Impact of Periodic Self-imaging on the Nonlinear Propagation in GRIN Multimode Fibers

Tigran Mansuryan[2], K. Krupa[3,1], A. Niang[1], E. Deliancourt[2], A. Tonello[2], P. Leproux[2], M. Fabert[2], J. L. Auguste[2], A. Desfarges-Berthelemot[2], V. Kermene[2], A. Barthélémy[1], U. Minoni[1], D. Modotto[1], G. Millot[2], S. Wabnitz[1,4,5], and V. Couderc[3]

[1]Dipartimento di Ingegneria dell'Informazione
Università degli Studi di Brescia, via Branze 38, Brescia 25123, Italy
[2]Université de Limoges, XLIM, UMR CNRS 7252, 123 Avenue A. Thomas, Limoges 87060, France
[3]Université Bourgogne Franche-Comté, ICB, UMR CNRS 6303, 9 Avenue A. Savary, Dijon 21078, France
[4]DIET, Sapienza Universit di Roma, via Eudossiana 18, Rome 00184, Italy
[5]Instituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (INO-CNR)
via Branze 38, Brescia 25123, Italy

Abstract— Multimode optical fibers have recently regained a strong interest in particular because of their ability to deliver a quasi-Gaussian beam profile after nonlinear spatial clean-up of a multimode optical guided wave at high intensity [1, 2]. Indeed, a speckled beam obtained at the end of a multimode fiber in linear propagation regime can be transformed into a quasi-single-mode pattern at high input power [2]. Although such nonlinear dynamic has been mainly obtained in fibers with parabolic index profiles, evidences of nonlinear beam cleaning were also reported in a fiber with a quasi-step index structure [3]. This particular nonlinear spatial reshaping occurs spontaneously above some power threshold before the onset of significant spectral broadening by Kerr self-phase modulation (with hundred picoseconds long pulses). It is impacted by the distribution of power in the excited modal population. Far above threshold, the spatial reshaping is also accompanied by a temporal shortening of the launched pulse [4] and eventually by frequency conversions due to geometric parametric instabilities [5]. At higher power levels supercontinuum generation can be obtained covering all the spectral range between the visible to the IR domain (2.4 μm) with all the wavelengths carried by the fundamental transverse mode of the multimode silica fiber [6, 7].

The main mechanism at the origin of the spatiotemporal process is the periodic self-imaging effect and the subsequent periodic refractive index modulation induced by Kerr nonlinearity. A large number of four-wave mixing between guided modes can hence be phase-matched with the possibility of energy transfer among them. The periodic longitudinal modulation of the optical intensity can be experimentally unveiled and measured with an imaging system perpendicular to the guided light path using a camera sensitive to the visible radiation. Faint light generated by local non phase-matched harmonic generation leaks from the fiber core at some points where the beam intensity is the strongest.

During the conference presentation, we will report several experimental results of spatial Kerr self-cleaning as well as its impact in the temporal and spectral domains. More importantly we will also demonstrate that self-cleaning is a coherent process: this fact can open the way for coherent combining of cleaned beams and can bring new schemes for the design of powerful laser systems. Finally we will show new experimental results regarding the control of the output cleaned beam shape by adaptive tailoring of the input beam wavefront. The self-cleaning process can be improved by using rare-earth doped tapered optical fibers in view of making high energy fibered amplifier.

REFERENCES

1. Wright, L. G., et al., "Controllable spatiotemporal nonlinear effects in multimode fibres," *Nature Photonics*, Vol. 9, 306, 2015.
2. Krupa, K., et al., "Spatial beam self-cleaning in multimode fiber," *Nature Photonics*, Vol. 11, 237–241, 2017.
3. Guenard, R., et al., "Kerr self-cleaning of pulsed beam in ytterbium dopped multimode fiber," *Optics Express*, Vol. 25, 4783–4792, 2017.
4. Krupa, K., et al., "Spatiotemporal light beam compression from complex nonlinear mode mixing," *Physical Review A*, Vol. 97, No. 4, 043836-1–5, 2018.
5. Krupa, K., et al., "Observation of geometric parametric instability sidebands by the periodic spatial self-imaging of multimode waves," *Physical Review Letters*, Vol. 116, 183901, 2016.

6. Lopez-Galmiche, G., et al., "Visible supercontinuum generation in a graded index multimode fiber pumped at 1064 nm," *Optics Letters*, Vol. 41, 2553–2556, 2016.
7. Krupa, K., et al., "Spatiotemporal characterization of supercontinuum extending from the visible to the mid-infrared in a multimode graded-index optical fiber," *Optics Letters*, Vol. 41, 5785–5788, 2016.