High-power mode-selective amplification in large mode area ytterbium-doped fiber using a photonic lantern

S. Wittek, R. Bustos Ramirez, J. Alvarado Zacarias, Z. Sanjabi Eznaveh, G. Lopez Galmiche, J. Bradford, J. Antonio-Lopez, L. Shah, R. Amezcua Correa

CREOL, The College of Optics and Photonics, the University of Central Florida, Orlando, Florida 32816, USA

swittek@knights.ucf.edu

Abstract: We demonstrate mode selective amplification in a LMA cladding pumped Yb-doped fiber amplifier employing a photonic lantern. Signal gains of up to 19 dB and >1W output power are demonstrated with high mode fidelity.

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1. Motivation

Fiber lasers have developed rapidly in recent years due to their excellent thermal management and ability to be integrated into modular systems [1]. As such, there are many examples of fiber laser systems providing kW average powers as well as MW peak powers. In both CW and pulsed systems, due to the high optical intensity in the core, the performance of the amplifier is subject to several detrimental nonlinear processes such as four-wave mixing (FWM), self-phase modulation (SPM), stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) [1]. To mitigate the nonlinear effects large mode area (LMA) fibers providing mode field diameters (MFD) larger than 50 µm have been developed [1-3]. The extreme core sizes of readily available LMA fibers allow for the propagation of higher order modes (HOMs), which can degrade the output beam quality. Recently, thermal modal instability (MI), manifesting itself as a sudden deterioration of beam quality in the fiber amplifier above a certain average output power threshold has been observed. This detrimental thermally induced nonlinear process is currently posing a critical challenge for power scaling in LMA ytterbium-doped (Yb-doped) fiber amplifiers with diffraction-limited output [3-5].

One important pathway to overcome MI relies upon actively controlling the signal modal content during amplification. As such, to achieve this goal in LMA amplifiers, Otto, et al. used an acousto-optic deflector to control the power coupled into the fundamental mode and HOMs at the fiber input [6]. This modulation scheme successfully disrupted the thermal gradient at the heart of MI and thereby enabled significant power scaling while maintaining nearly diffraction-limited beam quality. However, this technique is difficult to integrate in an all-fiber system.

In this work, we report a proof-of-concept experiment achieving superb modal control in a LMA cladding pumped Yb-doped fiber amplifier using a mode selective photonic lantern (MSPL) [7,8]. The proposed system is capable of exciting and amplifying three modes (LP_{01}, LP_{11a}, LP_{11b}) of the 5/125 um core/clad diameter LMA fiber. We demonstrate that this technique could enable active mode-selection using an all-fiber component.

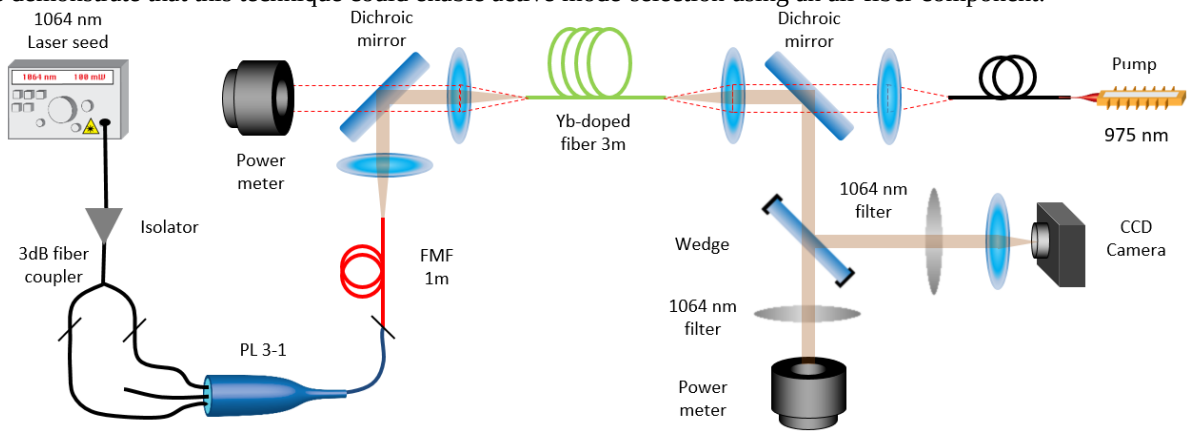

Fig. 1.: Schematic of experimental setup. The output of the MSPL was free space coupled to the LMA Yb-doped fiber.

2. Setup and experimental results

The three modes LP_{01}, LP_{11a} and LP_{11b} were generated in a PL seeded by a narrow-linewidth diode laser at 1064 nm. After propagating through an isolator, the seed was split by a fiber 3dB coupler allowing coupling to different branches of the lantern at the same time. A 1 m long few mode fiber (FMF) with 15/125 um core/clad diameter was spliced directly to the lantern output and free space coupled to the LMA fiber by a dichroic mirror, as depicted in Fig. 1. For all our measurements, a 3 m length of LMA Yb-doped fiber with 25/250 um core/clad diameter was cladding pumped by a high-power 975 nm multimode diode. The output of the amplifier was characterized using a CCD camera and power meters.

The modes at the PL and FMF outputs are displayed in Fig. 2 (a) and 2 (b) respectively, clearly showing small modal crosstalk. In order to evaluate amplifier's performance, each of the modes was first amplified individually. The LP_{01}, LP_{11a} and LP_{11b} modes were amplified to 1.02 W, 0.62 W and 0.36 W with corresponding gains of 19 dB, 18 dB and 13 dB respectively. Even at the highest pump power, high mode fidelity was preserved as can be seen in Fig. 2 (c). The evolution of the signal output power as a function of pump power is presented in Fig. 2 (d). Finally, the two lantern arms exhibiting the best performance (LP_{11a}+LP_{01}) were concurrently coupled into the amplifier and amplified to 1.15 W. We expect to be able to extract higher powers by using a pre-amplifier and optimizing the pumping scheme and fiber length.

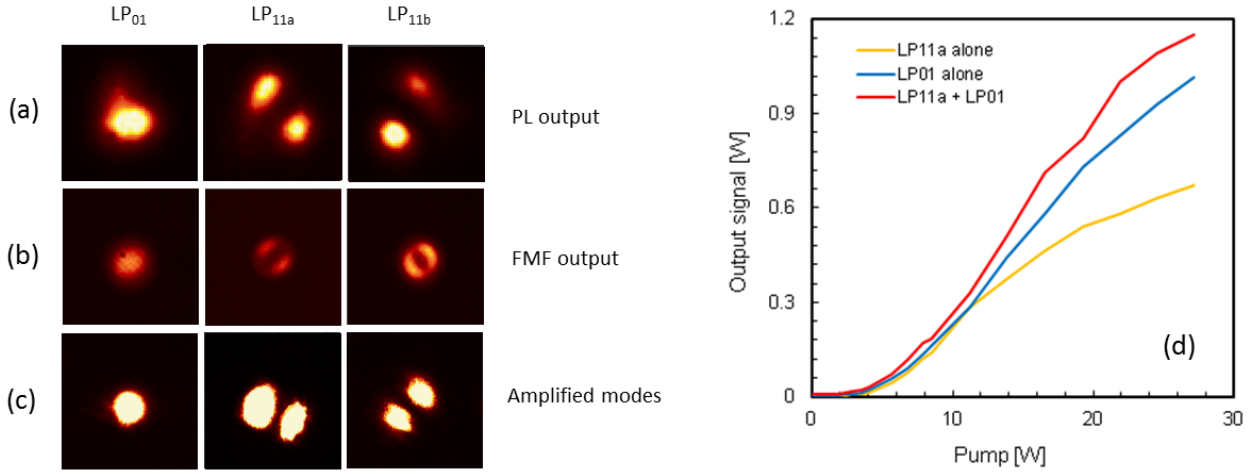

Fig. 2.: The three lantern modes LP_{01}, LP_{11a} and LP_{11b} at the PL (a), FMF (b) and amplified in the LMA Yb-doped fiber to around 1W (c). Each lantern arm was spliced to the same coupler output. (d) Amplification of the modes LP_{01} and LP_{11b} having spliced them to the coupler outputs.

3. Conclusion

We show mode selective amplification in a 3-mode LMA cladding pumped Yb-doped fiber up to 1W using a mode selective PL, while maintaining high mode fidelity. The proposed LMA fiber with PL amplifier system is very promising for a wide range of applications utilizing active mode-selection and control, and opens up new perspectives for mitigating MI in LMA fiber amplifiers.

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4. References

[1] D. J. Richardson, et al., "High power fiber lasers: current status and future perspectives," J. Opt. Soc. Am. B 27, B63-B92, 2010.
[2] F. Stutzki, et al., "High average power large-pitch fiber amplifier with robust single-mode operation," Opt. Lett. vol. 36, no. 5, pp. 689, 2011.
[3] T. Eidam, et al., "Experimental observations of the threshold-like onset of mode instabilities in high power fiber amplifiers," Opt. Exp. vol. 19, no. 14, pp. 13218–13224, (2011).
[4] C. Jauregui, et al., "Physical origin of mode instabilities in high-power fiber laser systems," Opt. Express 20, 12912-12925, 2012.
[5] K. R. Hansen, et al., "Theoretical analysis of mode instability in high-power fiber amplifiers," Opt. Exp. Vol. 21, no. 2, pp. 1944-1971. 2013.
[6] H.J. Otto, et al., "Controlling mode instabilities by dynamic mode excitation with an acousto-optic deflector," Opt. Exp. Vol. 2, no. 14, 2013.
[7] A. M. Velazquez-Benitez, et al., "Six mode selective fiber optic spatial multiplexer," Opt. Lett. 40, 1663-1666, 2015.
[8] T. A. Birks, et al., "The photonic lantern," Adv. Opt. Photon. 7, 107-167, 2015.