Modal attraction on low order modes by Kerr effect in a graded refractive index multimode fiber

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Abstract: Modal attraction towards low order modes in a GRIN multimode fiber was experimentally observed at high power and characterized, thus enriching the dynamics of the Kerr self-cleaning effect leading to quasi fundamental mode generation.

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1. Introduction

Nonlinear propagation of laser pulses in GRIN multimode fibers (MMFs) has recently unveiled an effect which was named Kerr self-cleaning, i.e. the reshaping at high power of the speckle output pattern into a bell-shaped beam. Such nonlinear beam shaping was observed at power levels below the thresholds for parametric or Raman frequency conversion, and with sub-nanosecond to femtosecond pulses in the normal dispersion regime [1-4]. It is admitted today that Kerr self-cleaning results from a complex four-wave mixing interaction among a large population of guided modes. However, a simple and complete interpretation of the underlying nonlinear dynamics remains under discussion. In this communication, we report experiments showing that Kerr induced modal self-organization can be achieved also in favor of transverse low-order modes in a gradient index (GRIN) MMF.

2. Experimental results

The Gaussian laser beam from a Q-switched Nd:YAG microchip laser was focused by a positive lens to a diameter of ~30 µm onto the input facet of a GRIN MMF. The fiber with a core diameter of 52 µm has a measured refractive index profile well fitted by a quadratic curve with a core cladding index difference of $15x10^{-3}$. The fiber sample was ~8 m long and laid loosely coiled on the optical table. A three-axes precision translation stage served to adjust the position of the fiber. During the experiments, we varied the light coupling conditions playing with the position and incidence angle of the input beam or/and with the cleave angle of the fiber end. In an initial step, we achieved Kerr beam self-cleaning. Starting at low power with a wide output speckle, we observed, above a threshold power of about 1 kW, the expected bell-shaped beam sitting on the center of a low background level. For some specific settings, we observed, still at high power, that the bell-shaped beam evolved into a two lobes pattern very close to that of the LP11 mode (Fig.1). In order to assess if the self-organized output actually corresponds to a LP11 mode field, the MMF output far field was simultaneously recorded in a new experiment. The observations shown that the low power speckle far field pattern covering most of the MMF numerical aperture, reshaped at high power into a two lobes structure with a zero on axis. The transverse pattern in the wavevector space was therefore in agreement with the optical field of an LP11 mode with angular momentum +/- 1. The power threshold for this modal attraction toward the LP11 was higher than that for self-cleaning, namely, about 4-5 kW (coupled power).

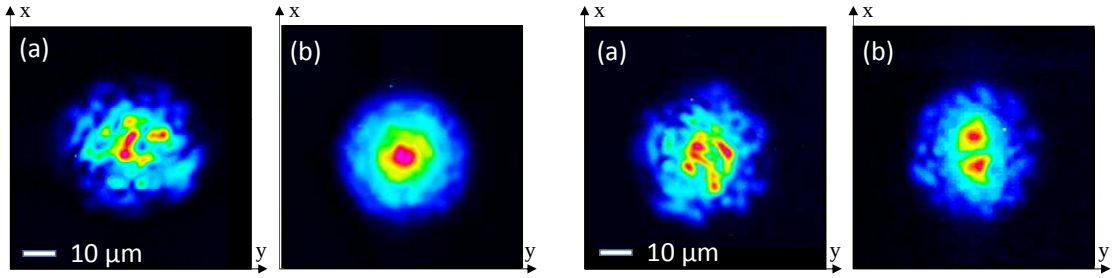

Fig. 1. Comparison between Kerr beam self-cleaning (left) and modal attraction for a LP11 mode pattern (right) observed for two different input couplings. Low power intensity patterns in (a) and high intensity pattern in (b), pulse duration 740 ps.

By using correlations between the recorded images of the MMF output and the theoretical LP11 mode intensity image, we studied the strength of modal attraction versus laser peak power. The computed data are plotted on Fig.2. The traces exhibit quite similar dynamics for the near field and far field correlation parameters, leading to a significant increase of the correlations at high powers. It is worth mentioning that the fiber excitation to achieve Kerr modal attraction on a low order mode was far more critical than that corresponding to a LP01 like mode. An adaptive coupling system may be advantageous in this context. On the other hand, we achieved LP11 modal attraction on different samples of GRIN MMF and with different laser sources (delivering short or long pulses). Modal attraction into a LP21 mode was also observed.

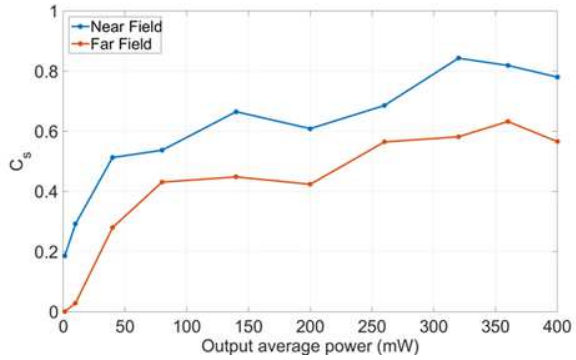

Fig. 2. Correlation between the experimental patterns recorded at the GRIN-MMF output and the LP11 theoretical figure versus the coupled laser power for the near field (blue) and far field (orange) intensity patterns

3. Conclusion

The reported experiments demonstrate, for the first time, that modal attraction, resulting from complex multiple four-wave mixing in a GRIN-MMF, besides generating the fundamental mode, also generates different transverse low-order modes in an environmentally stable manner. Additional results will be presented at the conference, showing, in particular, the dynamics of modal attraction build-up, and its robustness with respect to external perturbation. These experiments open the way for synthetizing orbital angular momentum modes in multimode fibers [5].

4. References

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