Dual-wavelength erbium-ytterbium co-doped fibre laser operating at 1064 and 1534 nm

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Abstract. We demonstrate a simple erbium-ytterbium co-doped fibre laser with dual-wavelength output, which operates at 1064 and 1534 nm using a single gain medium. The laser operates on a recently developed erbium-ytterbium doped fibre (EYDF) with the erbium and ytterbium ion concentrations of 1000 and 1500 ppm respectively, in conjunction with a linear cavity setup based on two fibre Bragg gratings. By pumping a 5 m long EYDF with a 980 nm laser diode, simultaneous generation at 1064 and 1534 nm is reached, with the corresponding peak powers of 3.4 and –8.3 dBm. The lasing thresholds are 40 and 80 mW respectively for 1064 and 1534 nm.

Keywords: dual-wavelength laser, erbium-ytterbium co-doped laser, fibre Bragg grating

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1. Introduction

Development of fibre-based lasers and amplifiers utilizing erbium-ytterbium co-doped fibres (EYDFs) has continued over the past fifteen years [1, 2]. Recently, many works have been focused on developing erbium-ytterbium doped fibre lasers (EYDFLs) that operate at the wavelengths near 1550 nm. This is due to availability of high-power InGaAs laser diodes with their emission located near 980 nm, as well as many advantages revealed by these lasers over the other types of rare-earth doped fibre lasers. Apart from a simple energy level structure, the lasers under discussion have offered broad gain bandwidths ranging from 975 to 1200 nm and excellent power conversion efficiency [3, 4]. The EYDFLs are weakly affected by the concentration quenching phenomenon and do not exhibit the excited-state absorption which usually reduces the pump efficiency. Then the concentration of dopants in a fibre can be made relatively high so that reasonably high output powers can be achieved with short lengths of the gain media. From the practical viewpoint, all-fibre dual-wavelength fibre laser sources have attracted considerable attention in the recent years because of their potential applications in microwave photonics, optical communications and fibre sensing systems [5–10].

Up to date, various techniques have been explored to achieve dual-wavelength lasing output, e.g. distributed-feedback erbium-doped fibre lasers based on special fibre grating structures [7, 8] and comb filters introduced into laser cavities [9, 10]. Fibre Bragg gratings (FBGs) seem to be ideal wavelength-selective components for the fibre lasers, due to their advantages concerned with intrinsic fibre compatibility, ease of use, and low cost.

Dual-wavelength sources also appear to be a promising instrument for many ultrafast researches, including generation of difference, harmonic and sum frequencies. Moreover, two independent fibre lasers built according to arrangement called as a ‘two-colour experiment’ are clearly needed for so-called two-colour pump–probe studies performed in several fields of science and technology. In an earlier work, Rusu et al. [11] have demonstrated a dual-wavelength pulsed fibre laser operating at largely separated wavelengths of 1.04 and 1.55 μm, using two different gain media, erbium and ytterbium fibres which share the same cavity. In this report, a dual-wavelength-output EYDFL operating at 1064 and 1534 nm is demonstrated using a single gain medium. Our laser is based on a newly developed EYDF supplemented with two FBGs operating at 1064 and 1534 nm in a linear configuration.

2. Experimental

The experimental setup of our dual-wavelength EYDFL is shown in Fig. 1. It includes a 5 m long EYDF as a gain medium. The EYDF was fabricated using a modified chemical vapour deposition technique combined with a solution doping process. The compositions of core and cladding of our EYDF were respectively SiO_2–GeO_2–Al_2O_3–Er_2O_3–Yb_2O_3 and SiO_2–F. The fibre was characterized by the numerical aperture of 0.20, the core diameter of 4.0 μm, and the cutoff wavelength of around 980 nm. The doping levels of the erbium and ytterbium ions in the fibre were 1000 and 1500 ppm, respectively. They were determined using an electron probe microanalysis. The pumping source was a laser diode with the wavelength of 980 nm. It was coupled to the EYDF through a 980/1550 nm wavelength division multiplexing coupler. A circulator was used in our setup with a port 1 connected to a port 3 (see Fig. 1) to act as a mirror for laser operation. Two FBGs with the operating wavelengths of 1060 and 1534 nm and 99% reflectivities were employed in this experiment as a wavelength selective filter. A 3 dB coupler was introduced to tap the output of the laser via one of the ports, which is then probed by an optical spectrum analyzer with the resolution of 0.02 nm.

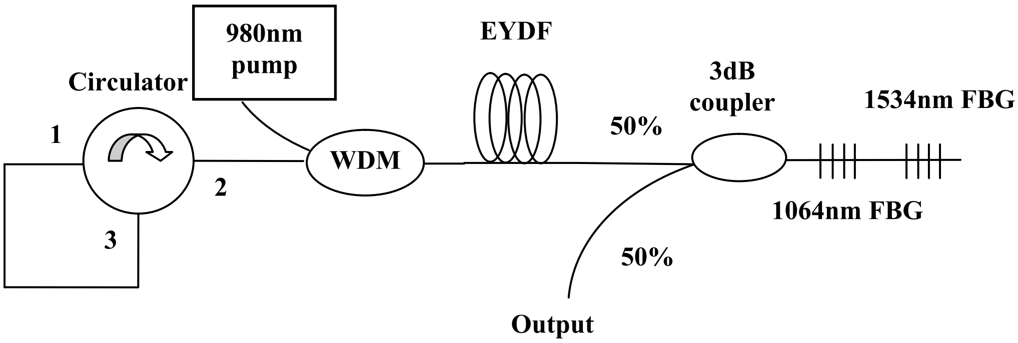

Fig. 1. Experimental set-up of our EYDFL: WDM denotes wavelength division multiplexer and the rest of the components are explained in the text.

3. Results and discussion

Fig. 2 shows the output spectra of our laser taken in the presence and absence of the FBGs, under the condition that the 980 nm pump power is fixed at 80 mW. By pumping the EYDF with the laser diode, the ytterbium and erbium ions are excited to their $^2F_{5/2}$ and $^4I_{11/2}$ levels, respectively. Then the excited ytterbium ions decay down to $^2F_{7/2}$ to release energy, of which a portion is used to emit photons near 1050 nm. Another energy portion is transferred to the erbium ions, which are excited to their $^4I_{11/2}$ level. These erbium ions undergo a non-radiative transition to their metastable state $^4I_{13/2}$ and form a population inversion with the state $^4I_{15/2}$. With no FBGs, an amplified spontaneous emission is observed in the two different wavelength regions centred at 1030 and 1550 nm, as depicted in Fig. 2. This is because the EYDF used by us has significantly lower ytterbium concentration when compared to that of standard commercial EYDFs, thus allowing for co-emission of the ytterbium ions. Fig. 2 shows that the amplified spontaneous emission spectra have their peaks at 1034 and 1534 nm, with the corresponding peak powers equal to –18 and –52 dBm. When the FBGs are incorporated in the laser cavity, co-lasing of the ytterbium takes place to form a dual-wavelength output (see Fig. 2). The laser operates at the FBG wavelengths (1064 and 1534 nm) and the corresponding peak powers are equal to –8.7 and –19.9 dBm.

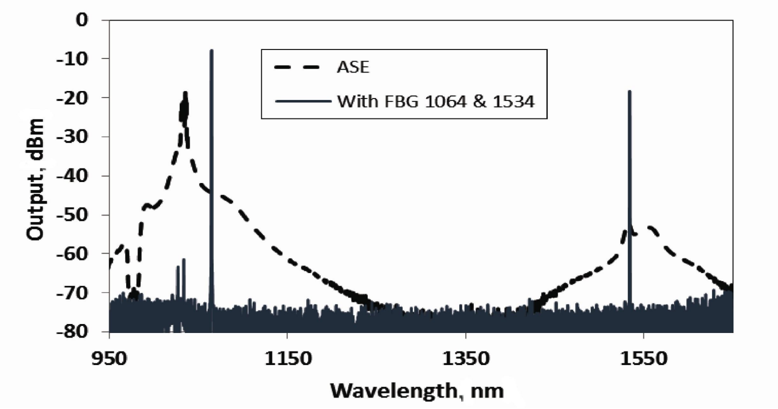

Fig 2. Spectrum of amplified spontaneous emission (abbreviated as ASE) observed in the absence of FBGs and spectrum of lasing observed in the presence of FBGs occurring at 1064 and 1534 nm in the case of forward-pumped EYDF.

Fig. 3 shows in greater scale the output spectra of our EYDFL centred at 1064 and 1534 nm. In these experiments, the 980 nm pump power was fixed at 140 mW. The 1064.4 nm output (with the peak power being equal to 3.39 dBm and the 3.0 dB bandwidth being 0.14 nm) are due to emission of Yb^{3+} ions as a result of population inversion available between the $^2F_{5/2}$ and $^2F_{7/2}$ states. The 1534 nm output is obtained from the stimulated emission between the $^4I_{13/2}$ and $^4I_{15/2}$ levels of erbium ions, producing the peak power of –8.27 dBm and the 3dB bandwidth of 0.05 nm. Notice that the output power at 1064 nm is higher when compared to that associated with 1534 nm. One of the reasons may be that the energy transfer from Yb^{3+} to Er^{3+} is not strong enough.

Fig. 4 shows the measured output powers at the both working wavelength as functions of the 980 nm pump power. The laser starts to lase at 1064 nm at 40 mW, whereas the 1534 nm output begins at higher pump powers (80 mW). Above these thresholds, the both output powers increase with increasing pump power. The fact that the threshold for the 1064 nm lasing is lower than that for 1534 nm is noticeable. This is attributed to relatively small ratio of the Yb^{3+} and Er^{3+} concentrations, so that only a small portion of the energy accumulated by Yb^{3+} ions is transferred to Er^{3+} ions. Larger portions of Yb ions may be used to emit more photons at 1064 nm and so create a laser with a lower threshold compared to that typical for 1534 nm which requires the energy transfer.

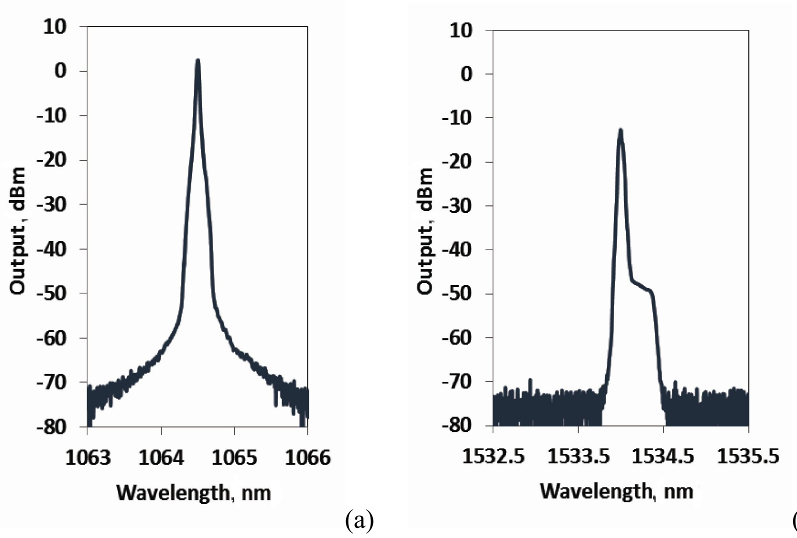

Fig. 3. Parts of output spectra of our EYDFL centred at (a) 1064 and (b) 1534 nm and expanded to a greater scale.

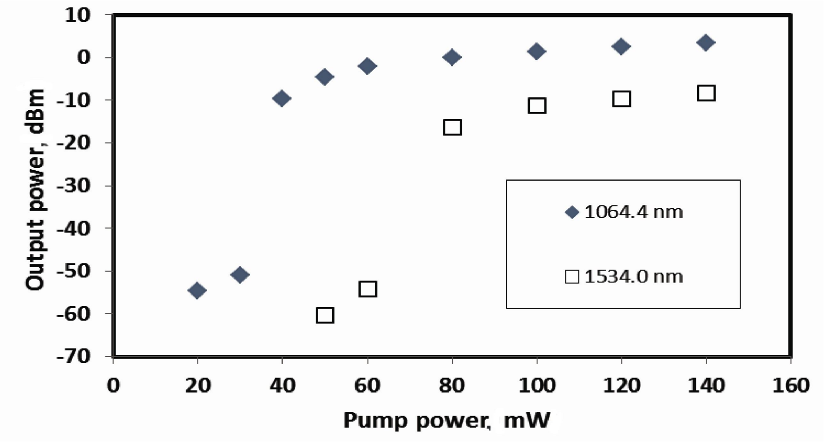

Fig. 4. Output power characteristics of our EYDFL as measured for the two operating wavelengths.

Conclusion

A simple dual-wavelength EYDFL operating in two different wavelength regions is demonstrated, using a 5 m long EYDF with a specific composition as a gain medium and a linear cavity setup utilizing two FBGs. The EYDF has the composition SiO_2–GeO_2–Al_2O_3–Er_2O_3–Yb_2O_3 of its core, the numerical aperture of 0.20, and the cut-off wavelength of 980 nm. The laser suggested by us produces two output peaks at 1064 and 1534 nm, with the corresponding maximal powers as large as 3.4 and –8.3 dBm. The EYDFL starts to lase at 1064 and 1534 nm at the pump powers of 40 and 80 mW, respectively.

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Анотація. *В роботі повідомляється про функціонування лазера на основі волокна легованого ербієм та ітербієм, який випромінював на двох довжинах хвиль 1064 і 1534 нм. У цьому, нещодавно розробленому, волокні концентрація ербію та ітербію становила 1000 та 1500 млн*$^{-1}$*, відповідно. Роль резонатора лазера відігравали дві брегівські волоконні гратки. Довжина волокна була рівною 5 м. Нагнітаючий лазерний діод випромінював на довжині хвилі 980 нм. Генерація відбувалась на довжинах хвиль 1064 і 1534 нм з потужністю 3.4 та –8.3 dBm, відповідно. Поріг генерації становив 40 мВт для довжини хвилі випромінювання 1064 нм і 80 мВт для – 1534 нм.*