Nonlinear multimode fibers for high power fiber lasers

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Nonlinear multimode optical fibers have recently emerged as an easily accessible and versatile platform to control complex spatiotemporal optical beam and pulse reshaping phenomena [1]. In the anomalous dispersion regime of the fibers, multimode optical solitons have been observed in graded-index (GRIN) MMFs, resulting from the compensation of both chromatic and modal dispersion by Kerr nonlinearity [2]. On the other hand, light intensity oscillations owing to the self-imaging effect in graded-index GRIN MMFs lead, via the Kerr effect, to a dynamic long-period index grating, which may phase-match the generation of ultra-broadband sideband series. These can be generated by either spatiotemporally oscillating solitons in the anomalous dispersion regime [3], or quasi-CW pulses in the normal dispersion regime [4,5].

For relatively short GRIN fibers, beam self-cleaning activated by the Kerr effect was only recently observed, at a lower power threshold than that for the well-known Raman beam cleanup. The highly multimode speckled beam at the fiber output evolves, at high powers, into a high brightness, bell-shaped beam sitting on a low-power background of high-order modes [6]. A similar effect has been reported in the femtosecond pulse propagation regime, always with normal group velocity dispersion [7]. A remarkable property of beam self-cleaning is that it is frequency transferred to all parametric sidebands [4], and even to octave spanning supercontinua [8-9].

The brightness enhancement and spatial beam compression, accompanied by significant temporal compression [10], resulting from Kerr beam self-cleaning could be exploited as a building block of a new class of high power multimode fiber lasers. In fact, we have shown that self-cleaning is reinforced in active, Yb-doped MMF, thanks to the cooperation between the dispersive and the dissipative effects resulting from modal gain selection [11]. Intracavity self-cleaning in a composite cavity laser configuration involving an Yb-doped MMF has been reported, leading to mode-locking and parametric sideband generation within the laser [12].

In order to fully exploit laser beam dynamics in MMFs for applications to spatiotemporal laser beam mode-locking [13], it is necessary to accurately determine the conditions for the occurrence of the effect, by optimizing the spatial and temporal properties of the input laser pulses. We will describe a series of recent experiments that permit to unveil the physical mechanism of Kerr-beam self-cleaning, based on a complex cascade of parametric wave mixing processes.

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References

[1] L.G. Wright et al., Nature Photonics **9**, 306 (2015).
[2] W.H. Renninger, and F.W. Wise, Nature Communications **4**, 1719 (2013).
[3] L. G. Wright, et al., Phys. Rev. Lett. **115**, 223902 (2015).
[4] K. Krupa et al., Phys. Rev. Lett. **116**, 183901 (2016).
[5] L.G. Wright et al., Nat. Photonics **10**, 771 (2016).
[6] K. Krupa et al., Nat. Photonics **11**, 237 (2017).
[7] Z. Liu et al., Opt. Lett. **41**, 3675 (2016).

[8] G. Lopez-Galmiche et al., Opt. Lett. **41**, 2553 (2016).
[9] K. Krupa et al., Opt. Lett. **41**, 5785 (2016).
[10] K. Krupa et al., Physical Review A **97**, 043836 (2018)
[11] R. Guenard et al., Optics Express **25**, 4783 (2017).
[12] R. Guenard, et al., Opt. Express **25**, 22219 (2017).
[13] L.G. Wright et al., Science **358**, 94 (2017).