4-Core Er/Yb Co-doped Fiber Amplifier for Extending L-band with 1018 nm Cladding Pumping

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***Abstract*—In this paper, we propose a 4-core Er/Yb co-doped fiber amplifier for the extended L-band operation. With the 1018 nm pumping configuration, the improvement of the gain and core-dependent gain variation was theoretically confirmed. An average gain of ~22 dB over 1575-1625 nm was experimentally obtained with a 4 W pump power and a 3 dBm total signal power.**

Keywords—multicore EYDFA, extended L-band, cladding pumping, space division multiplexing

I. Introduction

Current rapid development in space division multiplexing (SDM) technology based on multi-core fibers or few-mode fibers is occurring to accommodate the capacity demand [1]. In particular, cladding-pumped multi-core erbium-doped fiber amplifiers (MC-EDFA), have attracted considerable attention for lengthening transmission distance and realizing component integration in long-haul transmission links [2]. On the other hand, cladding-pumped MC-EDFA combined with dense wavelength division multiplexing to provide more bandwidth over multiple spatial paths is envisaged as one of the effective solutions to increase capacity by orders of magnitude. Nevertheless, the bandwidth of MC-EDFA is only developed to 1605 nm to date, ascribing to signal excited state absorption (SESA) [3]. Using Er/Yb co-doped fiber has shown the potential to achieve extended L-band amplification in our previous report, profiting from SESA suppressing [4]. Moreover, introducing Yb^{3+} helps not only to increase pumping absorption but also broaden the selection of pump wavelengths in the cladding-pumped configuration, where the decreased overlap between the pump and doped cores results in low pump efficiency [5]. However, the energy transfer saturation between Yb^{3+} and Er^{3+}, has a great influence on the gain and efficiency performance, especially for the extended L-band EYDFA [6].

In this paper, we present a 4-core EYDFA base on 1018 nm cladding pumping, for SDM application in the extended L-band. The numerical simulation confirmed the conjecture that 1018 nm pumping helps ameliorate amplification characteristics. Based on the 4-core EYDFA with homemade active fiber, amplification performance was measured and the experimental results are in good agreement with simulations.

II. Numerical Simulation

The simulations were executed to give a characteristic comparison between the two types of pumping schemes, ie. traditional 976 nm pumping vs 1018 nm pumping, based on single-stage configuration with forward cladding pumping. The model was conducted based on the power propagation and rate equation as described in [7], and the typical cross-section of the active fiber refers to [8].

For different fiber lengths, gain and NF spectrums are plotted in Fig. 1, with signal power (covering 1570-1625 nm) and pump power set to 3 dBm and 4 W, respectively. The gain curves for all fiber lengths rise integrally while using 1018 nm pumping, compared to 976 nm. Moreover, the gain at the long-wavelength direction with 1018 nm pumping increases as the fiber length increases to 28 m, which exceeds ~24.5 dB. However, as can be observed from the dash line, the gain at the long-wavelength direction obtained by 976 nm pumping reaches only ~16.3 dB with a fiber length of 17 m. In addition, the NF at the short-wavelength direction deteriorates to ~5.8 dB, which is attributed to a low population inversion and a longer fiber length. Using 1018 nm pumping presents that gain enhancement in the extended L-band is more significant than that of 976 nm pumping.

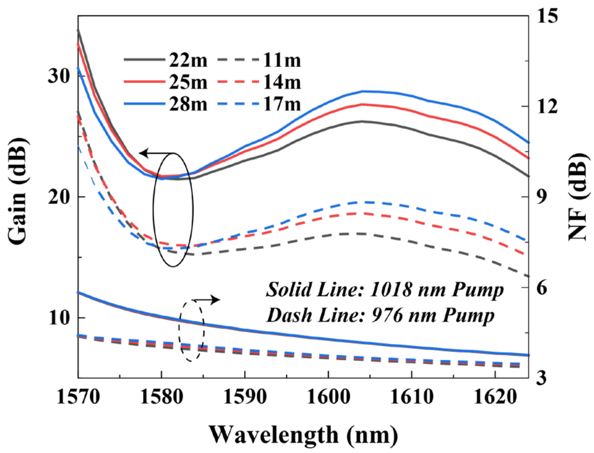

Fig. 1. Gain and NF spectrums for different fiber lengths.

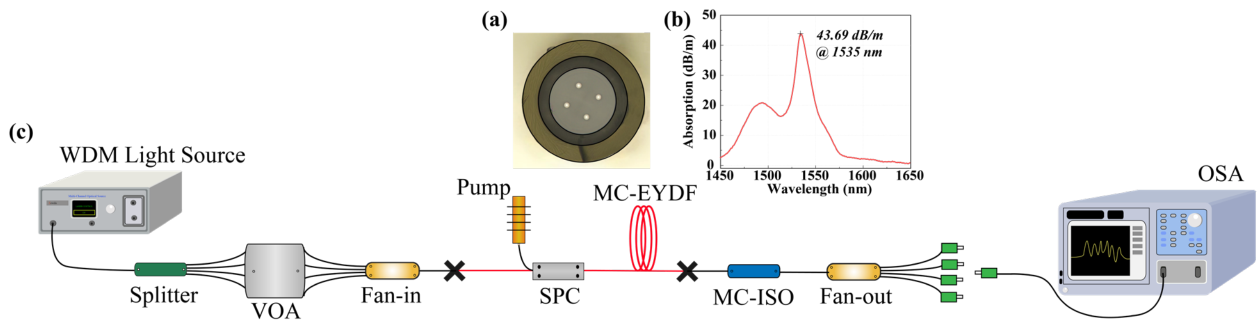

Fig. 2. (a) The cross section and (b) absorption coefficient of the 4-Core EYDF. (c) Schematic of the 4-Core EYDFA.

III. 4-Core Er/Yb Co-doped Fiber Amplifier

A. Fiber Fabrication

The 4-core EYDF was fabricated using the modified chemical vapor deposition process in combination with solution doping technology, and the Er/Yb co-doped preforms were fabricated to have the same refractive index profile. Finally, the double-cladding 4-core EYDF was drawn with the diameters of core, inner cladding, and outer cladding of 9.9 µm, 125 µm, and 175 µm, respectively, shown in Fig. 2(a). Moreover, the core-to-core pitch of 43 µm and used fiber lengths of a few tens of meters make the crosstalk in this fiber much less of an issue. The core absorption coefficient was measured by PK2500 through the cutback method, with a value of 43.7 dB/m at 1535 nm, as plotted in Fig. 2(b).

B. Experimental Setup

The integrated experiment setup of 4-core EYDFA was constructed to characterize the amplification performance, as depicted in Fig. 2(c). The 59-channel wavelength division multiplexing signals were utilized (covering 1575.8-1625.3 nm with ~0.8 nm spacing) for the input light. The variable optical attenuator (VOA) was incorporated to counterbalance the core-to-core loss of the Fan-in, ensuring a uniform input signal power of -3 dBm across individual cores. The forward pump light was injected into the inner cladding of 4C-EYDF with a power of 4 W, coupled by a side pump coupler (SPC) with a coupling efficiency of ~65%. The multicore isolator (MC-ISO) was placed at the other end of the active fiber to prevent parasitic oscillation from the back reflections of the fiber end in the Fan-in/out couplers. Ultimately, the amplified signal spectrums were collected via an optical spectrum analyzer (OSA) at the Fan-out output port. Measurement was conducted by simultaneously amplifying all the fiber cores.

C. Amplification Characteristics

The amplification characteristics of two pumping schemes with a total signal power of 3 dBm were investigated as shown in Fig. 3. Lengths of the fiber were optimized to be 9.5 m and 19.5 m for 976 nm and 1018 nm pumping, respectively. The results show that 1018 nm pumping obtains a higher average gain, of about 17.7 dB for short-wavelength and 14.7 dB for long-wavelength. In contrast, for 976 nm pumping, the average gain is ~12.3 dB and ~7.9 dB. The gain curves exhibit a consistent upward trend while using 1018 nm pumping, in agreement with simulations presented in Fig. 1, although the error between gain measurement and simulation exists due to the relatively strong relations of the fiber parameters, and the insertion loss of the components and splices. In addition, NF performance manifests the same as the simulation model as well, with slight deterioration. On the other hand, the advantages of being away from peak absorption wavelength make the max CDG reduce to ~1.7 dB as depicted in Fig. 3, compared to ~2.1 dB for 976 nm. Overall, the experimental results support the simulations and demonstrate that the 1018 nm pumping configuration improves the performance of the extended L-band EYDFA, not only for multicore applications.

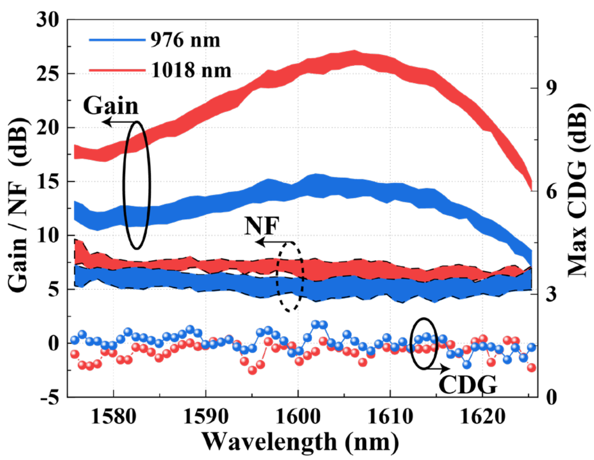

Fig. 3. Measured gain, NF, and the max CDG spectrums.

IV. Conclusion

In conclusion, an integrated 4-core EYDFA using 1018 nm pumping for the extended L-band operation has been demonstrated. Based on the integrated 4-core EYDFA with homemade active fiber using 1018 nm cladding pumping, the average gain of ~22 dB was obtained covering 1575-1625 nm with a 4 W pump power and a 3 dBm total signal power, and the max CDG was reduced to ~1.7 dB. This result appears a potential candidate for demanding SDM amplification in the extended L-band.

Acknowledgment

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