Linear cavity erbium-doped fiber laser with over 100 nm tuning range

Xinyong Dong, Nam Quoc Ngo*, and Ping Shum

Network Technology Research Center, School of Electrical & Electronics Engineering,
Nanyang Technological University, Singapore 639798
eqnngo@ntu.edu.sg

Hwa-Yaw Tam

Department of Electrical Engineering, The Hong Kong Polytechnic University, Hong Kong

Xiaoyi Dong

Institute of Modern Optics, Nankai University, Tianjin, 300071, China

Abstract: We report a widely tunable single-frequency linear-cavity erbium-doped fiber laser covering both the conventional wavelength band (C-band) and the long wavelength band (L-band). The laser has low threshold, high slope efficiency and high signal-to-noise radio. A large tuning range of over 100 nm is realized by optimization of the active fiber length.

OCIS codes: (060.2320) fiber optics amplifiers and oscillators; (140.3500) lasers, erbium; (140.3600) lasers, tunable

---

References and links

1. P. L. Scrivener, E. J. Tarbox, and P. D. Maton, "Narrow linewidth tunable operation of Er^{3+}-doped single-mode fiber laser," Electron. Lett. **25**, 549-550 (1989).
2. J. L. Zyskind, J. W. Sulhoff, J. Stone, D. J. Digiovanni, L. W. Stulz, H. M. Presby, A. Piccirilli, P. E. Pramayon, "Electrically tunable, diode-pumped Erbium-doped fiber ring laser with fiber Fabry-Perot etalon," Electron. Lett. **27**, 1950-1951 (1991).
3. Th. Pfeiffer, H. Schmuck, and H. Bülow, "Output power characteristics of Erbium-doped fiber ring laser," IEEE Photon. Technol. Lett. **4**, 847-849 (1992).
4. S. Yamashita, and M. Nishihara, "Widely tunable erbium-doped fiber ring laser covering both C-band and L-band," IEEE J. Select. Topics Quantum Electron. **7**, 41-43 (2001).
5. A. Bellemare, M. Karasek, C. Riviere, F. Babin, G. He, V. Roy, and G. W. Schinn, "A broadly tunable Erbium-doped fiber ring laser: experimentation and modeling," IEEE J. Select. Topics Quantum Electron. **7**, 22-29 (2001).
6. Y. T. Chieng, G. J. Cowle, and R. A. Minasian, "Optimization of wavelength tuning of Erbium-doped fiber ring lasers," J. Lightwave. Technol. **14**, 1730-1739 (1996).
7. M. Mignon, E. Desurvire, "An analytical model for the determination of optimal output reflectivity and fiber length in Erbium-doped fiber lasers," IEEE Photon. Technol. Lett. **4**, 850-852 (1992).
8. E. Delevaque, T. Georges, M. Monerie, P. Lamouler, and J.-F. Bayon, "Modeling of pair-induced quenching in erbium-doped silicate fibers," IEEE Photon. Technol. Lett. **5**, 73-5 (1993).
9. P. Myslinski, D. Nguyen, and J. Chrostowski, "Effects of concentration on the performance of erbium-doped fiber amplifiers," J. Lightwave Technol. **15**, 112-120 (1997).
10. J. L. Wagener, P. F. Wysocki, M. J. F. Digonnet, H. J. Shaw, and D. J. Digiovanni, "Effects of concentration and clusters in erbium-doped fiber lasers," Opt. Lett. **18**, 2014-2016 (1993).
11. X. Dong, N. Q. Ngo, P. Shum, B.-O. Guan, H.-Y Tam, X. Dong, "Concentration-induced nonuniform power in tunable erbium-doped fiber laser," to be published.
12. A. Bellemare, J.-F. Lemieux, M. Têtu, and S. LaRochelle, "Erbium-doped fiber ring lasers step-tunable to exact multiples of 100 GHz (ITU-grid) using periodic filters," ECOC'98, 153-154 (1998).
13. B.-H. Choi, H.-H. Park, M. Chu, and S. K. Kim, "High-gain coefficient long-wavelength-band erbium-doped fiber amplifier using 1530-nm band pump," IEEE Photon. Technol. Lett. **13**, 109-111 (2001).

#2545 - $15.00 US
Received June 02, 2003; Revised July 05, 2003

1. Introduction

Widely tunable, narrow linewidth, single frequency erbium-doped fiber lasers (EDFLs) have been studied extensively as an essential laser source for wavelength-division-multiplexed (WDM) transmission systems and for performance testing of optical components [1-3]. They can be tunable over a large wavelength range of the erbium-doped fiber amplifiers (EDFAs), have low threshold, high signal-to-noise radio, moderate effective linewidth (0.1~1.0 GHz), and excellent wavelength and power repeatability [4,5]. In recent years, there is a greater demand on widely tunable fiber lasers to take advantage of the L-band of EDFA to increase transmission capacity. Some investigations have been carried out to study the effect of the laser cavity parameters such as erbium-doped fiber (EDF) length, intra-cavity loss, output coupling ratio, and pump wavelength and power, on the laser performance [3,5,6]. It was shown by theoretical analysis that the tuning range of EDFL could be larger than 100 nm in 1992 [7], but it was only in recent years that such a large tuning range can be experimentally obtained in a ring cavity EDFL [5]. The key idea is to make the EDF operate in deep saturation by optimizing the EDF length and reducing the intra-cavity loss [5]. Compared with ring lasers, linear cavity lasers have the advantage that the gain medium amplifies the laser light twice per circulation that makes it easy to reach deep saturation. Therefore, a large tuning range as well as low threshold pump power and high slope efficiency can be easily achieved.

In this paper, we report a single-wavelength, linear cavity EDFL with large tuning range of over 100 nm by optimizing the EDF length. The effects of the EDF length and output coupling ratio on the laser performance are investigated. The laser has low threshold, high slope efficiency, and high signal-to-noise radio.

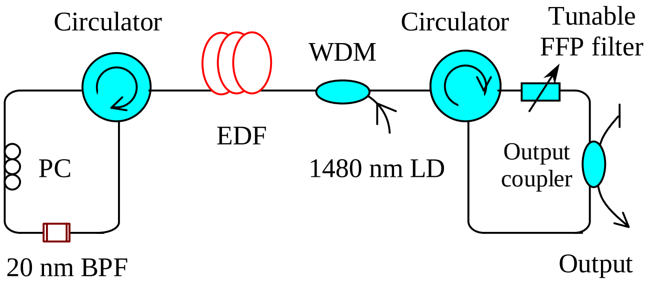

Fig. 1. Schematic diagram of the proposed laser configuration.

2. Laser configuration

Figure 1 shows the proposed laser configuration. Two circulators with port-to-port loss of 0.5 dB are used as the end mirrors, which allows us to insert the polarization controller (PC), output fiber coupler, and filter elements into the two loops rather than into the laser cavity to minimize the insertion loss. The lightwave propagates through the two loops once per circulation but it is twice through the cavity. Thus, the insertion loss introduced by these components is reduced by two fold. We can also choose to insert a given component, such as the filter, into one of the two loops to optimize the laser performance. The EDF was backward pumped through a micro-optic WDM coupler by a 90 mW laser diode emitting at 1480 nm. At the left end of the EDF, incident laser light, which is “reflected” by circulator on the left, has relatively high power because it is amplified once by the EDF. The high-power laser light enters the EDF again and this makes the EDF reach deep saturation easily so that a large tuning range can be obtained [5]. The EDF has high erbium concentration of ~ 9.2×10^{24} ions/m^3, absorption coefficients of α (1480 nm) = 7 dB/m and α (1532 nm) = 15 dB/m, cutoff wavelength of 1000 nm, and a numerical aperture of 0.29.

#2545 - $15.00 US
Received June 02, 2003; Revised July 05, 2003

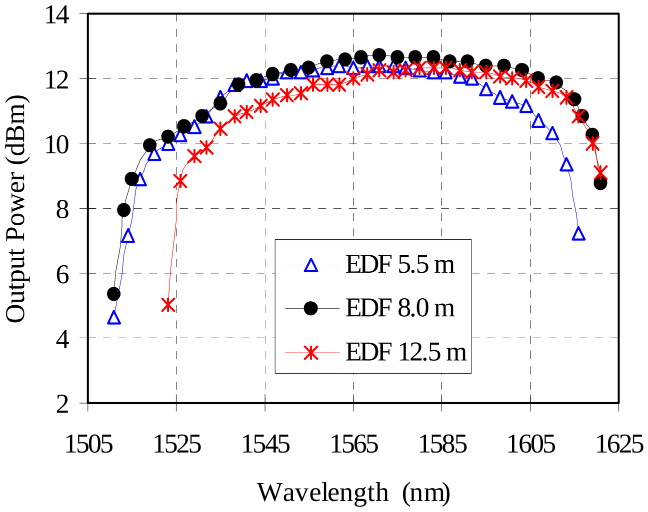

Fig. 2. Laser power against emission wavelength for different EDF lengths.

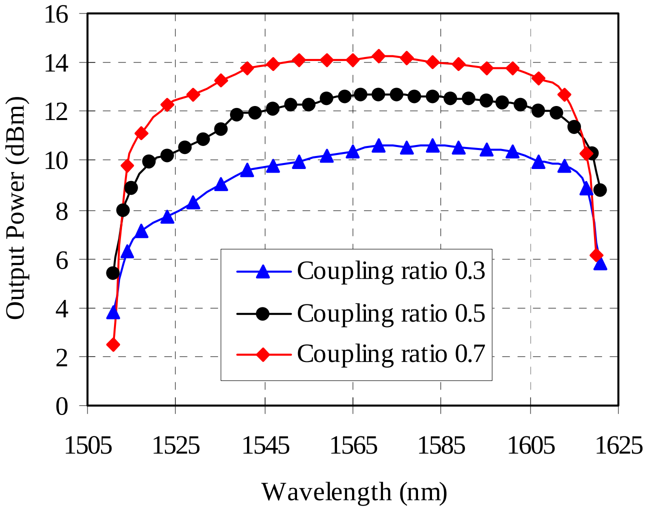

Fig. 3. Laser power against emission wavelength for different output coupling ratios.

As a tunable filter with a sufficiently large tuning range is not commercially available, a tunable narrow-bandpass fiber Fabry-Perot (FFP) filter with a bandwidth of 0.2 nm and free spectral range (FSR) of 28 nm and six bandpass filters (BPFs) with 20 nm bandwidth are used as an alternative to demonstrate the effectiveness of the proposed method. The BPFs are used one by one. For each BPF, its 20-nm bandwidth is less than the FFP's 28-nm FSR and thus continuous wavelength tuning can be obtained within the 20 nm range by changing the voltage applied to the piezoelectric transducer of the FFP. Hence, a total tuning range of 120 nm can be achieved by using the six BPFs in turn. Furthermore, as each BPF is inserted into a separate fiber loop from that of the FFP, improvement on the laser performance is also expected because the limited 20-nm bandwidth of the BPF will suppress the amplified

Received June 02, 2003; Revised July 05, 2003

spontaneous emission (ASE) power in the laser cavity. The total insertion loss of the two filters is about 3.5 dB.

3. Results and discussion

Figure 2 shows the measured laser output powers for various EDF lengths. The coupling radio of the output coupler is 0.5. For EDF lengths of 5.5, 8.0 and 12.5 m, laser emission can be tuned in large wavelength ranges of 105 nm (1511-1616 nm), 110 nm (1511-1621 nm) and 98 nm (1523-1621 nm), respectively. It can be seen that optimization of the EDF length is necessary to obtain high power over a large tuning range. It influences the short and long wavelength ends of the tuning range noticeably. For 5.5 m of EDF, the output power decreases more rapidly in the L-band region because the EDF is too short to obtain sufficient gain. On the contrary, for 12.5 m of EDF, the power decreases more rapidly in the C-band region and is very small below 1525 nm due to absorption from the long EDF length. Thus, the optimal EDF length is about 8.0 m, which gives the largest tuning range with the highest average power. In this case of 8.0 m of EDF, tunable ranges for 1 dB and 3 dB power flatness are 76 nm (1537-1613 nm) and 100 nm (1519-1619 nm), respectively.

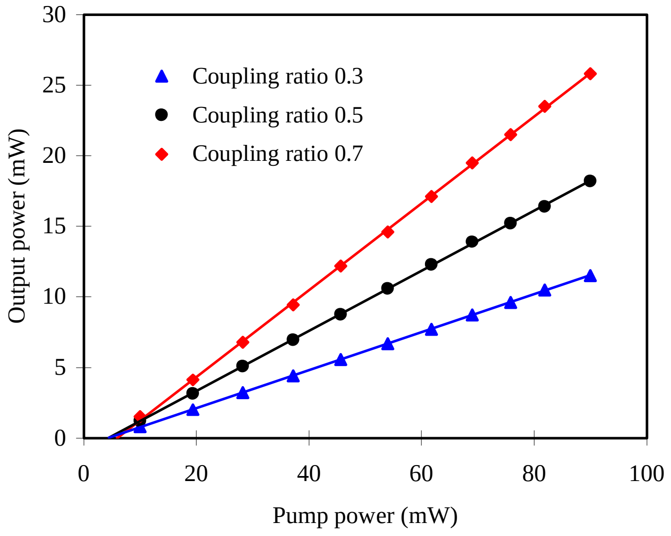

Fig. 4. Laser power against pump power at 1580 nm for different output coupling radios.

Figure 3 shows the laser output powers over the tuning range of 1511 nm to 1621 nm for various output coupling ratios of 0.3, 0.5 and 0.7. The EDF length is 8.0 m. It can be seen that the output power increases with an increase in the output coupling ratio over the mid-band of the wavelength range but it decreases at the short and long edges of the wavelength tuning range which results in a smaller tunable range. This is because as the output coupling ratio increases the intra-cavity loss also increases and a larger intra-cavity loss leads to a less tuning range in a tunable laser [5]. The maximum output powers are 10.6, 12.7 and 14.3 dBm at around 1580 nm for the output coupling radios of 0.3, 0.5 and 0.7, respectively. Fig. 4 shows the measured the laser output power at 1580 nm versus the pump power for various output coupling radios. The threshold pump powers are 4.4, 4.6 and 5.9 mW and the calculated slope efficiencies are 13.5%, 21.3% and 30.7% for the output coupling radios of 0.3, 0.5 and 0.7, respectively.

We have also measured the threshold pump power and have calculated the slope efficiency at other emission wavelengths. The results show that the threshold pump power increases and the slope efficiency decreases slightly at a wavelength shorter than 1540 nm, and this causes a power drop at around 1530 nm and hence degradation on the power flatness

Received June 02, 2003; Revised July 05, 2003

(see Fig. 2 and Fig. 3). This phenomenon is mainly caused by concentration quenching due to clustering of erbium ions in the high-concentration EDF. Concentration quenching has been identified as the main cause of EDF's performance degradation [8], which may cause a decrease in the population inversion and hence quantum efficiency, resulting in a reduction of EDFA gain and an increase in the threshold of EDFLs [9,10]. Our recent theoretical studies on fiber ring laser have shown that it may lead to nonuniform output power in tunable EDFLs because it influences the laser performance more in the C-band, especially at around 1530 nm, than in the L-band [11]. The laser power profile we obtained in this paper is similar to the simulation result of Ref. [11]. Using low-concentration EDF can overcome this undesirable effect but at the cost of increasing the device size due to the long EDF length required.

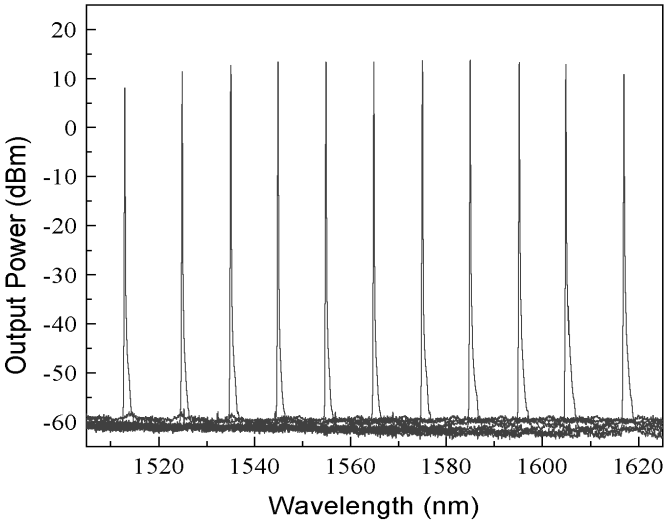

Fig. 5. Tunable laser spectrum over 105 nm wavelength range.

Figure 5 shows the laser spectrum from 1513 nm to 1618 nm measured using an optical spectrum analyzer (OSA). The EDF length is 8.0 m and the output coupling radio is 0.7. It can be seen that the signal-to-noise radio is better than 60 dB within the whole tuning range of 105 nm. The ASE noise is very small because the FFP filter was placed in front of the output coupler. The linewidth of each spectral peak is about 0.014 nm measured with 0.01 nm resolution of the OSA. The asymmetric line shape is due to the OSA's response.

We also measured the laser output power when the BPF was inserted into the fiber loop in which the FFP filter was placed. We found that the laser tuning range was reduced by about 15 nm in the short wavelength region although the maximum power increased slightly by about 0.2 dBm. We believe that it is due to the ASE light generated in the EDF, which is usually high when an EDFL emits at wavelengths below 1530 nm and in the L-band [4,12]. In the original design with the BPF and FFP filter in two separate loops, the ASE light was filtered and greatly suppressed by the BPF before it was fed back into the cavity. However, in the case of the BPF and FFP filter in the same loop, the ASE light was directly fed back into the EDF through the left fiber loop. This ASE light, with most of its power in the C-band, was amplified in the EDF when the laser was tuned to wavelengths below 1530 nm, resulting in a reduction of the gain of the EDF. However, when the laser emitted in the L-band, the ASE light provided an additional pump source to the EDF [13]. This is the reason why the tuning range of the laser decreased at the short wavelength end and the maximum power increased slightly when we placed the BPF and FFP filter in the same fiber loop. From this observation, it is clear that the original design of the laser provides a larger tuning range.

Received June 02, 2003; Revised July 05, 2003

4. Summary

We have demonstrated a widely tunable, single wavelength, linear cavity erbium-doped fiber laser covering both the C-band and L-band. The dependence of the laser output power on the emission wavelength for different EDF lengths and different output coupling radios has been studied. Large wavelength tuning range of over 100 nm has been obtained by optimizing the EDF length. The laser has low threshold power, high slope efficiency, and high signal-to-noise ratio.

5. Acknowledgement

This work was partially supported by the Research Council of the Hong Kong Polytechnic University. The authors would like to thank Dr. Bai-Ou Guan, Dr. Chunliu Zhao, Dr. W. H. Chung for useful discussions.

Received June 02, 2003; Revised July 05, 2003