Erbium Ytterbium doped fiber amplifier and laser based on 927 nm multimode pumping

Z. JUSOH[a,b], S. W. HARUN[a,c,*], S. M. M. ALI[a], N. M. ALI[a], H. AROF[a], H. AHMAD[c]
[a]*Department of Electrical Engineering, Faculty of Engineering, University of Malaya 50603 Kuala Lumpur Malaysia*
[b]*Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Malaysia*
[c]*Photonics Research Center, University of Malaya 50603 Kuala Lumpur, Malaysia*

The performance of a high output power Erbium Ytterbium doped fiber amplifier (EYDFA) and Erbium ytterbium doped fiber laser are investigated using a star shape double clad fiber in conjunction with 927 nm cladding pumping. The EYDFA provides a flat gain of 22.4 dB within a wavelength region ranging from 1545 nm to 1570 nm when the input signal and pump powers are fixed at 0 dBm and 3 W, respectively. The corresponding noise figure is 5.73 dB at 1550.4 nm. A broadband fiber Bragg grating (FBG) is used in conjunction with a perpendicularly cleaved output fiber to achieve lasing at 1565.5 nm with a threshold pump power of as low as 0.1 mW. The output power of 1060 mW is achieved with pump power of 2.8 W, which translates of 39% efficiency without any sign of roll over.

(Received May 23, 2014; accerpted July 10, 2014)

Keywords: Fiber Laser, Fiber Amplifier, Ytterbium, Double clad fiber, Multimode combiner

1. Introduction

Recently, high output power cladding pumped rare-earth doped fiber amplifiers and lasers attract considerable attention for various applications such as telecommunications (standard wavelength division multiplexing (WDM) [1], passive optical network (PON) [2], free space optical communications [3], booster amplifier for CATV applications [4], medicine and industry. Fiber laser sources are considered as very promising alternative to standard high power solid state lasers [5] due to its excellent beam quality, reliability, efficiency, utilization of standard telecommunications equipment and good compactness as well as efficient heat dissipation. High output power amplifiers operating at 1550 nm wavelength allow to build eye safe high power light source in so called Master Oscillator Power Amplifier (MOPA) configuration and employ the most often double clad Erbium or Erbium-ytterbium doped fibers.

For cladding pumping, the absorption of erbium is impractical and thus ytterbium is added to absorb more pump power. The pump energy is transferred nonradiatively from Yb-ions to Er -ions, which then emit photons at around 1550 nm [6]. Co-doping with Ytterbium prevents the formation of Erbium clusters and effectively controls the up-conversion from $^4I_{13/2}$ level; so that a higher doping level can thus be used [7-8]. The pair induced energy transfer from Ytterbium to Erbium provides an efficient indirect pumping mechanism. Ytterbium ions, which have a high absorption at wavelengths between 900 nm and 1000 nm, absorb pump light and transfer their energy to erbium ions through a non-radiative cross-relaxation effect. The double clad structure increases the amount of pump power coupled to the fiber. The first cladding provides a multimode waveguide for the pump light, thus allowing the use of high power multiple laser diodes for pumping. The pump light propagating in this fiber is absorbed in the core region for the amplification of the signal.

In this paper, the amplification and lasing characteristic of a double-clad Erbium/Ytterbium co-doped fiber (EYDF) under 927 nm multimode pumping are investigated. The EYDF amplifier (EYDFA) combines the multimode pump into the star shape inner cladding EYDF using a multimode combiner. The lasing is achieved using a broadband fiber Bragg grating (FBG) in conjunction with a perpendicularly cleaved output fiber to form a linear cavity.

2. Experimental setup

The configuration of the proposed high power EYDFA and EYDF laser (EYDFL) are shown in Fig 1 (a) and (b) respectively. A 10 m long double clad EYDF is used as the gain medium. It has a star shape inner cladding with the core and outer cladding diameters of 6 and 130 μm respectively. The inner cladding has an absorption coefficient of approximately 0.5 dB/m at around 927 nm for Ytterbium ion. The erbium peak absorption is 40dB/m at wavelength of 1535 nm. Pump beams from 927nm multimode laser diode are launched into the EYDF via multimode combiner (MMC) with a numerical aperture (NA) of around 0.15. The splice region between the EYDF and MMC is covered by low-index gel so that the multimode pump beam is effectively guided into the cladding of the EYDF. Optical isolator is used in the

EYDFA system of Fig. 1(a) to prevent any spurious reflections from oscillating in the system. The input signal is provided by a tunable light source (TLS) that operates in the C-band region. The amplified signal is routed into a power meter (or OSA) for optical power (or attenuated optical spectrum) measurement. A broadband fiber Bragg grating (FBG) operating in C-band region is used as a reflector in the proposed EYDFL system of Fig. 1(b). The FBG has a 40 nm bandwidth centered at 1546 nm with a reflectivity of more than 99%. The fiber at the output part of the laser is perpendicularly cleaved to provide feedback for the laser. This allows the generated amplified spontaneous emission (ASE) light to oscillate in the cavity between the 4% reflecting bare fiber facet and the FBG and generates laser at 1550 nm region. The output of the EYDFL is characterized by using both power meter and OSA.

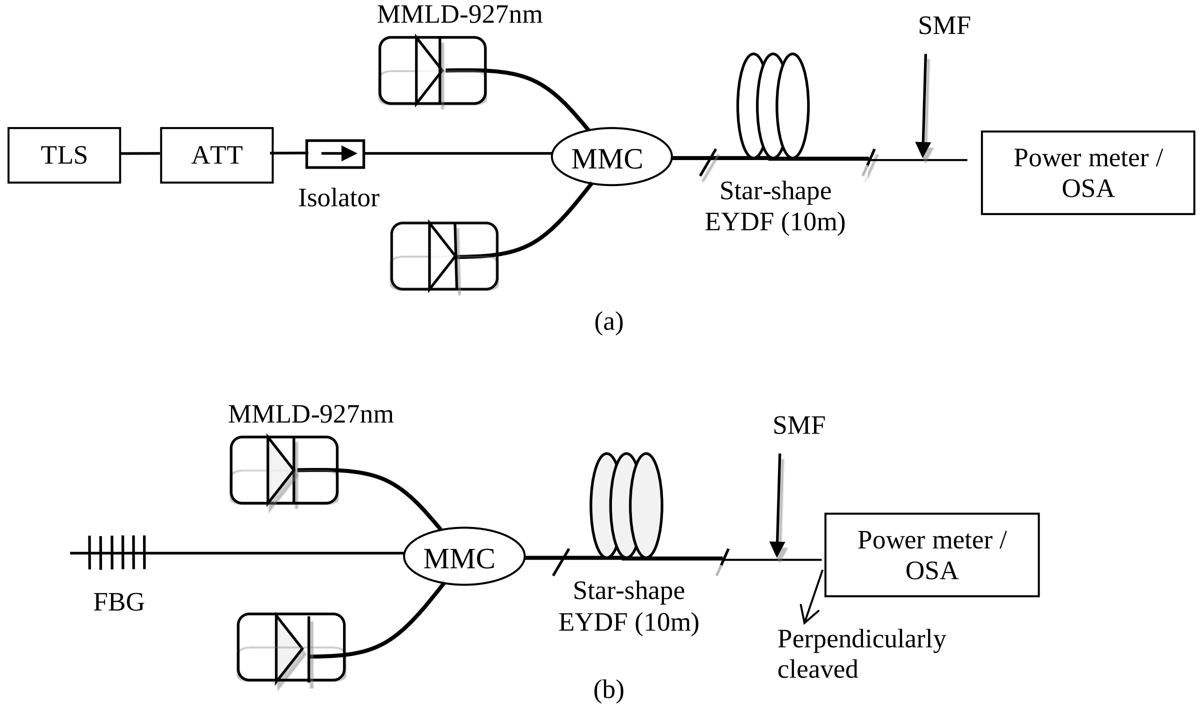

Fig. 1(a). Experimental set-ups for (a) EYDFA and (b) EYDFL based a star-shape double-clad EYDFL.

3. Result and discussion

By pumping the EYDF with 927 nm laser diode, the ytterbium ions are excited to the upper level state ($^2F_{5/2}$). The energy of the ytterbium ions is next transferred to erbium ions, which are excited to the $^4I_{11/2}$. The excited Erbium ion decays nonradiatively to reach $^4I_{13/2}$ level, which is the metastable level. Stimulated emission is prompted by the arrival of the input light, an additional photon is created with the same optical phase and direction as the incident photon and thus amplification is achieved. Fig. 2 shows the gain spectra of the EYDFA at three different pump powers of 1, 2 and 3 W when input signal power is fixed at 0 dBm. As seen, a flat gain is achieved in the C-band region ranging from 1545 to 1570 nm. The gain increases as the pump power increases whereby the flat gains are obtained at 19.8 dB, 21.7 dB and 22.4 dB for pump power of 1 W, 2 W and 3 W respectively. At the maximum pump power of 3W, the gain variation is less than 0.3 dB within the flat gain region. Inset of Fig. 2 compares the attenuated spectrum from the EYDFA with the input signal spectrum at operating wavelength of 1550.46 nm. It is observed that signal to noise ratio reduces after amplification. Spontaneous decay of the excited ions which do not participate in amplification becomes a source of optical noise. This noise gets amplified along with the incident light and results in ASE. Based on both spectra and the gain value, the noise figure (NF) is measured around 5.7 dB using the following well known equation;

$$NF = \frac{P_{ase}}{h\nu G \Delta\nu} + \frac{1}{G}$$

where P_{ase} is the ASE power, h is the plank constant, n is the frequency of the input signal, $\Delta\nu$ is the resolution of the OSA and G is the gain.

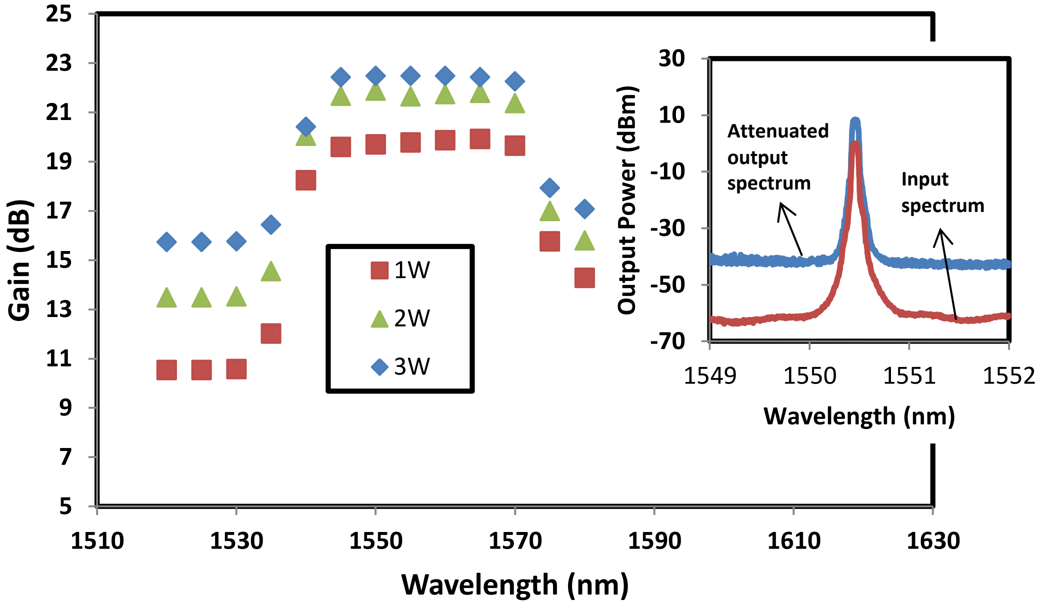

Fig. 2. Gain spectra of the proposed EYDFA at three different pump powers. Inset compares the attenuated output spectrum with the input spectrum of the signal.

Fig. 3 shows the gain characteristic of the EYDFA against the pump power at two different operating wavelengths of 1550 nm and 1555 nm. The input signal power is fixed 0 dBm in this experiment. As seen in the figure, the signal gain increases as the pump power increases and both curves are almost identical. The maximum signal gains of 22.48 dB and 22.40 dB are obtained for operating wavelengths of 1550 nm and 1555 nm respectively at the maximum pump power of 2.8 W. This shows that the gain variation is around 0.08 dB and the proposed EYDFA has a significantly flat gain. The EYDFA can be used to build eye safe high power source based on MOPA configuration, which is also useful for short laser pulse amplification.

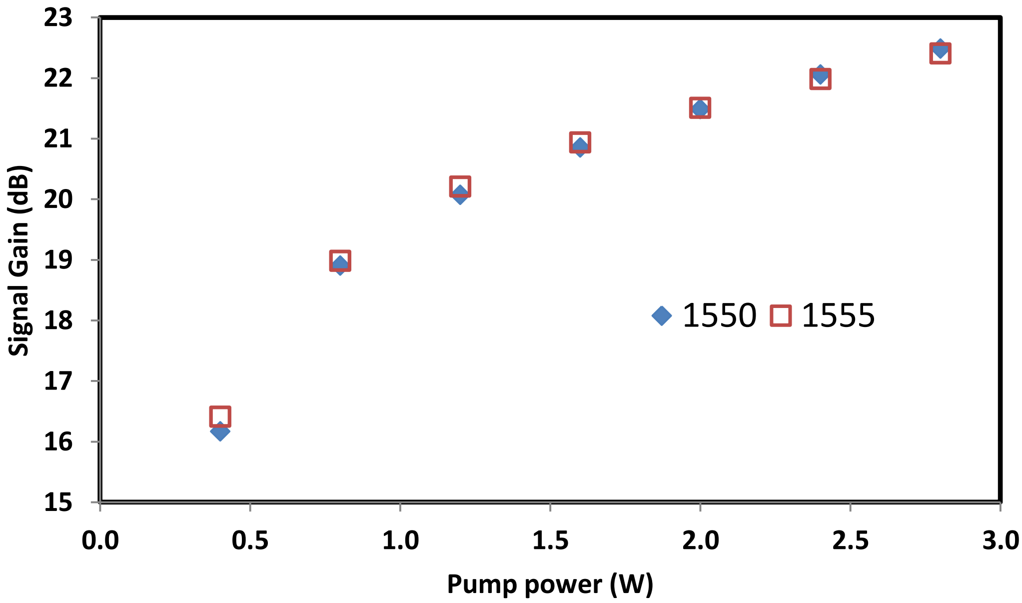

Fig. 4. Signal gain versus pump power for the EYDFA at two different operating wavelengths.

Fig. 5 shows the output power characteristic versus pump power for the proposed EYDFL at two different operating wavelengths. The laser threshold is observed to be less than 0.1 mW while the maximum output power of 1060 mW is obtained at the maximum pump power of 2.8 W without any sign of roll over. The slope efficiency is calculated to be around 39% with respect to input pump power. Insert shows the attenuated output power spectral obtained at the 927 nm pump power of 1 W. As shown in the figure, the laser operates at wavelength of 1565.5 nm, which is within the reflection band of the FBG. As discussed earlier, the EYDF provides a flat gain up to wavelength of 1570 nm and thus the lasing occurs at the longer wavelength which has a smaller cavity loss. The lack of roll-over suggests that the proposed EYDFL could deliver significantly higher powers with stronger pumping.

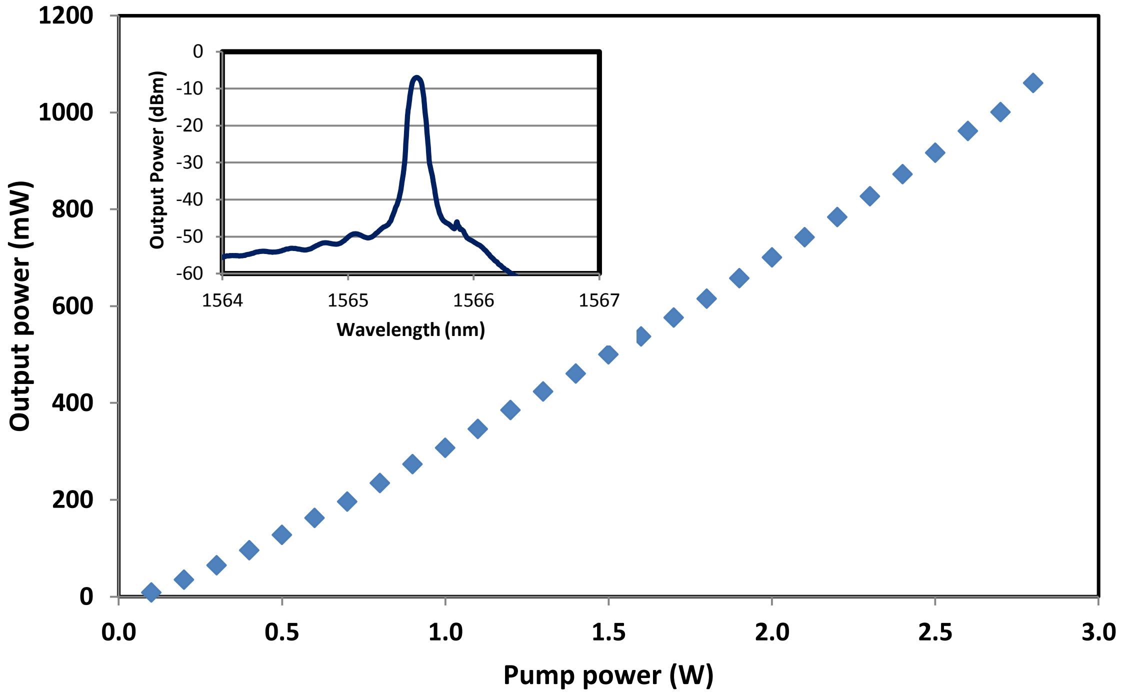

Fig. 5. Output power versus pump power for EYDFL. Insert shows the attenuated output power spectral at 1 W pump power.

4. Conclusion

A high power EYDFA and EYDFL are demonstrated by cladding pumping a 10 m long star-shape double-clad EYDF at 927 nm. The EYDFA provides a flat gain of 22.4 dB within a wavelength range from 1545 nm to 1570 nm when the input signal and pump powers are fixed at 0 dBm and 3 W, respectively. The noise figure is calculated to be around 5.73 dB at operating wavelength of 1550.4 nm. The EYDFL has achieved the maximum output power of 1060 nm at the maximum 927 nm pump power of 2.8 W. The slope efficiency is observed to be around 39% without any signs of roll over.

Acknowledgement

The authors acknowledge the financial support from the University of Malaya and Ministry of Higher Education (MOHE) under various grant schemes (Grant No: ER012-2013A, RP008D-13AET and PG139-2012B).

References

[1] P. Wysocki, T. Wood, A. Grant, D. Holcomb, K. Chang, M. Santo, L. Braun, G. Johnson, Optical Fiber Conference (OFC), paper PDP17, 2006.

[2] J. H. Lee, C.H. Kim, Y.-G. Han, S. B. Lee, Electronics Letters, **42**(9), 67 (2006).

[3] M. W. Wright, G. C. Valley, Journal of Lightwave Technology, **23**(3), 1369 (2005).

[4] D. Anthon, J. Fisher, M. Keur, K. Sweeney, D. Ott, in Optical Fiber Communication Conference, OFC 2001, **2**, TuI1-1- TuI1-3 (2001).

[5] J. Nilsson, Y. Jeong, D. B. S. Soh, C. A. Codemard, P. Dupriez, C. Farell, J. K. Sahu, J. Kim, S. Yoo, D. N. Payne, LPHYS'05: 14th International Laser Physics Workshop, Kyoto, Japan, 4-8 Jul 2005.

[6] J. Nilsson, J. K. Sahu, Y. Jeong, V. N. Philippov, D. B. S. Soh, C. Codemard, P. Dupriez, J. Kim, D. J. Richardson, A. Malinowski, A. N. Piper, J. H. V. Price, K. Furusawa, W. A. Clarkson, D. N. Payne, in Optical Fiber Communication Conference, 2005, Technical Digest. OFC/NFOEC, **2** (2005).

[7] S. W. Harun, S. D. Emami, F. Abd Rahman, S. Z. Muhd-Yassin, M. K. Abd-Rahman, H. Ahmad, Laser Physics Letters, **4**(8), 601 (2007).

[8] S. W. Harun, H. A. Abdul-Rashid, S. Z. Muhd-Yassin, M. K. Abd-Rahman, K. K. Jayapalan, H. Ahmad, Optics & Laser Technology, **40**, 88 (2008).

*Corresponding author: swharun@um.edu.my