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37.2 dB small-signal gain from Er/Yb Co-doped fiber amplifier with 20 mW pump power

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Abstract

An efficient erbium–ytterbium-doped fiber amplifier (EYDFA) is demonstrated by forward and backward pumping a 3 m erbium/ytterbium co-doped fibers (EYDF) in single- and double-pass configurations using a 20 mW pump. At the input signal wavelength of 1536 nm, the forward- and backward-pumped double-pass amplifiers achieved a maximum low-signal gain of 37.2 and 28.6 dB and a corresponding noise figure of 5.4 and 10.8 dB, respectively. Whereas, the forward- and backward-pumped single-pass amplifiers (at the same wavelength) achieved a maximum low-signal gain of 20.0 and 22.2 dB and a corresponding noise figure of 4.6 and 10.3 dB, respectively. The double-pass design offers an economical solution to high-efficiency and high-gain optical amplifiers.

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Keywords: EYDFA; Small signal gain amplifier; Er/Yb-doped fiber amplifier

1. Introduction

The demand for efficient optical amplifiers that utilize a short length of fiber gain medium has lead to the discovery of erbium/ytterbium co-doped fibers (EYDF) [1,2]. An EYDF utilizes co-dopant ytterbium ions as an intermediary medium for pump energy transfer to erbium ions for stimulated emission in a four-level laser system (Fig. 1). In this system, the ytterbium ions are first pumped at the absorption wavelength of 800–1100 nm to the $^2F_{5/2}$ state. The energy of the ytterbium ions is next transferred to the erbium ions, which are excited to the $^4I_{11/2}$ state. These excited erbium ions undergo a non-radiative transition to the $^4I_{13/2}$ metastable state and form a population inversion with the $^4I_{15/2}$ state. An incident optical signal traveling through the fiber is amplified via stimulated emission between these two states.

In a typical erbium-doped fiber (EDF), the erbium ions cluster together once a certain dopant threshold is met. When these clustered ions undergo lasing, an undesirable effect known as pair-induced quenching (PIQ) reduces the amount of stimulated emission in the fiber. PIQ imposes a concentration limit that restricts the amount of lasing ions available for amplification. In an EYDF, however, highly doped ytterbium ions act as ionic buffers that (due to their similar atomic radius) effectively surround the erbium ions. This reduces the clustering (PIQ) between erbium ions and allows for ion doping of up to 1000 ppm [3]. The energy transfer efficiency from the pump to the erbium ions increases at the right ratios of ytterbium ions [4]. In comparison to an EDF, an EYDF can achieve the same signal amplification with higher pump efficiency by using a shorter length of fiber.

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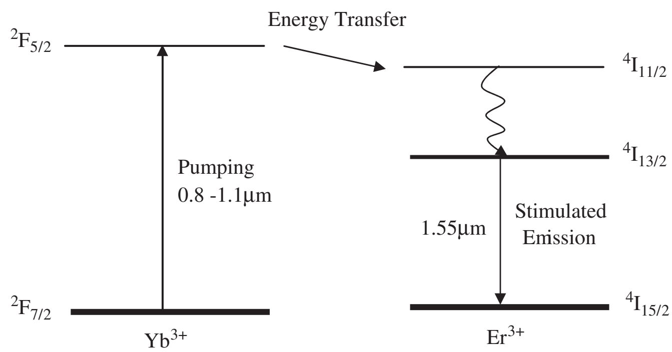

Fig. 1. Energy levels in an EYDF.

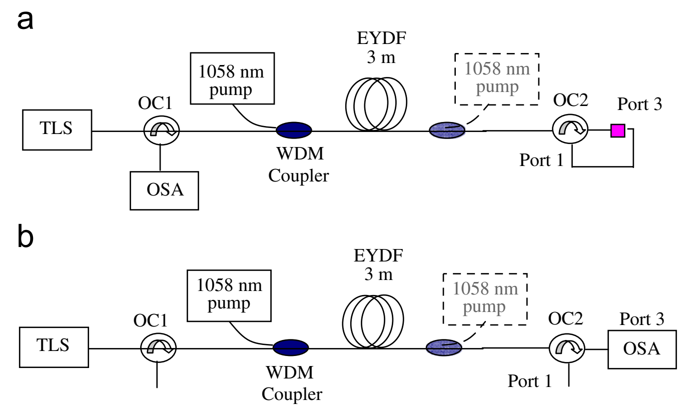

Fig. 2. Experimental setup of the proposed (a) double-pass EYDFA and comparison (b) single-pass EYDFA. The pump is alternated between the input (solid box) and output (dashed box) of the fiber to simulate forward and backward pumping.

EYDFs as optical amplifiers or EYDFAs provides many practical benefits. An EYDFA also has the benefit of a wide pump absorption band, which enables and extended range of pump laser wavelengths. In an EYDFA, energy transfer from the excited states of Yb to that of Er is utilized to form a population inversion between lasing levels of Er. Besides the compactness, pre-amplifiers and in-line amplifiers also require high levels of small signal gain to amplify weak signals before receiver photo-detection or before the next span in a fiber link. To achieve gains above 30 dB in the amplifiers one usually needs a pumping power about 100 mW. Typical EDFAs for example, require at least 120–140 mW of pump power and a fiber length of 10–14 m to achieve 30–40 dB of small signal gain [5,6]. However, achieving such high gain with lower pump power (20 mW) is desirable for CATV and FTTH applications. This is because the pump power level can be achieved using a LED or low-cost laser diode.

In this paper, we present experimental results that demonstrate 37.2 dB small signal amplifier gain from a simple double-pass, single-pump EYDFA using 3 m of EYDF pumped by 20 mW at 1058 nm. This represents a gain increase of 17.2 dB compared to the single-pass configuration. To our knowledge, this is the highest small signal gain achieved by a doped-fiber amplifier using very low pump power of 20 mW.

2. Experiment

Fig. 2 (a) shows the experimental setup of the proposed double-pass EYDFA. The EYDF used in this setup has an Er^{3+} and Yb^{3+} ion concentration of 1000 and 45000 ppm, respectively, a length of 3 m and a cutoff wavelength of 1032 nm. It also has a fiber diameter of 125 µm and NA of 0.22 with a host material of phosphate glass. Two optical circulators, OC1 and OC2 are connected to the input and output ends of the amplifier, respectively. OC1 is used to block any spurious signal reflections in the fiber and to route amplified signals into an optical spectrum analyzer (OSA) for gain and noise figure measurement. Ports 3 and 1 of OC2 are interconnected to retro-pass an amplified optical signal back into the EYDF for re-amplification. The fiber was pumped with a 1058 nm laser diode at 20 mW, which was alternated between the input and output of the EYDF to simulate forward and backward pumping. Combination of the pump and signal beams was done using a wavelength division multiplexing (WDM) coupler and signal generation was done using a tunable laser source (TLS). The amplifier's performance was compared with a single-pass EYDFA (Fig. 2(b)), which was improvised by disconnecting the ports 3 and 1 of OC2 and measuring the amplified signal from port 3 of the circulator using an OSA. The input signal power is measured at point between OC2 and TLS using an OSA. Measurements for net gain and noise figure were taken for double-pass and single-pass configurations at both forward- and backward-pumping schemes. The performances for other possible pump wavelengths (800 or 975 nm) is not presented due to low pump efficiency [7] and cutoff wavelength.

3. Results and discussion

Fig. 3 shows the amplifier gain and noise figure as a function of input signal wavelength for double-pass and single-pass configurations at forward- and backward-pumping schemes. The input signal power was fixed at −50 dBm. The forward and backward double-pass amplifiers each achieved a maximum small signal gain of 37.2 and 28.6 dB, respectively, at the input signal wavelength of 1536 nm. The corresponding noise figures of the amplifiers were 5.4 and 10.8 dB. The higher noise figure levels seen in the backward-pumped double-pass amplifier are mainly due to the amplified spontaneous emission (ASE) induced by the counter-propagating pump beam, which reduces overall population inversion in the gain medium. Both double-pass pumping schemes maintained a small signal gain of over 15 dB within a bandwidth of 16 nm (1532–1548 nm).

In the case of the forward- and backward-pumped single-pass amplifiers, a maximum small signal gain of 20.0 and 22.2 dB, respectively, was achieved at the wavelength of 1536 nm. The corresponding noise figures of the