Six Mode Erbium-doped Fiber Amplifier Using Mode Selective Photonic Lantern

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Abstract: We demonstrate a six-mode erbium doped fiber amplifier incorporating a photonic lantern for modal gain control. Signal gain >20 dB and differential modal gain <3 dB were obtained through mode selective pumping using LP_{21} mode.

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1. Introduction

Space division multiplexing (SDM) is a promising approach to scaling capacity of current optical fiber communication systems based on single mode fibers (SMF). In SDM, few mode fibers (FMFs), multimode fibers (MMFs), and multicore fibers are used to increase the number of available transmission channels in a single fiber [1, 2]. In addition to novel optical fibers a new and very promising fiber device known as mode selective photonic lantern (MSPL) is emerging as a crucial element for SDM. Today, MSPL spatial multiplexers have received considerable attention due to their capability of mapping single mode inputs to fibers modes of a multimode fiber with low crosstalk. MSPLs consist of an adiabatic tapered arrangement of fibers with different core diameters or outer diameters surrounded by a low refractive index capillary tube [3-5]. For long distance transmission in optical communications systems, fiber amplifiers are required. As single mode fiber has been scaled to FMF and MCF, erbium-doped fiber amplifier (EDFA) have also been scaled for few mode and multicore operation and applied in SDM systems. Recently, low differential modal gain has been demonstrated by mode selective pumping of an EDFA using phase plates to generate the required fiber modes [6,7]. While this approach is promising, it is based on free space optics, which comes with drawbacks when highly efficiency and robust optical systems are required. Here, we demonstrate the use of a MSPL for mode selective excitation and pump profile control in a few mode EDFA. The proposed scheme replaces all free space components. In addition, the integration of a MSPL with a few mode EDFA allows for novel few mode amplifier systems with reconfigurable gain. In this work we demonstrate the first implementation of an EDFA system supporting six spatial modes with low differential modal gain through mode selective pumping using MSPL.

2. Results

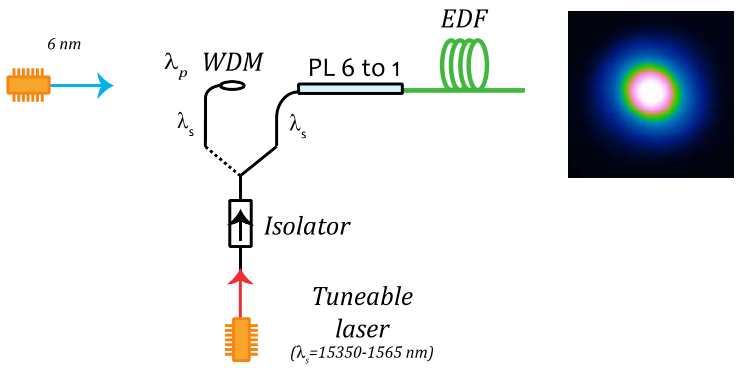

Fig. 1. (a) Schematic diagram of 6 mode EDFA with PL. Modal gain flattening by LP_{21a} pumping using mode selective PL. (b) Amplified signal mode profiles at λ =1550 nm and 60mW pump.

Fig. 1 shows the diagram of the EDFA for selective amplification of the first four mode groups (LP_{01}, LP_{11a}, LP_{11b}, LP_{21a}, LP_{21b} and LP_{02}). The EDF has a fully doped core with a flat doping profile with 13 μm/163 μm core/cladding diameters respectively. The measured absorption coefficient at 976 nm is 6.506 dB/m. A PL supporting six modes was used to selectively excite the signal and pump modes [5].

The EDFA was forward pumped on the LP_{21a} mode using a single mode laser diode (LD) at $\lambda_p = 976$ nm. The single mode output from the 976 nm LD was converted to the LP_{21a} mode using the corresponding MSPL port. A 976/1550 nm wavelength division multiplexer (WDM) was used to couple the pump light. The signal was generated with a tunable laser (TL). An isolator was placed after the TL. The TL was spliced to the test port of the MSPL for selective modal amplification. The few mode output end of the MSPL was spliced to an intermediate passive FMF with core/cladding diameter of 16/125 μm in order reduce coupling losses. Finally, the FMF was spliced to a 5 m long EDF. In order to measure the modal gain, the pump and amplified signals were separated at the EDFA output using a band pass filter. The output power was measured utilizing a photo detector. In order to confirm the clear amplification of the six input modes, the amplified signal modes profiles were captured using an infrared camera. Figure 1 (b) shows the amplified signal modes at $\lambda_s = 1550$ nm. The amplified signal modes were found well defined after amplification. Strong mode mixing between the LP_{21a} and the LP_{21b} modes was observed.

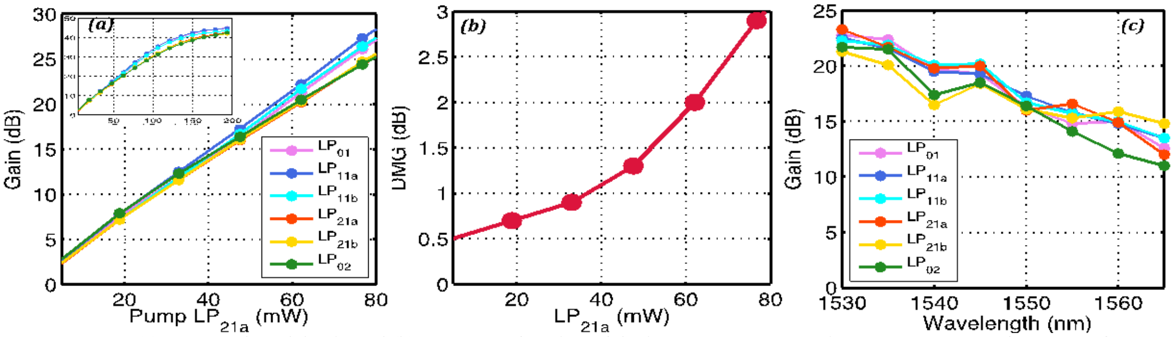

Fig. 2. (a) Measured modal gain and (b) DMG as a function of the input pump power at $\lambda = 1550$ nm. (c) Performance of the individually amplified modes across the C-band.

The modal gain and the differential modal gain (DMG) as functions of the launched pump power were investigated. An input signal of 0.5 μW launched from the MSPL was used to selectively amplify the modes. In Fig. 2(a) we observed that for a pump power between 48 mW to 76.7 mW, we obtained gain values between 16 and 28 dB. The obtained DMG values are between 1.3 to 2.9 dB, see Fig. 2 (b). In Fig. 2(c) we show the modal gain across the C-band, the input signal and the input pump were fixed to be 0.5 μW and 47.5 mW, respectively. It was observed that the modal gain decrease for longer wavelengths. A flatter gain spectrum can be achieved by optimized the EDF length.

3. Summary

We demonstrate the first implementation of a six mode MSPL EDFA with mode selective pumping. We obtained individual modal gain values between 16 and 28 dB with relatively low DMG. It is expected that lower values of DMG can be obtained by modifying the modal content of the pump, by using a superposition of modes. In addition, the proposed MSPL EDFA is a scalable and simple all-fiber system with the possibility of providing reconfigurable modal gain control.

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4. References

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