# Laguerre-Gaussian Modes Excitation and Nonlinear Propagation in Graded-Index Multimode Fiber

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The investigation of light evolution during propagation in multimode (MM) fibers is of fundamental interest [1] in the context of further use in telecommunication, medicine and fiber laser systems. Special attention is paid to graded-index (GRIN) MM fibers in which the propagated beam can be expanded into a series of Laguerre-Gaussian (LG) modes. In these fibers such nonlinear effects as Kerr beam self-cleaning [2], and thermalization [3] were experimentally demonstrated for the first time. Results of the mentioned works confirmed applicability of a thermodynamic approach for nonlinear multimode waveguide systems [4]. It is worth noting, however, that the input radiation parameters there varied only within a narrow range, by means of transverse offset and tilting. Whereas it would be useful to investigate the evolution of light structured into different LG modes at the input of the fiber. In this work we perform effective LG modes excitation using the spatial light modulator (SLM) with further coupling into the GRIN MM fiber.

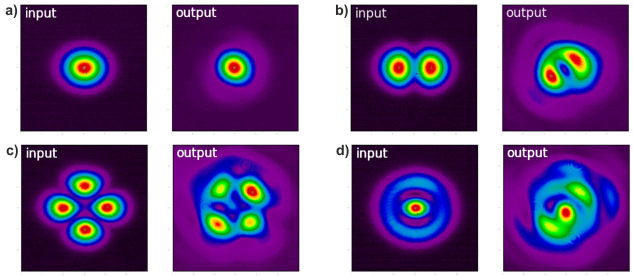


Figure 1: Input and output beam profiles for a) $LG_{0,0}$ mode, b) $LG_{0,-1}$ mode, c) $LG_{0,2}$ mode, d) $LG_{1,0}$ mode

For light structuring we improved the algorithm from [5]. In our modification modulation function was found numerically and optimized which led to the twofold increase of the mode excitation efficiency while maintaining the accuracy of reproducing the mode field distribution. In the far field after SLM diffraction pattern is formed. By filtering out the first maximum one may obtain any field distribution encoded into the hologram. The experimental setup is a standard $4f$ scheme with the addition of telescope system for reducing of the image and further coupling into the fiber. Focal lengths of all lenses were chosen so as to reduce the beam to the size of the corresponding LG mode. Coupling efficiency was about 85% for the first 10 modes. GRIN MM fiber has a standard 50-µm core and 10-cm length. Such small piece of fiber was taken to minimize random mode coupling taking place on disorders and bending.

Fig. 1 demonstrates experimentally captured intensity patterns of different LG modes at the input and output of the fiber. Beam profiles have a high degree of similarity. However, it should be noted that the random mode coupling still takes place which affects the output field distribution. It is especially visible for the cases of degenerate modes, *e.g.* $LG_{0,2}$ and $LG_{0,-2}$.

To summarize we demonstrated LG mode excitation method with the highest efficiency of field transform while maintaining sufficient level of accuracy. Moreover, we coupled structured light into the GRIN MM fiber accompanied by proper sizing. The output field profile is the proof that the direct excitation of specific LG mode at the input of fiber is possible. At the next stage we will study nonlinear propagation of these beams. This work is the first step to the investigation of beam thermalization with different shapes of initial radiation (*e.g.* particular modes, modes superposition, vortex beams) which should expand experimental research of nonlinear evolution of the light propagation in the GRIN MM fibers.

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## References

[1] I Cristiani, C Lacava, G Rademacher, *et al.*, J. Opt. **24**, 083001 (2022)

[2] K Krupa, A Tonello, B M Shalaby, M Fabert, A Barthélémy, G Millot, S Wabnitz and V Couderc, Nat. Photonics **11**, 237 (2017)

[3] E V Podivilov, F Mangini, O S Sidelnikov, *et al.*, Phys. Rev. Let. **128**, 243901 (2022)

[4] F O Wu, A U Hassan and D N Christodoulides, Nat. Photonics **13**, 776 (2019)

[5] V Arrizón, U Ruiz, R Carrada and L A González, J. Opt. Soc. Am. A **24**, 3500 (2007)