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Experimental observation of phase mode locking in multimode graded index optical fiber

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The best-known example of phase locking in multimode optical systems is the laser cavity incorporating an ultrafast saturable absorber [1]. Here, the relative phase between the longitudinal cavity modes turns out to be synchronized in order to form a pulse. This mechanism is based on the presence of dissipation or nonlinear losses. These conditions are far from the case of beam self-cleaning, which occurs in lossless fiber systems [2]. However, in literature there are several example of phase-locking among modes for a purely conservative nonlinear optical system. An example is provided by the interaction among waves with different states of polarization, where phase-locked states emerge as stable attractors [3].

Self-cleaning is known to lead to coherent beams at the fiber output [2]. To further investigate this aspect, we collected, in our experiments, both the intensity and the phase content for each mode, by using a holographic mode decomposition method, based on a spatial light modulator [4]. Mode information was collected by injecting in a graded-index (GRIN) fiber, picosecond pulses with input peak powers leading to self-cleaning. This permitted us to observe that the self-cleaning mechanism leads to a phase-locking among the lowest-order modes, which carry most of the power to the fundamental mode.

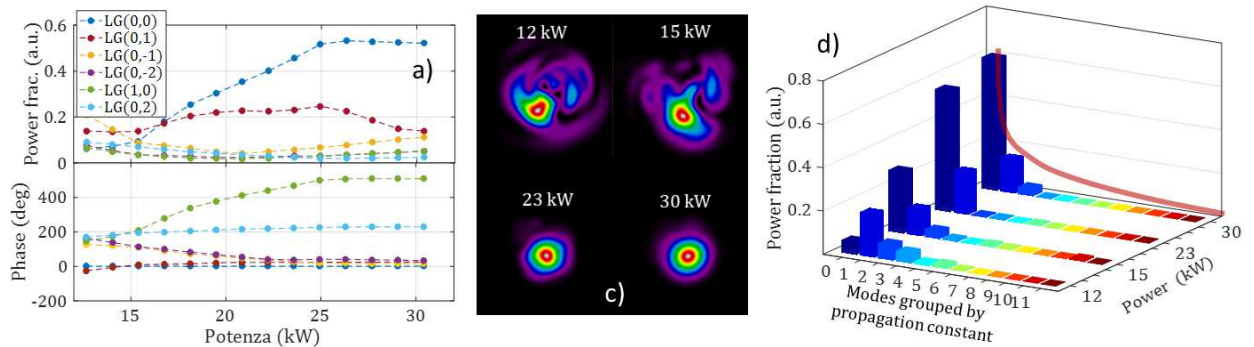


Fig. 1 Evolution of the modal a) power fraction and b) phase vs. input peak power. c) Near-field intensity profile acquired at four different input powers. d) Mode distribution (bars) and the thermalization (RJ) distribution) at maximum input power (red line).

The experimental results are shown in Fig. 1, where we report the mode power fraction (Fig.1a) and the phase (Fig.1b) at the fiber output, for four different input peak powers. As we can see, at the self-cleaning power threshold (around 23 kW), all of the first six spatial modes experience phase-locking. At the same time, the output mode power distribution reaches a state of thermal equilibrium, described by the Rayleigh-Jeans (RJ) distribution (see red line in Fig. 1d) [5,6].

In conclusion, we experimentally demonstrated that self-cleaning leads to spatially coherent beams, having both a well-defined thermodynamic mode power distribution and a locking of the modal phases. Our findings are of importance for applications beam self-cleaning, e.g., biomedical imaging and fiber lasers.

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