Spectrally Flat and High-Power Er-Yb Amplifier for Telecommunications Applications

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***Abstract*—A multimode Erbium-Ytterbium doped fiber can be advantageously used for the amplification of WDM channels over an extended spectral band with respect to conventional designs. Bit error ratio at 10 Gb/s, gain and noise figure are provided.**

I. INTRODUCTION

With the increasing use of dense WDM channels, optical amplifiers operating in the conventional 1530 nm-1565 nm (C) band are required to provide an output power compatible with high channel count, and this at the lowest cost achievable. For instance, filling the C-band with ~10 mW channels spaced by 50 GHz requires a total power of ~1 W and thus an amplifier design enabling an output power reaching 30 dBm. Erbium-doped fiber amplifiers (EDFAs) are of limited use to fulfill this task because of the relatively low solubility or Er ions in silica and their relatively low absorption level. As a result, EDFAs are typically limited to a few hundreds of mW, even when using double-cladding Erbium-doped fiber geometry [1].

In comparison with EDFAs, Yb-codoped EDFAs (EYDFAs) can offer significantly higher output powers because the high solubility and absorption of Yb ions and energy transfer to Er ions via cross-relaxation [2]. Means of increasing even further the amplifier output power in EYDFAs include the use of multimode pump lasers [3] and using double-cladding fibers that are compatible with multimode pumps [4]. In all cases, the fiber core is designed for single mode propagation.

The main limitation of current high-power EYDFAs to amplify WDM signals is their narrow gain bandwidth that spreads in the 1545-1565 nm band [5]-[7] and that thus leave the 1530-1545 nm band without useable gain. The most straightforward way to fill this gap is to ensure a stronger population inversion of the Er ions throughout the EYDF [8]. Given a constant pump power, this can be achieved by ensuring a better overlap between the pump mode and the co-doped area (usually the fiber core) and thus by choosing a core/cladding ratio that is as close to unity as possible. A first option that has been previously investigated is to reduce the cladding diameter and keep the core diameter untouched [9]. Although successful, this option is currently unpractical because it requires using non-standard pumps lasers with multimode fiber pigtail compatible for coupling into the modified EYDF. A second option consists in increasing the core diameter and keeping the cladding diameter unchanged. This option preserves the compatibility with commercially available multimode pump lasers but results into multimode signal propagation.

In this paper, we study the impact of using an EYDFA with multimode core geometry. We show that this amplifier provides a gain spectrum that covers most of the C-band as well as providing a high power output. The configuration tested is also optimized towards low components costs and is assembled out of a few commercially available components. We tested this configuration for WDM transmission at 10 Gb/s and show bit error ratio (BER) transmission curves as well as gain and noise-figure spectra.

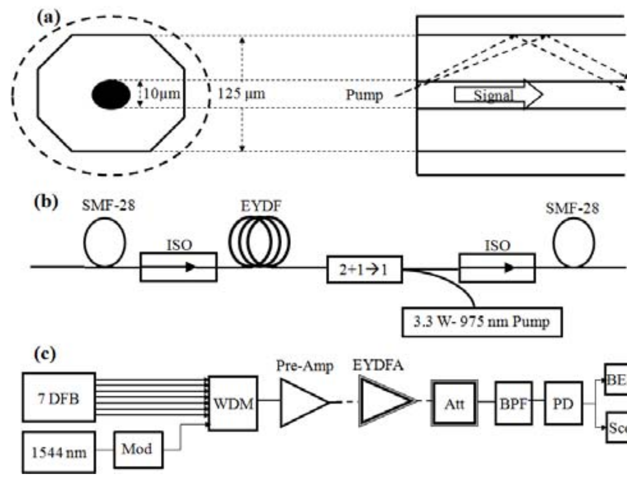

Fig. 1.Schematics of (a) the EYDF, (b) the EYDFA, and (c) the bit error ratio measurement setup. Mod: modulator, BPF: bandpass filter@1544 nm, Att: variable attenuator, PD: Photodiode, BERT: BER tester.

II. EXPERIMENTAL SETUP

Fig. 1a shows the structure of the Er/Yb double-cladding fiber provided by Coractive High-Tech inc. The multimode fiber has been designed with a circular core diameter of 10 µm, a numerical aperture of 0.20 and a V-number of 8.1. The core is co-doped with Er and Yb with a concentration ratio of l:10. The fiber also has a double cladding geometry, thus confining the propagation of the pump light in the inner octagonal, having a diameter of 128 µm and NA=0.46.

Fig. 1b shows a schematic structure of the power amplifier configuration. 2.15 m of EYDF have been used in the EFDFA. The pump radiation from only one multimode 3.3 W broad-area laser at 976 nm is coupled in counter-propagation in the EYDF via a commercially available 2+1→1 multimode pump/single mode signal combiner. Since the fundamental mode of the EYDF matches closely the mode of a G.652 fiber, standard patchcords of G.652 fiber were spliced directly at the input and output of the EYDF.

Fig. 1c shows the setup used to measure the impact of using the multimode ETDFA. A WDM signal consisting of 8 channels spreading throughout the C-band was used to characterize the gain and noise-figure of the EYDFA. The power of the channels was equalized at the output of a pre-amplifier and totalizes 18 dBm. The pre-amplifier stage ensures a good saturation of the EYDFA and a low noise-figure of the signal after amplification. An additional probe laser with a power level of -15 dBm was also used to measure gain and noise-figure at intermediate wavelengths between the saturating tones. A BER measurement was performed at 10 Gb/s with the 1545 nm channel to measure the signal degradation caused by inserting both the preamplifier and power amplifier in the communication link.

III. Experimental Results

Fig. 2 shows the spectrum of the WDM signal before and after the EYDFA. The result demonstrates the capability of the amplifier to provide sufficient gain in the spectral band from 1535 nm to 1565 nm. The total power after amplification is 30 dBm and could be increased by increasing the pump power. Fig. 3 shows the gain and noise-figure of the EYDFA taken alone. The natural gain in the spectral band from 1535 nm to 1565 nm has a 5 dB variation and could be flattened using an appropriate filter in the mid-stage of the dual-stage amplifier [10]. The noise-figure varies between 4 dB and 10 dB in the same wavelength band. An important noise contribution is assumed to arise from the spontaneous noise filling the available modes of the multimode fiber and partially coupled to the output fiber. The use of a low-noise preamplifier and the high-power amplifier in tandem is greatly beneficial in reducing the overall noise-figure of the amplifying system since the noise-figure of the preamplifier dominates.

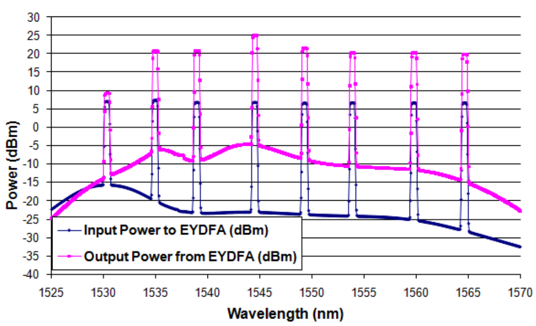

Fig. 2 Spectra before and after amplification of 7 channels spreading from 1535 nm to 1565 nm.

Fig. 4 shows the BER of the 1545 nm channel with and without the EYDFA amplifier. The signal degradation is limited to a power penalty of 0.5 dB, which corresponds to the power penalty theoretically expected by intermodal dispersion through the 2.15 m EYDF length. From an eye-diagram, no noticeable trace of pulse broadening can observed between the signal before amplification and after amplification. As a result, the multimode geometry of the fiber used in the EYDFA does not represent a major source of degradation for the signal. The power penalty due to intermodal dispersion could be reduced even further by shortening the EYDF length.

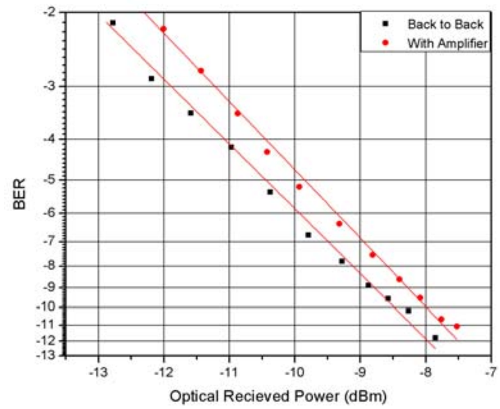

Fig. 4 Bit error ratio at 10 Gb/s with and without the EYDFA in the communication link.

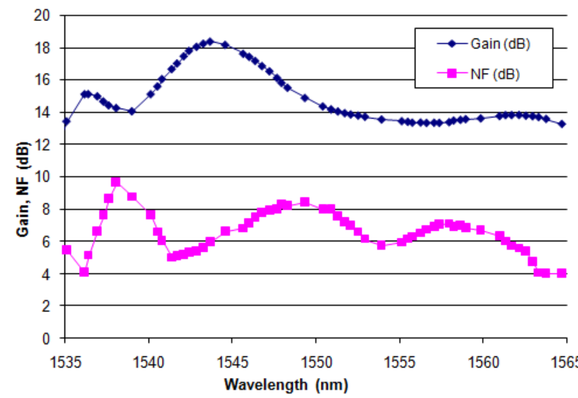

Fig. 3 Gain and noise-figure of the EYDFA taken alone.

IV. Conclusion

We have shown that a high power amplifier made of a multimode Er-Yb co-doped fiber enables the amplification of WDM signals over an extended wavelength span of 1535 nm to 1565 nm and with an output power of 30 dBm. The multimode geometry of the fiber is responsible for a 0.5 dB power penalty of the bit error ratio at 10 Gb/s. Signal degradation could be reduced further by shortening the EYDF length.

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