Single frequency erbium doped fiber laser with a highly doped erbium-doped fiber

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A single frequency Erbium-doped fiber laser (EDFL) operating at 1552.5 nm has been demonstrated by using a 2 m long of newly developed Zirconia-based Erbium-doped fiber (Zr-EDF) as a gain medium. The Zr-EDF is fabricated by combining Zr and Al to achieve the maximum Erbium ion concentration of 4320 ppm wt. By using a fiber Bragg grating (FBG) in a ring configuration, a laser which operates at 1552.5 nm with signal to noise ratio of 60 dB is generated. The linewidth of the EDFL is measured to be approximately 95 MHz using a heterodyne technique.

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1. Introduction

Coherent laser sources with single-frequency narrow linewidth output are required for many applications such as laser spectroscopy, remote sensing, and coherent laser seeding application. Diode-pumped single-frequency solid-state lasers (e.g., monolithic nonplanar Nd:YAG ring oscillator laser) are normally used for low-noise coherent laser sources with a spectral linewidth ranging from hundreds of kilohertz to as narrow as a few kilohertz [1-3]. Recently, much attention has been given to the development of diode-pumped single frequency fiber lasers because these fiber-based lasers offers many unique advantages over conventional solid-state lasers in terms of reliability, ruggedness, and compactness. Most of the fiber-based lasers use Erbium-doped fiber (EDF) as a gain medium and are normally referred as Erbium-doped fiber lasers (EDFLs). To date, extensive research has been done on the ion composition of the EDF to achieve a flat-gain and efficient operation. For instance, Erbium/Ytterbium-doped fiber (EYDF), Bismuth-based EDF and phosphate-based EDF are proposed to allow a higher Erbium ion concentration to be doped into a fiber without any concentration quenching effect [4-6].

Recently, Zirconia (ZrO2) based EDF (Zr-EDF) is also proposed because of its non-hygroscopic characteristic as well as its high refractive index in the visible and near infrared region of the spectrum [7-9]. High index materials tend to exhibit wide emission and absorption bandwidths. In this paper, a compact and single frequency EDFL is demonstrated using a Zirconia-based EDF and a fiber Bragg grating (FBG) in a ring configuration. The laser only uses a 2 m long EDZF instead of more than 50 m long conventional EDF as the gain medium for operation in 1550 nm region.

2. Experimental set-up

The experimental set-up of the EDFL is shown in Fig. 1(a). It consists of a piece of Zirconia-based EDF, a 1480/1550 nm WDM coupler, a three-port optical circulator, an FBG and an output coupler. A 1480 nm laser diode pump is coupled into the EDF via the WDM coupler. The FBG is connected to port 2 of the circular, and the reflection from the FBG is routed to port 3. The light is split 90/10 by the 10dB output coupler. 90% of the light propagates through the WDM to initiate laser oscillation. Output is obtained from the other port of the coupler. The FBG has a reflectivity of 99.9 % at the center wavelength of 1552.6 nm and a 3dB bandwidth of 0.2 nm. The gain medium is a short piece of EDZF which has been fabricated using a ternary glass host, zirconia-yttria–aluminum codoped silica fiber through solution doping technique along with modified chemical vapor deposition (MCVD) [7]. With a combination of both Zr and Al, we could achieve the maximum erbium doping concentration of 4320 ppm wt in the glass host without any phase separations of rare-earths. Only a minor amount of Y_2O_3 is used in the preform to prevent cracking problem. A fiber of 125 micrometers in diameter is drawn from the fabricated preform at temperature of around 2000 ^{o}C using the conventional fibre drawing technique. The fabricated Zr-EDF has a numerical aperture of 0.17, core diameter of 10.5 µm and background loss of 0.11 dB/m at 1300 nm. The output laser is characterized using an optical spectrum analyser (OSA) with a resolution of 0.015 nm.

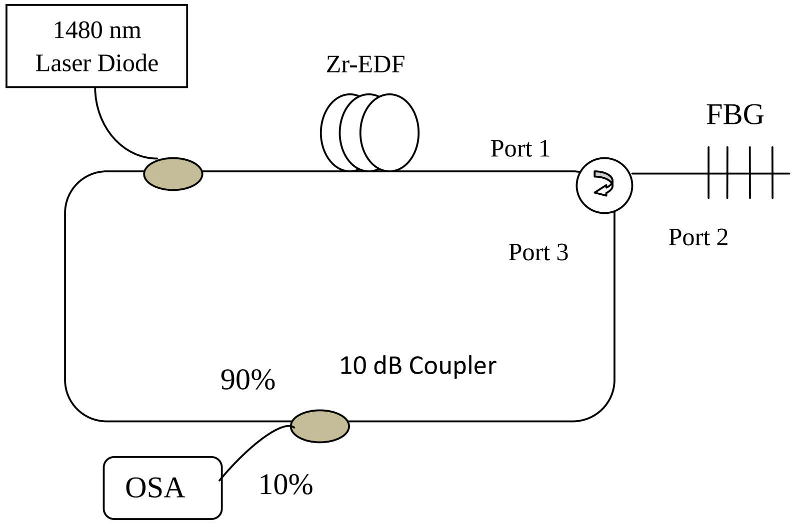

Fig. 1. Schematic diagram of the setup for a single-wavelength ring laser which utilizes a Zr-EDF with high Erbium ion concentration as a gain medium.

Although laser linewidth can be measured by the homodyne method in which a signal is mixed with its time-delayed replica, achieving incoherent self-mixing of BFL is difficult in practice since the coherence length is estimated to be at least hundreds of kilometres [10]. Besides, this method is sensitive to environment perturbations although insensitive to fluctuations in the frequency of the laser itself. In this work, the laser linewidth measurement is done by evaluating the beat signal resulting from the interference of the BFL with another uncorrelated BFL using a heterodyne beat technique [11]. This method requires another laser either with a comparable well-known spectrum or with an extremely narrow and negligible linewidth. The linewidth of the proposed EDFL is measured by combining the laser output signal with another uncorrelated BFL, which has an extremely narrow linewidth [12] using a 3 dB coupler as shown in Fig. 2. The BFL consists of an optical circulator, a 3 dB optical coupler and a piece of 10 km long non-zero dispersion shifted fiber (NZ-DSF). A tunable laser source (TLS) with the maximum pump power of around 4 dBm is used as a BP, which was directed into the NZ-DSF via a 3dB coupler to create the narrow linewidth Stokes in the opposite direction. The coupler allows a certain ratio of the light to oscillate in the cavity to generate Brillouin laser, which is partly coupled out through the coupler and circulator. The BFL wavelength should be very close to the output EDFL wavelength. The wavelength separation between both signals should be less than 0.01 nm so that the frequency of the beat wave generated in the output coupler is within the radio-frequency spectrum analyzer (RFSA) wavelength region. The combined output is converted into electrical signal by a fast-response photo detector and the generated radio beat frequency signal is analyzed by an RFSA. The accuracy of the linewidth measurement is limited by the resolution of the RFSA.

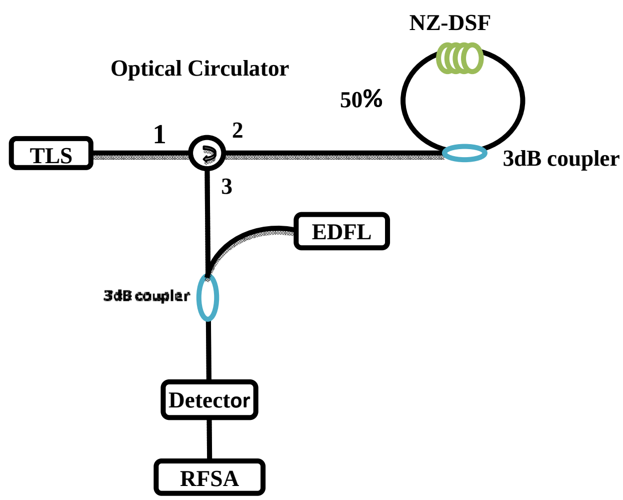

Fig. 2. Linewidth measurement setup using a heterodyne method.

3. Result and discussion

Fig. 3 shows the EDFL output power as a function of the 1480 nm pump power. As shown in this figure, the EDFL has a lasing threshold of 25.1 mW with a slope efficiency of 6%. The output power of approximately 6.8 mW is achieved at the maximum 1480 nm pump power of 120 mW. The inset of Fig. 3 shows a typical output spectrum of the EDFL, which has a stable output operating at 1552.5 nm with an extinction ratio of 60dB with respect to the ground noise and an output spectral width of 0.02 nm limited by the OSA resolution. The laser threshold is extremely low since it takes very little pump power to almost fully invert the Erbium ion. One of the advantages of this EDFL is the use of high concentration EDF instigating high absorption per unit length. Therefore only 2 m long Zr-EDF is required in the proposed EDFL to achieve an efficient EDFL. Since only a short fiber is used, less cavity loss is expected in this EDFL which in turn should result in the increase of the oscillating laser power in the cavity. The EDZF also shows a wideband emission characteristic which covers both C- and L-band regions. As a result, EDZF may be able to generate laser with wider tunability to cover more WDM bandwidth. The tuning of the laser output can be achieved by thermal as well as strain tuning of the FBG.

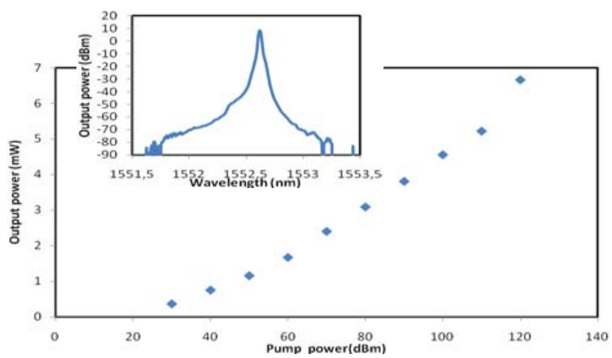

Fig. 3. Lasing output power against 1480 nm pump power for the proposed Zr-EDFL. Inset shows the output spectrum of the laser.

Fig. 4 shows the beat spectrum of the EDFL and the uncorrelated BFL from the 10 km NZ-DSF. The BFL linewidth is reported to be approximately a few Hz, which is so much smaller than the TLS linewidth of around 15 MHz, which is used as a BP [12]. As shown in Fig. 4, the output beat spectrum has only a single line or harmonic, which illustrates a single frequency characteristic of the EDFL. Assuming Lorentzian line shape, the full-width at half-maximum (FWHM) linewidth of the EDFL can be derived from full width -20dB point while any deviation of the spectrum from the Lorentzian feature is attributed to the frequency noise of the laser [11]. This may significantly increase the measurement tolerance to frequency fluctuations and thus improve the accuracy. As shown in the inset of Fig. 4, the full width at -20 dB points are measured to be approximately about 95 MHz. The narrow linewidth is due to the use of a short length of gain medium in the proposed EDFL. A more accurate FWHM linewidth measurement requires an electrical spectrum analyzer with a higher bandwidth resolution.

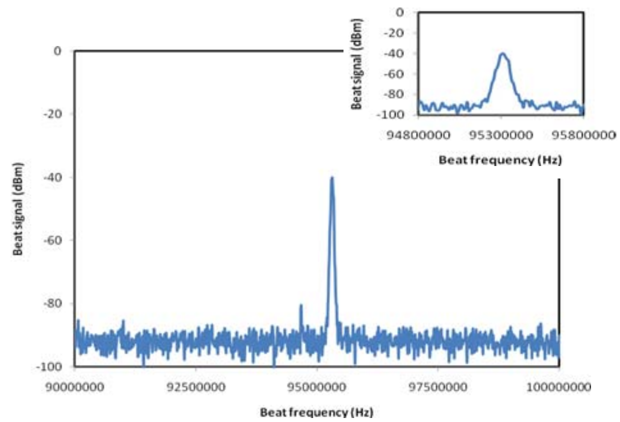

Fig. 4. Measured beat frequency spectrum of the EDFL and the uncorrelated BFL. Inset shows the enlarged spectrum.

4. Conclusion

A compact single frequency EDFL operating at wavelength of 1552.5 nm is demonstrated using a newly developed Zr-EDZ. The EDZF is fabricated by incorporating Zr and Al ions into the fiber to achieve the maximum Erbium ion concentration of 4320 ppm wt. The laser uses 2 m long EDF in a ring configuration with an FBG. The EDFL has a low threshold pump power of 25 dB with a slope efficiency of 6 % and a signal to noise ratio of 60 dB. The linewidth of the EDFL is measured to be approximately 95 MHz using a heterodyne technique.

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References

[1] T. Pfau, S. Hoffmann, O. Adamczyk, R. Peveling, V. Herath, M. Porrmann, R. Noé, Opt. Express **16**(2), 866 (2008).
[2] Ch. Spiegelberg, J. Geng, Y. Hu, Y. Kaneda, S. Jiang, N. Peyghambarian, J. Lightwave Technol. **22**, 57 (2004).
[3] S. Agger, J. H. Povlsen, P. Varming, Opt. Lett. **29**, 1503 (2004).
[4] M. R. A. Moghaddam, S. W. Harun, M. R. Tamjis, H. Ahmad, Laser Physics Letters, **6**(8), 586 (2009).
[5] S. W. Harun, S. Shahi, H. Ahmad, Laser Phys. Lett. **7**(1), 60 (2010).

[6] B. C. Hwang, S. Jiang, L. Luo, J. Watson, S. Honkanen, Y. Hu, F. Smektala, J. Lucas, N. Peyghambarian, Electronics Lett. **35**, (12), 1007 (1999).
[7] 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, J. Lightwave Technol. **28**, 2919 (2010).
[8] 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, Opt. Lett. **35**, 2882 (2010).
[9] A. Hamzah, M. C. Paul, S. W. Harun, N. A. D. Huri, A. Lokman, R. Sen, M. Pal, S. Das, S. K. Bhadra, H. Ahmad, Optoelectron. Adv. Mater. – Rapid Commun. **4**(8), 1099 (2010).
[10] E. Ip, A. P. Lau, D. J. Barros, J. M. Kahn, Opt. Express **16**(2), 753 (2008).
[11] P. Horak, W. H. Loh, Opt. Express **14**(9), 3923 (2006).
[12] R. Hui, M. O'Sullivan, Academic Press, Chap. 2 (2009).
[13] M. R. Shirazi, S. W. Harun, M. Biglary, K. Thambiratnam, H. Ahmad, ISAST Trans. Elec. Signal Proc. **1**(1), 30 (2007).

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