (k_0^2 - k^2)\Xi = 0 \qquad \text{(Eq. 1)}$$

As a result, the information of the approximate spatial profile of the beam is already included in the fundamental description of beam propagation. In order to solve the Gauss-BPM (Eq. 1) several discretization schemes are compared and the best suitable space stepping method is evaluated. Moreover, a 3-dimensional finite element approach is applied to resolve the spatial dependence of beam amplification.

It is demonstrated that the Gauss-BPM method exhibits a remarkable improvement in accuracy compared to the classical BPM. This improvement is pointed out by comparing the transversal beam profile resulting from both methods after amplification by a Ho:YAG crystal with respect to the meshsize of the simulation domain. Furthermore, the properties of the Gauss-BPM method are precisely analyzed and possible limitations are pointed out.