Using Phase Only SLM for a Fast Mode Decomposition of Graded-Index Multimode Raman Fiber Laser Emission

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Renewed interest in multimode (MM) fibers push researchers to take a broader look at already familiar laser systems like Raman fiber lasers (RFL). Demonstrated a great potential in terms of operating wavelengths, they also show high efficiency in conversion of multimode pump light into high-quality Stokes emission. Thus, in recent works, the effect of high brightness enhancement of the Stokes beam was observed in gradient-index (GRIN) MM RFL. Such investigation requires newel measurements technique, and the mode decomposition (MD) is one of them. The technique of MD can be realized by several approaches like genetic algorithm [1], phase modulation by a spatial light modulator (SLM) [2] or deep learning [3]. The last one can reach the decomposing rate of about 200 Hz for a few-mode beam, while the SLM-based technique is not limited by the number of modes but require high stability of the beam. In this work, we use the MD setup based on phase-only SLM and propose a way to overcome its limitation to resolve the real-time dynamic of modes.

The analyzing setup consists of a spatial light modulator (SLM), a lens which acts as a Fourier processor, and a CCD camera for recording the output transverse intensity distribution [4] and takes into account the features of the RFL under study. Its scheme consists of a high-power, a highly multimode laser diode (LD) that serves as a pump, a 1-km long piece of 100-µm GRIN MM fiber and a pair of fiber Bragg gratings (FBG). The important detail here is that the output FBG reflectivity is 10 dB higher for the fundamental mode than for the HOM. Such construction of the laser leads to forming of Stokes radiation with significantly improved beam quality and brightness due to nonlinear effects inside of the fiber. However, even though the output Stokes beam has a near-Gaussian shape, higher-order modes (HOM) still contribute largely, as it is shown by measuring the M2 parameter. In [5], it was shown that the M2 is equal to 2, whereas the same parameter for the pump has a value of about 30. That is why the beam analysis in terms of modal content is a relevant and important task.

Using the MD, we found out that there are more than 750 modes were excited by the pump radiation. During the transition through the Raman threshold, all modes that have the principal quantum number (PQN) < 5 are depleted significantly. This leads to mode excitation in the Stokes beam with relatively small PQN: 40% of the power is contained in the fundamental mode, 20-30% in modes with a PQN=1. We discovered that the mode amplitude distribution of the Stokes beam is close to an exponential law, which can be explained by the simple theoretical model [6]. So, the next step in the investigation of MM RFL is observing the modes dynamic resulting in rapid fluctuation of the output intensity pattern.

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