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Multicore fibers: a novel platform for a robust and reconfigurable self-organization of light

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We report on novel dynamics of light self-organization based on the interaction amongst forward and backward supermodes of a multicore (MC) fiber (Fig.1). As compared to recent studies in standard single-core fibers [1,2], the MC platform offers many degrees of freedom - e.g. disposition of cores, core-to-core distance, relative size and shape of the cores etc- that pave the way to a rich mix of unexplored types of self-organization.

We demonstrate that a strong nonlinear regime can be achieved where the propagation of light is described by the following coupled Schrödinger equations: $\partial_z F_n + v_n^{-1}\ \partial_t F_n = -i\gamma_{nn}|F_n|^2F_n + iF_n\sum 2\gamma_{nm}(|B_m|^2 + |F_m|^2) + iB_n^{*}\sum_{m\neq n} 2\gamma_{nm}B_mF_m$, $F_n(z,t)$ and $B_n(z,t)$ being the amplitude of the forward and backward supermode *n* of the fiber, v_n the related group velocity, γ_{nm} the Kerr intermodal nonlinear coefficient for supermodes *n* and *m* (a similar equation holds true for B_n). An example of the new self-organization dynamics is illustrated in Fig.2. Four independent sources are injected into the 4 cores of a MC fiber. A combination of 4 forward supermodes with time-varying random phase and power is excited. A CW-backward control beam CB, coupled to one supermode, is injected at the other end of the fiber. When the power of CB is large enough, an effective self-organization takes place that leads to the condensation of the forward field towards the supermode excited by the CB. A similar outcome is found when the CB is coupled to a combination of supermodes (reconfigurable self-organization). Most importantly, this process takes place independently of the number of cores and, due to the counter-propagating setup, it turns out to be robust against random geometrical imperfections of the fiber [3]. These results pave the way to novel devices for spatial division multiplexing and to high-power/highly scalable MC fiber lasers where independent optical sources, connected to different cores of the fiber, are all-optically and coherently combined.

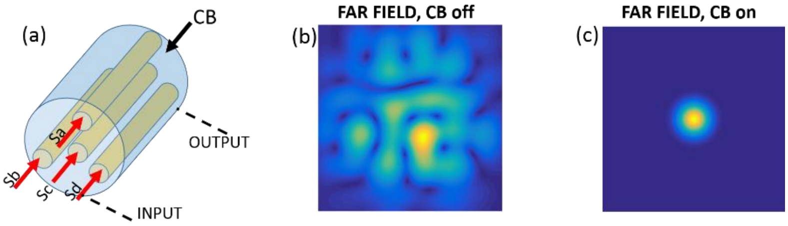

Fig. 1 A 4-core fiber is illustrated in panel a, with independent sources Sa, Sb, Sc and Sd feeding the cores at the input end. A backward control beam CB is injected at the output end and excites a supermode. If the CB is off, no self-organization takes place. The output forward supermodes preserve the original random relative phase and amplitude, which results in a random speckled far-field (panel b). If the CB is on and with sufficient power, a strong self-organization dynamics takes place. The forward field is attracted towards the supermode excited by the CB, which finally results in a high-quality and high-power density far–field (panel c). Similar results are obtained if CB excites a linear combination of supermodes, to which correspond different far-field configurations.

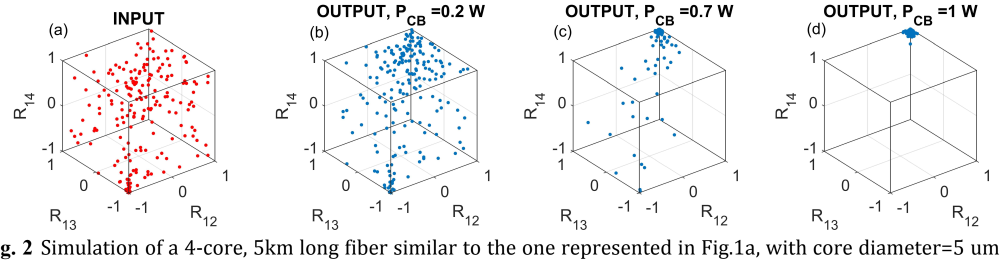

Fig. 2 Simulation of a 4-core, 5km long fiber similar to the one represented in Fig.1a, with core diameter=5 um and core-to-central core distance=10 um. Four independent sources with 250 mW average power excite a linear combination of forward supermodes at the input. A backward beam CB coupled to supermode 1 in injected at the output end (see fig.1). R_{nm} indicates the relative power between the forward supermodes n and m. The input distribution of R12,R13 and R14 is random in time (200 temporal samples are represented in panel a). However, when increasing the power P_{cb} of CB, the forward field undergoes an increasing attraction towards supermode 1 at the fiber output (see panels b,c,d where all samples collapse into R12=R13=R14=1).

References

[1] A. Picozzi, G. Millot, and S. Wabnitz, “Nonlinear virtues of multimode fibre,” Nat. Photonics **9**, 289–291 (2015).

[2] K. Krupa et al. “Spatial beam self-cleaning in multimode fibres”, Nature Photon **11**, 237–241 (2017).

[3] J.Fatome, S. Pitois, P.Morin, E.Assémat, E., D.Sugny, A. Picozzi, H.R. Jauslin, G.Millot, V.V.Kozlov, S.Wabnitz, “A universal optical all-fiber omnipolarizer”, Sc. Reports **2**, 1-8 (2012).

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