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Mode dynamics during transition into Kerr self-cleaning regime for laser beams propagated in a multimode GRIN fiber

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For a long time, interest in multimode (MM) optical fibers has remained limited, owing to the poor quality of laser beams emerging at their output. A typical indicator of beam quality is inversely proportional to the number of excited modes. However, recent intensive research of nonlinear propagation effects, involving high-power laser beams in MM graded-index (GRIN) fibers, has led to the discovery of previously unexpected phenomena, such as the Kerr-activated self-cleaning of a beam [1]. The manifestation of self-cleaning is that most of the beam energy flows into the fundamental mode of the fiber. This process is accompanied by a redistribution of energy towards higher-order modes [2]. Increasing the fundamental mode energy leads to improving the output beam quality. The standard method to determine the beam quality is to measure the M2-parameter (m-squared). This parameter measures the divergence of the beam with respect to the Gaussian beam. However, since self-cleaning involves a nonlinear redistribution of energy carried by a large number of fiber modes, this approach is not entirely correct, and a full mode decomposition (MD) of the output beam appears to be a much more informative method.

The MD is a beam analysis technique, which measures both amplitudes and relative phases of all modes that carry the beam in the MM fiber. Existing MD methods are based on either genetic algorithms, adaptive optics, or phase modulation. The last option can be implemented by using a spatial light modulator (SLM) [3]. An SLM is a device that superimposes a certain form of spatial modulation (amplitude, phase, or amplitude and phase simultaneously) on an optical beam, and it is usually controlled by a computer. The aim of our work is to demonstrate that MD can be effectively used, in order to characterize the effect of Kerr beam self-cleaning.

By using the property of orthonormalization of fiber modes, the Jacobi-Anger expansion and the Fourier transform theorems, phase masks were formed, in a such way that the center of the first diffraction order contains the information about the mode amplitude or its relative phase with respect to the fundamental mode [4].

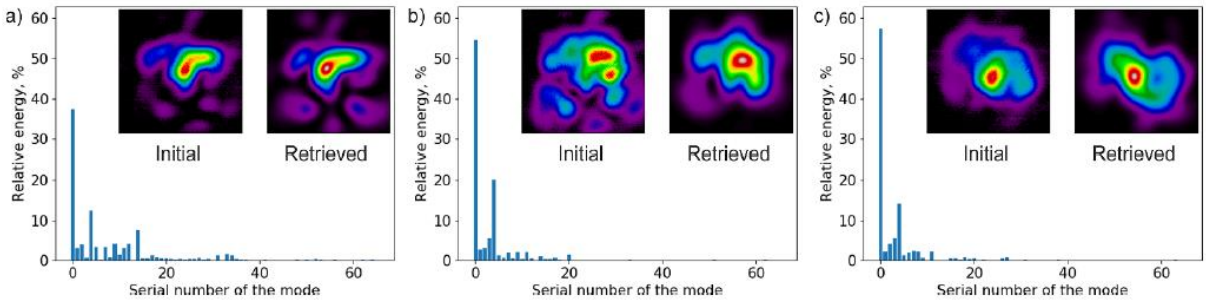

Fig. 1 Mode decomposition of the beam with three different input power levels: 0.92 kW (a), 2.3 kW (b) and 6 kW (c).

The Figure 1 illustrates mode energy distributions of ~80 modes, contributing to pulsed beams of different peak powers, showing the transition from the linear into the nonlinear propagation regime. In fact, MD allows us to reveal the dependence of the output mode energy distribution on the peak power of the input beam. As it can be seen by comparing figures 1(a-c), the fundamental mode contribution grows steadily from about 38% to more than 55% at high powers, which leads to a bell-shaped spatial intensity distribution at the GRIN fiber output.

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Example References

[1] K. Krupa, A. Tonello, B. M. Shalaby, M. Fabert, A. Barthélémy, G. Millot, S. Wabnitz & V. Couderc, “Spatial beam self-cleaning in multimode fibres,” Nature Photonics, **11**, 237-241 (2017).
[2] E. V. Podivilov, D. S. Kharenko, V. A. Gonta, K. Krupa, O. S. Sidelnikov, S. Turitsyn, M. P. Fedoruk, S. A. Babin, and S. Wabnitz, "Hydrodynamic 2D Turbulence and Spatial Beam Condensation in Multimode Optical Fibers," Phys. Rev. Lett. 122, 103902 (2019).
[3] D. Flamm, D. Naidoo, C. Schulze, A. Forbes, & M. Duparré, “Mode analysis with a spatial light modulator as a correlation filter,” Optics letters, **37**, 2478-2480 (2012).
[4] M. D. Gervaziev, I. Zhdanov, D. S. Kharenko, V. A. Gonta, V. M. Volosi, E. V Podivilov, S. A. Babin, and S. Wabnitz, "Mode decomposition of multimode optical fiber beams by phase-only spatial light modulator," Laser Phys. Lett. 18, 015101 (2021).