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# Multiwavelength fiber laser using S-band erbium-doped fiber amplifier and semiconductor optical amplifier

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**Abstract**

A multiwavelength fiber ring laser that is based on an S-band erbium-doped fiber amplifier (EDFA) and a semiconductor optical amplifier (SOA) is developed. An optical switch is used to switch the multiwavelength fiber laser between S-band and L-band. This fiber laser can stably lase seven wavelengths in the S-band or 28 wavelengths in the L-band. Additionally, the lasing wavelengths with a signal-to-noise ratio of over 33 dB and a wavelength spacing of 100 GHz are demonstrated experimentally. The average powers of the lasing wavelength in the S-band and the L-band are −7.53 and −12.15 dBm, respectively.


*Keywords:* S-band; L-band; Multiwavelength fiber laser; Erbium-doped fiber amplifier

## 1. Introduction

Multiwavelength fiber lasers have recently attracted much attention because they have potential applications in wavelength-division-multiplexed (WDM) systems, optical code division multiple access (OCDMA) systems, fiber sensor systems and optical test instruments [1–7]. Most multiwavelength fiber lasers operate in the C-band or the L-band because of the gain spectra of commercial EDFAs and SOAs. However, the operating wavelength region of the multiwavelength laser source must be extended to the S-band (1480–1520 nm) in the face of the rapid development of fiber communication systems. Recently, an S-band and L-band multiwavelength fiber laser that uses the second-order nonlinearity of the LiNbO3 waveguide and erbium-doped fiber amplifiers (EDFA) was proposed [8]. However, this laser source cannot easily achieve a high signal-to-noise ratio (SNR) and high output power in the S-band.

An S-band EDFA has recently been reported [9,10]. It uses the erbium-doped fiber (EDF) with depressed cladding design and a 980 nm pump laser to cause the EDF gain extension effect. Accordingly, this S-band EDFA is expected to extend the operating wavelength of the multiwavelength fiber laser to the S-band. This investigation experimentally demonstrates an S-band and L-band multiwavelength fiber laser using the S-band EDFA and a semiconductor optical amplifier (SOA). The SOA as a gain medium in the fiber laser enables stable multiwavelength lasing at room temperature [6]. Furthermore, it is possible to produce stable lasing wavelengths with wavelength spacing of 50 GHz [7] by using a 50 GHz spaced interleaver [11]. The lasing wavelength of the fiber laser can be flexibly switched in the S-band or the L-band using an optical switch. Seven lasing wavelengths in the S-band and 28 lasing wavelengths in the L-band are demonstrated. The lasing wavelengths output is good, with an SNR of over 33 dB and a wavelength spacing of 100 GHz. Furthermore,

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the performance of the S-band fiber laser with only the S-band EDFA is shown.

## 2. Experiment and results

Fig. 1 schematically depicts of the proposed S-band and L-band multiwavelength fiber laser. The fiber ring laser comprises an SOA, an S-band EDFA module, an interleaver, an optical switch, an optical isolator and a 90:10 optical coupler. The interleaver serves as a comb filter with a wavelength spacing of 100 GHz. The insertion loss is 2.3 dB. The 3 dB bandwidth of the interleaver is approximately 0.4 nm. The optical isolator is used to ensure the unidirectional operation of the ring laser. The 90:10 optical coupler (C) is utilized to direct the output of the ring laser to an optical spectrum analyzer. The S-band EDFA module has two amplifier stages and a 980 nm pump laser. The S-band EDF inside the EDFA module has a depressed cladding design, which provides a cutoff wavelength near 1530 nm and negates the propagation of any spectral components in the C-band and L-band. The composition of the S-band EDF core is around 2.5% $GeO_2$, 5.5% $Al_2O_3$, and 92% $SiO_2$, with 0.15 wt% erbium. The depressed cladding is around 3% fluorine, 0.5% $P_2O_5$, and 96.5% $SiO_2$. The numerical aperture of the core, relative to the depressed cladding, is 0.22 [10]. The EDF1 has a length of 20 m and can provide medium gain and a low noise figure by forward pumping. The EDF2 has the length of 30 m and can yield large output power by backward pumping. The optical isolator between the two EDFs can reject amplified spontaneous emission (ASE) from the EDF2 and improve noise figure performance. The maximum output power of the EDFA module at 1500 nm can be as high as 14 dBm when the pump power is 280 mW.

In this investigation, the SOA is driven by a 200 mA current source and has a maximum output power of 14 dBm. Because the EDF at room temperature is a mainly homogeneous broadened gain medium, it is difficult to achieve multiwavelength lasing in an EDF laser [3]. Therefore, the maximum output power of the EDFA module is adjusted to 2 dBm using an attenuator to cause SOA to dominate the property of hybrid amplifier. The optical switch is used to switch the fiber laser between S-band and L-band. The switching time of the optical switch is about 1 ms. Furthermore, the cavity length of the fiber laser at the state B is about 81 m. Therefore, the switching time to lase stably is at least 1.0004 ms from state A to state B. When the optical switch is switched to state A, the fiber laser operates in the L-band. Fig. 2 presents the output spectrum of the fiber laser in the L-band. The inset in Fig. 2 shows the spectrum of the interleaver in the L-band. Twenty-eight lasing wavelengths with an SNR of over 33 dB and a wavelength spacing of 100 GHz are produced. The lasing wavelengths are from 1580.84 to 1603.73 nm. Fig. 3 presents the fiber laser in the S-band output, when the optical switch is switched to state B. The inset in Fig. 3 depicts the spectrum of the interleaver in the S-band. Seven lasing wavelengths with an SNR of over 33 dB and a wavelength spacing of 100 GHz are observed. The lasing wavelengths are from 1503.58 to 1508.11 nm.

An experiment that involves only the S-band EDFA (such that the SOA shown in Fig. 1 is removed) in the laser cavity is conducted to compare the characteristics of gain media. Fig. 4 presents the results. The inset of Fig. 4 presents the ASE spectrum of EDFA. The homogeneous broadening of the EDFA causes this S-band fiber laser to have only one lasing wavelength at 1504.19 nm. Therefore, the SOA effectively dominates the hybrid amplifier. Fig. 5 shows the power distribution of the output wavelengths in the L-band and the S-band. The lasing wavelengths were monitored continuously for 20 min. The power fluctuations, within 20 min, of the lasing wavelengths in the L-band and S-band were less than 1.27 and 0.92 dB, respectively. Moreover, the power difference of the lasing wavelengths can be reduced by using optical power equalizers [12,13].

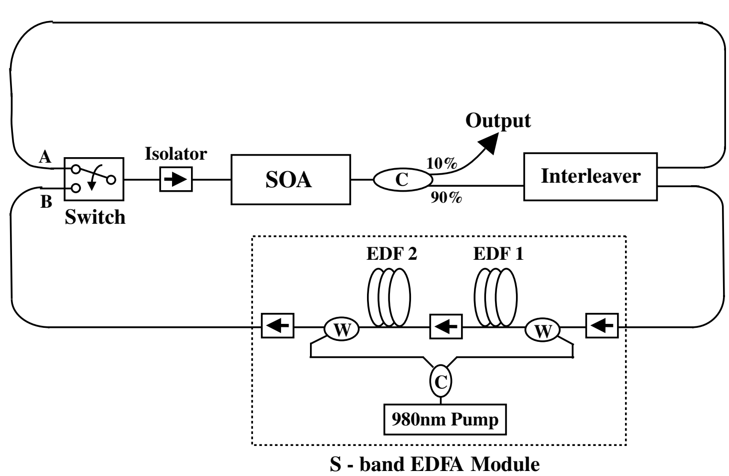


Fig. 1. Schematic diagram of S-band and L-band multiwavelength fiber laser. (SOA: semiconductor optical amplifier, EDF: erbium-doped fiber, W: WDM coupler, C: optical coupler).

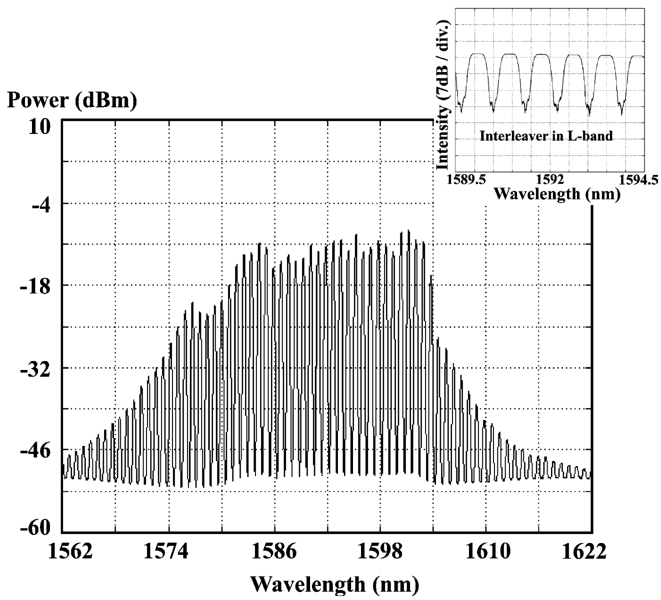


Fig. 2. Output spectrum of multiwavelength fiber laser in L-band; the inset shows the spectrum of the interleaver in the L-band.

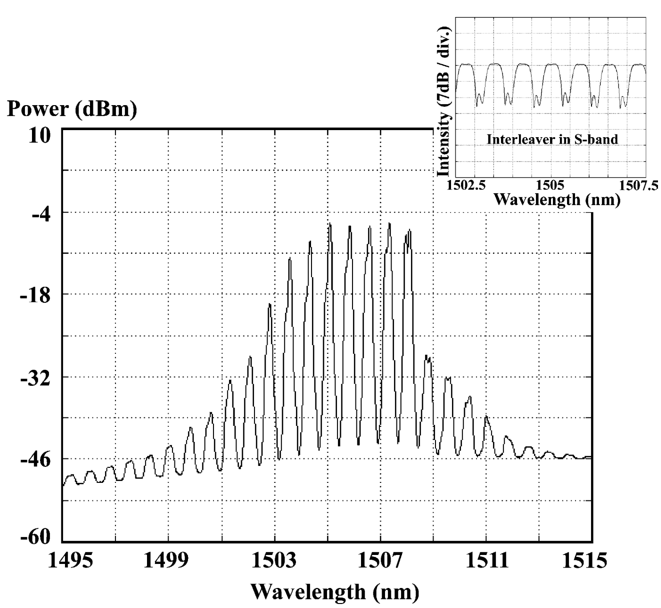


Fig. 3. Output spectrum of multiwavelength fiber laser in S-band; the inset shows the spectrum of the interleaver in the S-band.

The optical switch is used to switch the multiwavelength fiber laser between S-band and L-band. The insertion loss of optical switch is below 1 dB. Instead of using the optical switch, when a $1 \times 2$ optical coupler is applied in the fiber ring, the fiber laser would lase in both L-band and S-band simultaneously. However, the SNR and number of the lasing wavelengths would decrease. Additionally, the lasing wavelength would shift toward shorter wavelength due to the increased loss in the fiber ring [7]. This fiber laser would be producing L-band lasing wavelengths by the SOA. The

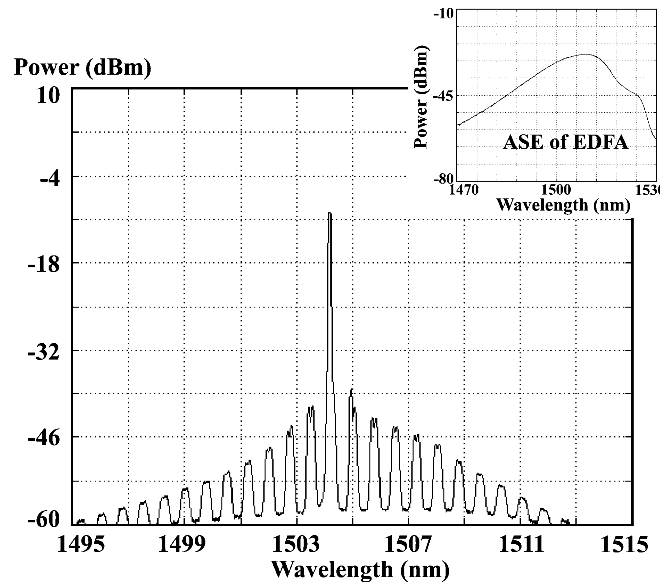


Fig. 4. Output spectrum of the fiber laser with only the S-band EDFA; the inset shows the ASE spectrum of the S-band EDFA.

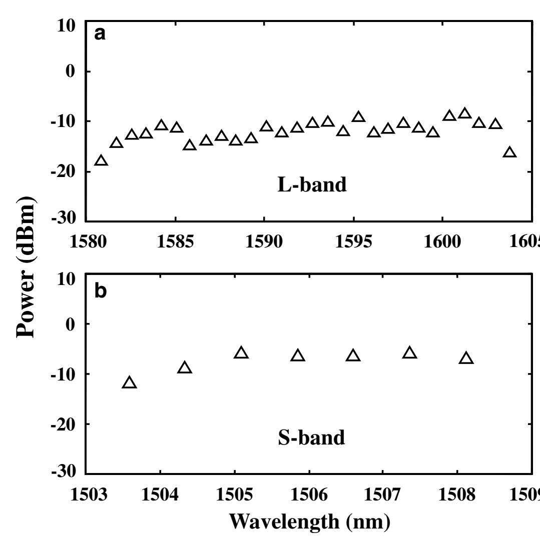


Fig. 5. Power distribution of output wavelengths in (a) L-band and (b) S-band.

S-band EDFA would be used as both an amplifier and a light source for the S-band lasing wavelengths.

## 3. Conclusion

An S-band and L-band multiwavelength fiber laser that is based on an S-band EDFA and an SOA is presented. This fiber laser can lase seven wavelengths in the S-band and 28 wavelengths in the L-band with an SNR of over 33 dB and a wavelength spacing of 100 GHz in a regular ring cavity. The average powers of the lasing wavelength in the L-band and the S-band are −12.15 and −7.53 dBm, respectively. This multiwavelength fiber laser has potential for future use in S-band and L-band applications.

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## References

[1] L. Talaverano, S. Abad, S. Jarabo, M. Lopez-Amo, Journal of Lightwave Technology 19 (2001) 553.
[2] R. Slavik, S. LaRochelle, in: Optical Fiber Communication Conference (OFC2002), paper WJ3, 2002, p. 245.
[3] H.L. An, X.Z. Lin, E.Y.B. Pun, H.D. Liu, Optics Communications 169 (1999) 159.
[4] D.N. Wang, F.W. Tong, X. Fang, W. Jin, P.K.A. Wai, J.M. Gong, Optics Communications 228 (2003) 295.
[5] G. Das, J.W.Y. Lit, IEEE Photonics Technology Letters 14 (2002) 606.
[6] Y.W. Lee, J. Jung, B. Lee, IEEE Photonics Technology Letters 16 (2004) 54.
[7] H. Dong, G. Zhu, Q. Wang, H. Sun, N.K. Dutta, J. Jaques, A.B. Piccirilli, IEEE Photonics Technology Letters 17 (2005) 303.
[8] J. Sun, W. Liu, Optics Communications 224 (2003) 125.
[9] M.A. Arbore, Y. Zhou, G. Keaton, T.J. Kane, in: Proc. SPIE, Optical Devices for Fiber Communication IV, vol. 4989, 2003, p. 47.
[10] C.H. Yeh, C.C. Lee, C.Y. Chen, S. Chi, IEEE Photonics Technology Letters 16 (2004) 90.
[11] S. Cao, J. Chen, J.N. Damask, C.R. Doerr, L. Guiziou, G. Harvey, Y. Hibino, H. Li, S. Suzuki, K.-Y. Wu, P. Xie, Journal of Lightwave Tech nology 22 (2004) 281.
[12] S.K. Liaw, K.P. Ho, K.Y. Hsu, S. Chi, Fiber and Integrated Optics 18 (1999) 297.
[13] J.E. Ford, J.A. Walker, IEEE Photonics Technology Letters 10 (1998) 1440.