Multi-wavelength fiber laser with erbium doped zirconia fiber and semiconductor optical amplifier

A. HAMZAH, S. W. HARUN*, N. A. D. HURI, A. LOKMAN, H. AROF, M. C. PAUL[a], M. PAL[a], S. DAS[a], S. K. BHADRA[a], H. AHMAD[b], S. YOO[c], M. P. KALITA[c], A. J. BOYLAND[c], J. K. SAHU[c]
Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[a]*Fibre Optics Division, Central Glass and Ceramic Research Institute, 196, Raja S.C. Mullick Road, Kolkata 700 032, India*
[b]*Photonics Research Center, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[c]*Optoelectronic Research Centre, University of Southampton, Southampton So17 1BJ, United Kingdom*

Multi-wavelength hybrid fiber lasers are demonstrated in both ring and linear cavities using a fabricated Erbium-doped Zirconia fiber (EDZF) and semiconductor optical amplifier (SOA) as gain media. In both configurations, the a fiber loop mirror, which is constructed using a 3 m long polarization maintaining fiber (PMF) and a polarization–insensitive 3dB coupler is used as a comb filter for the fiber laser. In the ring cavity, 10 simultaneous lines with peak power above -26 dBm is obtained at 1550 nm region. This is an improvement compared to the linear cavity configuration which has only 5 simultaneous lines observed from wavelength 1556.1 nm to 1563.0 nm with the peak power above -40 dBm. Both hybrid lasers has a constant line spacing of 1.7 nm, which is suitable for wavelength division multiplexing and sensing applications and shows a stable operation at room temperature.

(Received September 23, 2010; accepted October 14, 2010)

Keywords: Multi-wavelength laser, Zirconia-based Erbium-doped fiber, SOA

1. Introduction

Laser sources capable of producing multiple wavelengths with a constant spacing have important applications in optical sensors and wavelength division multiplexing (WDM) systems [1-4]. Two main ingredients of a laser are a gain medium that provides amplification and a suitable cavity that provides positive optical feedback [5-6]. Much research effort has been devoted recently on gain medium materials such as advanced Erbium-doped fiber (EDF), Erbium/Ytterbium-doped fiber and Bismuth-based EDF [7-9] to allow high erbium ion concentration without any concentration quenching effect. In earlier works, Erbium doped Zirconia fiber (EDZF) has been proposed as a gain medium for an optical amplifier [10]. By combining Zr and Al, a high doping erbium concentration of about 3000 ppm can be achieved without any phase separation. Furthermore, this fiber has a high refractive index in the visible and near infrared region and thus is capable of producing a wide-band light emission covering both C- and L-band regions.

Since EDF exhibits homogeneous broadening, a stable multi-wavelength oscillation in Erbium-doped fiber lasers (EDFLs) is difficult to achieve at room temperature. This is due to the existence of gain saturation which causes mode competition between different wavelengths. To reduce the cross-gain saturation and suppress the mode competition, various methods have been proposed to realize multi-wavelength oscillations at room temperature in EDFLs. These include the introduction of four-wave mixing (FWM) and stimulated Brillouin scattering (SBS) effects in the laser cavity [1-2], inserting frequency shifter in the laser cavity [11] and employing specially designed erbium-doped fibers or cavity structures [12-14]. Another approach for multi-wavelength laser generation is to employ a semiconductor optical amplifier (SOA), which has inhomogeneous broadening characteristic as a gain medium [14].

In this paper, a stable multi-wavelength laser is demonstrated using a hybrid gain medium by cascading EDZF and SOA in both linear and ring cavity set-up. A fiber sagnac loop mirror is employed in the cavity as an amplitude equalizer to induce intensity-dependent loss and alleviates the mode competition caused by homogeneous gain broadening in EDF.

2. Experimental set-up

In Fig. 1 two different architectures of the multi-wavelength hybrid EDZF / SOA lasers are shown where Figs. 1(a) and 1(b) depict the configurations with linear and ring cavity, respectively. In both configurations, the laser resonator consists of a piece of EDZF, a 1480/1550 nm wavelength-division multiplexer (WDM), a semiconductor optical amplifier (SOA), a polarization controller (PC) and a polarization maintaining fiber (PMF) cascaded with a polarization–insensitive 3dB coupler to act as a comb filter component of the fiber laser. The 2 m long EDZF, which is pumped through the WDM by 1480 nm laser diode with the maximum power of 120 mW is used in conjunction with an SOA to provide gain for the laser. The PC is used to rotate the polarization state and allows continuous adjustment of the birefringence within the cavity to balance the gain and loss for multi-wavelength lasing. The laser power is coupled out using a 90:10 coupler which allocates 10% for the output and 90% for feedback inside the cavity. An optical circulator is incorporated in both ends of the linear configuration to complete a round-trip oscillation. In the linear laser of Fig. 1(a), the amplified spontaneous and stimulated emissions light travels to the OC1 will be re-circulated back into both gain media. After the signal is amplified it moves to OC2 and reflected back to complete a round-trip oscillation. An optical isolator is incorporated in the ring configuration of Fig. 1(b) to ensure unidirectional operation of the laser. The output laser is characterized using an optical spectrum analyser (OSA) with a resolution of 0.01 nm.

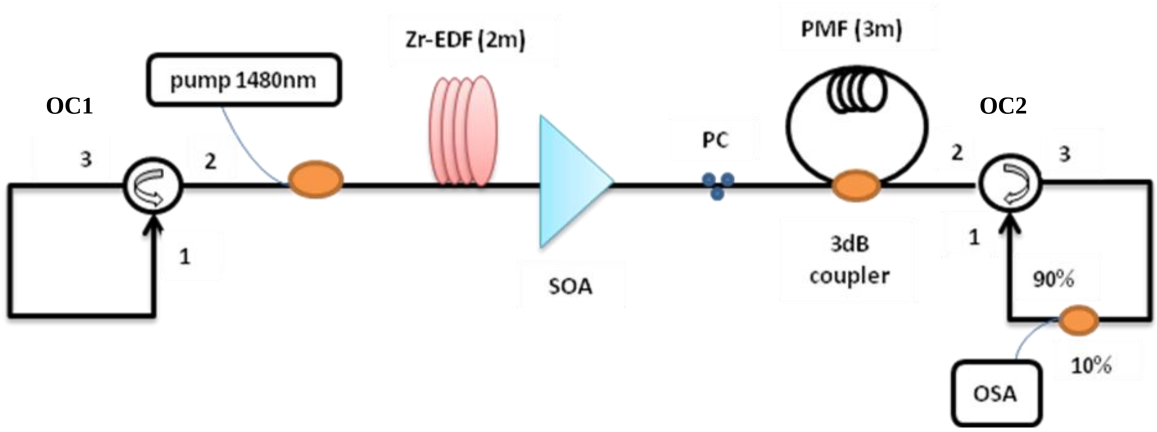


Fig. 1(a). Linear cavity configuration.

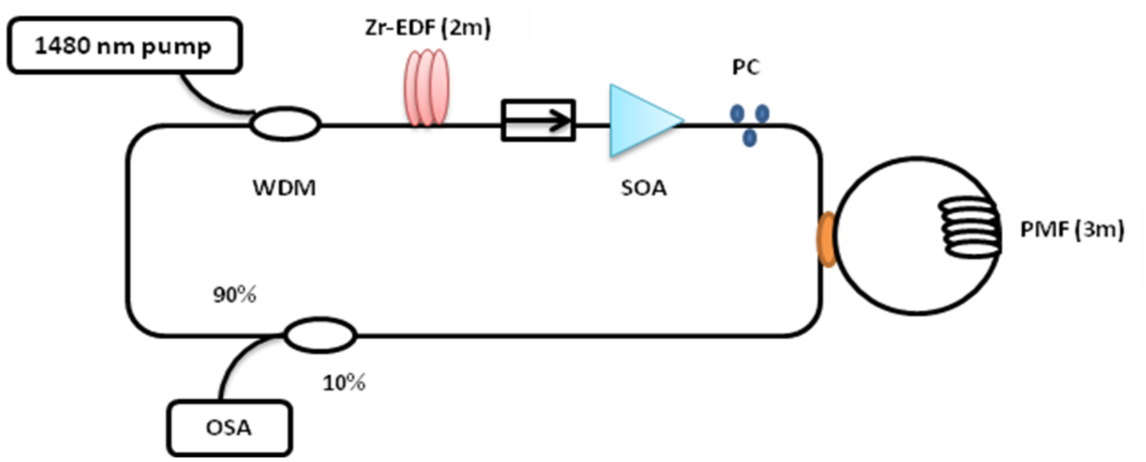
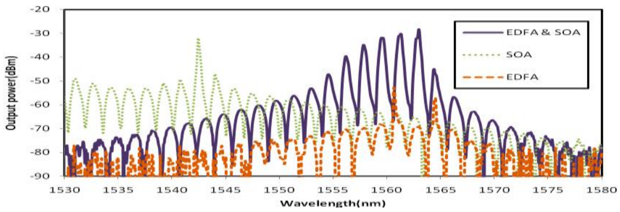


Fig. 1 (b). Ring cavity configuration.

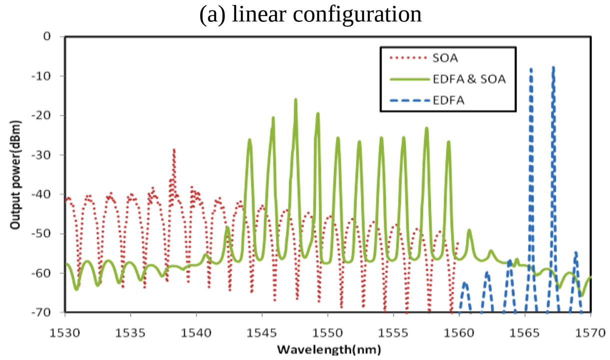
The EDZF is obtained from a fiber preform, which is fabricated in a ternary glass host, zirconia-yttria–aluminum codoped silica fiber using a modified chemical vapor deposition (MCVD) [13]. Doping of Er_2O_3 into Zirconia yttria-aluminosilicate based glass is done through solution doping process. With a combination of both Zr and Al, we could achieve the high erbium doping concentration in the glass host without any phase separations of rare-earths. To prevent thermal cracking minor amount of Y_2O_3 is used. The core composition of the fabricated fiber consists of 0.25 mole% of Al_2O_3, 0.65 mole% of ZrO_2 and 0.155 mole% of Er_2O_3. A fiber of 125 micrometers in diameter is drawn from the fabricated preform at temperature of around 2000 ^{o}C using the conventional fiber drawing technique. The peak absorption the Zr-EDF at 978 nm is found to be 14.5 dB/m which translates to the erbium ions concentration of 2800 ppm wt. The SOA used in this experiment is based on an InGaAsP-InP ridge waveguide with antireflection coated facets angled at 10^{o}. It has a centre operating wavelength of 1534 nm with a spectral width of 40 nm. A 3 m long of PMF is used with a 3dB coupler to form a Sagnac loop mirror.

3. Result and discussion

The performance of the hybrid amplifiers are compared with the singular EDZF- and SOA-based fiber amplifiers. In the experiment, the 1480 nm pump power is fixed at 120 mW and the SOA is biased with a fixed current of 300 mA. Figs. 2(a) and 2(b) show the output spectra of the amplifiers which are configured with linear and ring cavity architectures respectively. With a single gain medium and linear cavity configuration, the SOA-based laser generates a comb laser with the maximum peak of -32.1 dB at wavelength of 1542.4 nm, while the EDZF-based laser generates a comb with a relatively lower power as shown in Fig. 2(a). In the same configuration, the hybrid amplifier shows a better performance than the individual SOA- and EDZF– based lasers especially within the wavelength region of 1556.1 nm to 1563.0 nm by producing 5 simultaneous lines with a peak power above -40 dBm. The performance of the hybrid amplifier in the ring configuration of Fig. 1(b) is superior than the one with the linear cavity as shown in Fig. 2(b). From the figure, 10 simultaneous lines can be observed with the peak powers above -26 dBm and a constant line spacing of 1.7 nm at wavelength region around 1550 nm. The improvements are due to the unidirectional operation in this laser, which provides an effective amplification as well as successfully reducing the mode competition in the cavity. The line spacing was determined by the comb filter, which consists of a piece of PMF and a 3 dB coupler. The line spacing can be adjusted by controlling the cavity length inside the comb filter.



(a) linear configuration



(b) ring configuration

Fig. 2. Multi-wavelength optical amplifiers with an SOA and EDZF (a) linear (b) ring configurations.

Fig. 3 compares the output spectrum of the hybrid amplifiers obtained from linear and ring cavities. It is observed that the ring cavity configuration produces much higher output power than that of the linear cavity. The ring cavity configuration generates 10 simultaneous lines of multi-wavelength with output power above -40 dBm. This is twice the number of lines produced by the linear cavity configuration. The comb laser operates in a shorter wavelength region in the ring cavity compared to that of the linear cavity due to the cavity loss, which is higher in the ring cavity. This oscillating light requires more gain to compensate the loss and therefore the operating wavelength is shifted towards the peak gain of the amplifier in a shorter wavelength. Both spectra show the line spacing of 1.7 nm, which is determined by the PMF length in fiber loop mirror. Based on stability analysis, it is known that any small perturbation in the laser cavity will result in the energy distribution change of the laser modes. In an EDF laser, different modes experience different net gains, depending on the polarization state and the wavelength. Due to the homogeneous gain broadening of the EDF, the fiber laser suffers from a strong mode hopping, which makes it impossible to generate stable multi-wavelength lasing as shown in Fig. 2. When an SOA is incorporated into the ring laser cavity, it acts as an optical cavity buffer, producing elastic compression and expansion of the cavity length. When the rate of the cavity length shift is comparable with the relaxation time of the laser, none of oscillation modes will be temporarily dominant over others. Therefore, a simultaneous multi-wavelength comb is observed as shown in Figs. 2 and 3. The proposed laser has many potential applications for example as multi-wavelength sources in DWDM systems and sensor applications due to its larger channel spacing and stable operation at room temperature as compared to multi-wavelength Brillouin fiber laser.

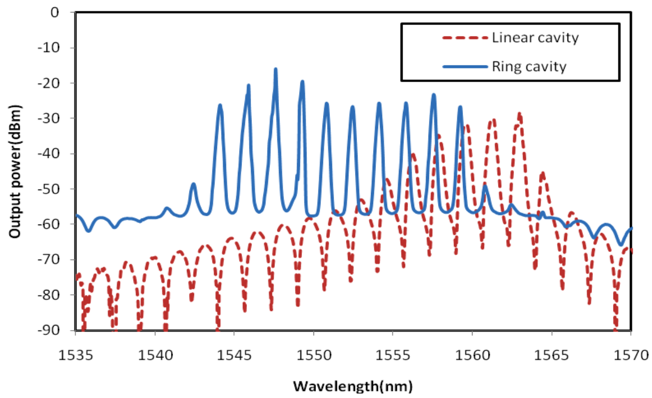


Fig. 3. Comparison of the output spectrum between two hybrid EDZF/SOA amplifiers configured with ring and linear cavity.

4. Conclusions

A compact multi-wavelength fiber laser is experimentally demonstrated using a hybrid gain media of EDZF and SOA and its performances for two different configurations with linear and ring cavities are investigated. A fiber loop mirror, which is constructed using a 3 m long PMF and a 3dB coupler is used as a comb filter in both configurations. The EDZF used is drawn from Erbium-doped preform fabricated through deposition of porous layer by the MCVD process in conjunction with a solution doping technique. By properly adjusting the polarisation state of the oscillating light, 10 simultaneous lines with peak power above -26 dBm and a constant line spacing of 1.7 nm are obtained at 1550 nm region for the ring configuration. This is an improvement compared to the linear cavity configuration which has only 5 simultaneous lines observed at 1560 nm region with the peak power above -40 dBm. Both hybrid lasers show a stable operation at room temperature.

References

[1] S. W. Harun, R. Parvizi, S. Shahi, H. Ahmad, Laser Phys. Letters, **6**(11), 813 (2009).
[2] M. R. Shirazi, N. S. Shahabuddin, S. N. Aziz, S. W. Harun, H. Ahmad, Laser Phys. Lett. **5**(5), 361 (2008).
[3] G. Qu, Y. P. Chen, M. J. Gong, X. F. Chen, IEEE J. Quantum Electronics, **46**(6), 945 (2010).
[4] K. S. Lim, M. R. A. Moghaddam, S. W. Harun, H. Ahmad, Lasers in Engineering, **20**(1-2), 39 (2010).
[5] N. Tamchek, S. W. Harun, W. Y. Chong, H. Ahmad, Optoelectron. Adv. Mater. - Rapid Comm. **3**(1), 24 (2009).
[6] S. W. Harun, M. C. Paul, M. Pal, A. Dhar, R. Sen, S. Das, S. K. Bhadra, N. S. Shahabuddin, H. Ahmad, Optoelectron. Adv. Mater. - Rapid Comm. **2**(8), 455 (2008).
[7] H. L. Yang, S. C. Ruan, Y. Q. Yu, H. Zhou, Opt. Commun., **283**(16), 3176 (2010).
[8] B. Ortac, J. Limpert, S. Jetschke, Appl. Phys. B – Lasers and Optics, **98**(1), 27 (2010).
[9] S. W. Harun, R. Parvizi, X. S. Cheng, H. Ahmad, Optics and Laser Technology, **42**(5), 790 (2010).
[10] M. C. Paul, S. W. Harun, N. A. D. Huri, A. Hamzah, S. Das, M. Pal, S. K. Bhadra, H. Ahmad, S. Yoo, M. P. Kalita, A. J. Boyland, J. K. Sahu, Optics Letters, **35**(17), 2882 (2010).
[11] O. Graydon et al., IEEE Photon. Technol. Lett., **8**(1), 63 (1996).
[12] Q. Mao, J. W. Y. Lit, J. Lightw. Technol., **21**(1), 160 (2003).
[13] H. Ahmad, K. Thambiratnam, A. H. Sulaiman, S. W. Harun, Laser Phys. Lett., **5**(10), 726 (2008).
[14] A. Dhar, M. C. Paul, M. Pal, A. K. Mondal, S. Sen, H. S. Maiti, R. Sen, Opt. Express, **14**, 9006 (2006).

*Corresponding author: swharun@um.edu.my