Random Mode Coupling Assists Kerr Beam Self-Cleaning in a Graded-Index Multimode Optical Fiber

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Spatiotemporal light beam dynamics in multimode fibers (MMF) recently has attracted renewed interest in both fundamental physics and various fields of practical application [1,2]. Recent experiments [2,3] have shown that, owing to the Kerr effect, a process of beam self-cleaning can be observed in graded-index (GRIN) MMFs. As a result, one observes a robust nonlinear beam, which has a size that is close to the fundamental mode at the fiber output, in contrast to a speckled output beam, which is obtained in the case of the linear regime.

In this paper, we numerically investigate the process of beam self-cleaning in GRIN MMFs. Unlike previous approaches [3], where the nonlinear propagation of a spatial beam along the multimode fiber was described by the generalized 3D nonlinear Schrdinger equation, we use the coupled-mode model, which has the following form:

$$2i\frac{dA_{p,m}}{d\zeta} = D(n+1)^2 A_{p,m} + p \sum_{m+m_1=m_2+m_3} \sum_{p+p_1=p_2+p_3} f^{m,m_1,m_2,m_3}_{p,p_1,p_2,p_3} A_{p_1,m_1} A_{p_2,m_2} A_{p_3,m_3} + \sum_{m_1,p_1} C^{m,m_1}_{p,p_1} A_{p_1,m_1}.$$

These equations separately describe the evolution of the amplitude of each mode $A_{p,m}$. The coupled mode approach significantly reduces the computation time, due to the use of a large integration step. To account for the various imperfections of the multimode fiber, caused by fabrication, bending or tilting, we added a random linear coupling term to the equation.

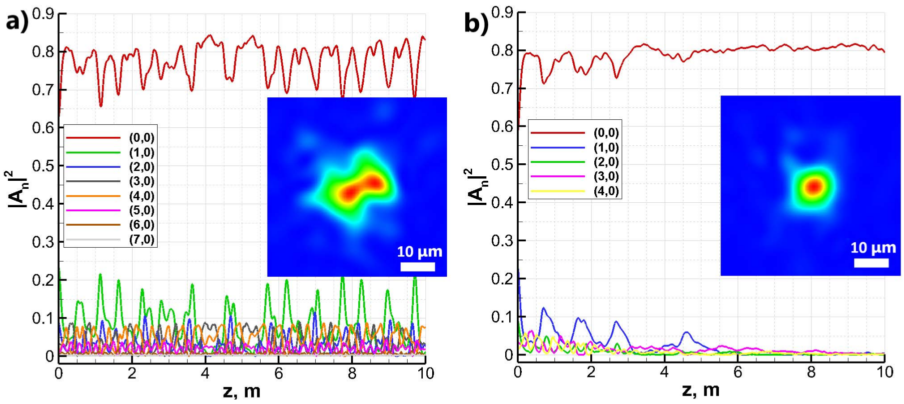

Fig. 1 Dynamics of energy distribution by modes and the output field for the model without random linear coupling (a) and with random linear coupling between degenerate modes (b).

In this contribution, we describe various models of random linear coupling between spatial modes, including coupling between all modes, or only between degenerate ones, and investigate the effects of random mode coupling on the beam self-cleaning process. Fig. 1a shows the spatial dynamics of energy distribution among the modes, corresponding to a model without any random linear coupling. In this case, in spite of being in a strong nonlinear regime, the power of the fundamental mode oscillates along the fiber, and we still obtain a speckled beam at the fiber output. On the other hand, if we consider a model with random linear coupling between spatial modes with equal mode numbers, one readily observes the appearance of a self-cleaning effect, and the fundamental mode power swiftly stabilizes upon the propagation (see Fig. 1b). The output beam in this case has a size that is close to that of the fundamental mode. The results of numerical investigations are in complete agreement with our experimental data.

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