Temperature Dependent Characteristics of L-band EDFA Using Phosphorus- and High Aluminum- Co-doped Silica Fibers

Z. Zhai, A. Halder, Y. Wang, M. Núñez-Velázquez and J. K. Sahu
Optoelectronics Research Centre, University of Southampton, Highfield, Southampton, SO17 1BJ, UK
Z.Zhai@soton.ac.uk

Abstract: We report a hybrid L-band amplifier employing phosphosilicate and high-aluminosilicate EDFs with 20.2±3.7dB gain and 4.2dB average NF from 1575-1615nm. The temperature-dependent-gain coefficient remains almost constant from 1585-1615nm over the temperature range -60 to +80°C. © 2022 The Author(s)

1. Introduction

There is a great interest in overcoming the bandwidth limitations of conventional L-band erbium-doped fiber amplifier (EDFA) to support the growing demand for optical fiber data transmission capacity. Several novel glass compositions have been investigated as co-dopants to extend the longer wavelength limit in the L-band [1–5]. The thermal stability of EDFAs is a significant factor in evaluating the environmental robustness of such devices in real-world optical communication systems. The EDFA gain spectrum can be expressed by equation (1), where $\Gamma(\lambda)$ and L are the confinement factor and fiber length, respectively. The temperature dependent $I_{nv}(T)$, $\sigma_e(\lambda,T)$ and $\sigma_a(\lambda,T)$ are the population inversion of Er ions and their emission and absorption cross-sections at the signal wavelength, respectively, which together determine the temperature dependent gain (TDG) performance [6]. It is reported that L-band EDFAs have a more temperature-sensitive gain than C-band EDFAs [7]. However, there are few reports concerning the temperature stability of EDFAs covering the longer wavelength side of the L-band (up to 1615nm).

$$G(\lambda,T) = \Gamma(\lambda)L\{\sigma_e(\lambda,T)I_{nv}(T) - \sigma_a(\lambda,T)[1 - I_{nv}(T)]\} \quad (1)$$

In this paper, we report two in-house fabricated EDFs co-doped with phosphorus (P-EDF) and high aluminum (high Al-EDF) in silica host to promote operation in the L-band and that provide an average gain of 20dB and an average NF of <5dB from 1575 to 1615nm. The study of the longer wavelength operation of the EDFAs was limited to 1615nm by the WDM (wavelength division multiplexed) signal source used in this work. We studied the temperature dependent amplifier performance from -60 to +80ºC. The P-EDF provided a gain increment of 2.8dB and 4.6dB at 1615nm over the high Al-EDF at room temperature (RT, 20ºC) and -60ºC, respectively. We propose a technique to flatten the TDG coefficient and to decrease the NF in the L-band EDFA by concatenating the P-EDF with the high Al-EDF. The hybrid EDF had a TDG coefficient varying from -0.008 to -0.032 dB/ºC from 1575 to 1615nm, with a negligible variation of 0.005dB/ºC from 1585 to 1615nm.

2. L-band Er-doped silica fiber amplifier

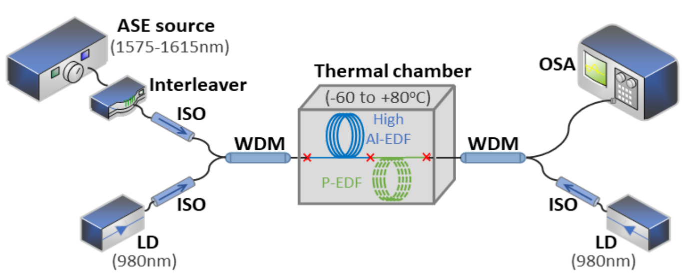

Fig. 1. Schematic of the experimental setup for the L-band EDFA.

The P-EDF preform was fabricated using the modified chemical vapor deposition (MCVD)-solution doping technique, where a $P\text{-}SiO_2$ porous layer was soaked with a solution containing salts of erbium and other co-dopants. Then, the preform was drawn into a fiber with a core/cladding diameter of ~5.5/125µm and with an LP_{11} cutoff wavelength of 1335nm. The high Al-EDF preform was fabricated using MCVD and all-vapor phase rare-earth doping technique. This preform was then drawn into a fiber with a core/cladding diameter of ~4.2/125µm and an LP_{11} cutoff wavelength of 1345nm. The background losses at 1200nm for the P-EDF and high Al-EDF were

17dB/km and 19dB/km, respectively. The unsaturable loss at the pump wavelength of 980nm was 8.8% for the P-EDF and 3.5% for the high Al-EDF. The absorption at 980nm was 8.5dB/m for the P-EDF and 16dB/m for the high Al-EDF. The peak Er absorption was 26dB/m at 1534nm for the P-EDF and 38dB/m at 1530nm for the high Al-EDF. The 4nm red shift of the Er absorption peak for the P-EDF indicated a potential shift in the gain peak to longer wavelengths.

The schematic of the EDFA experimental setup is shown in Fig. 1. An amplified spontaneous emission (ASE) light source combined with an optical interleaver were used to provide the 24-channel input signal from 1575 to 1615nm. The total input signal power was set to -11.5 dBm. Laser diodes (LDs) operating at 980nm were used to provide forward and backward pumps. Isolators (ISOs) were used to prevent back reflections. Two WDMs were used to combine and separate signal and pump wavelengths. The input and output signal spectra were measured by an optical spectrum analyzer (OSA, YOKOGAWA-AQ6370) using a resolution of 0.2nm. To characterize the TDG performance, the EDF was placed in a thermal chamber with an adjustable temperature range from -60 to +80°C.

3. Results and discussion

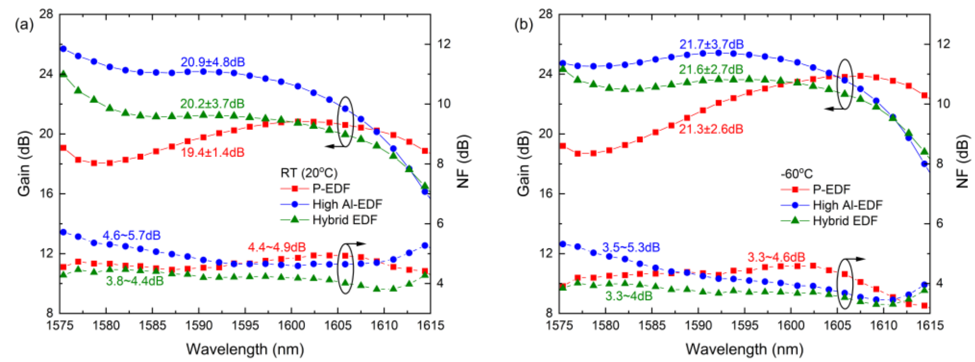

Fig. 2. (a) Gain and NF spectra at RT (20°C) and (b) -60°C for 30m of P-EDF, 15m of high Al-EDF, and hybrid EDF comprising 15m of P-EDF and 5.5m of high Al-EDF. The total pump power launched into the EDFs was 765mW.

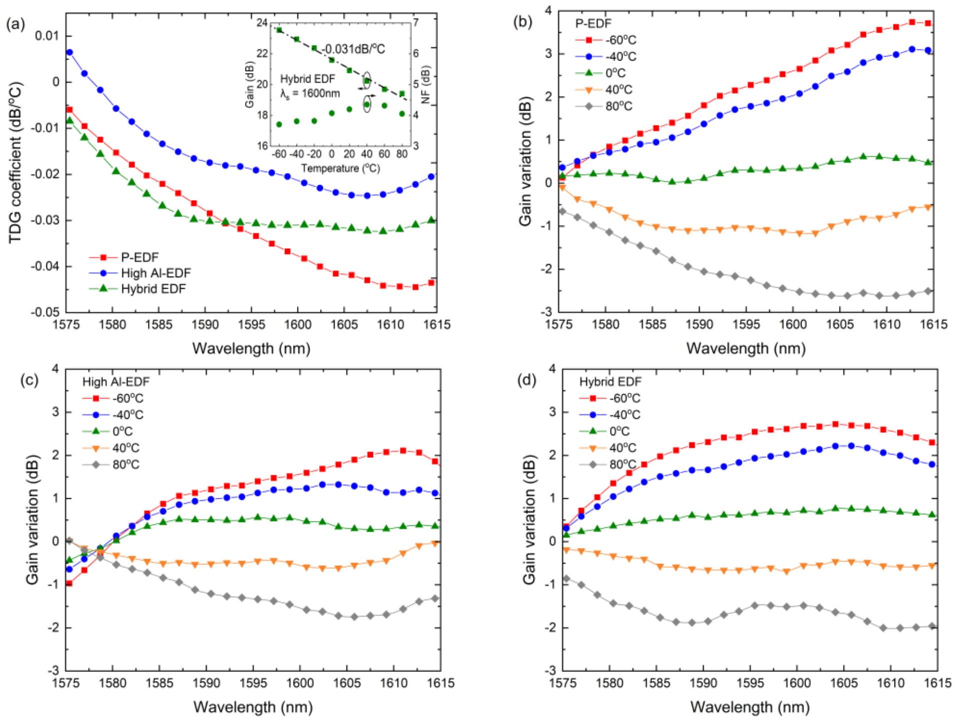

Fig. 3. (a) TDG coefficient spectra (the inset indicates the TDG at 1600nm for the hybrid EDF); the relative gain variations are referenced to RT for (b) 30m of P-EDF; (c) 15m of high Al-EDF; (d) hybrid EDF comprising 15m of P-EDF and 5.5m of high Al-EDF.

We first measured the gain and NF at RT using a single 30m of P-EDF and 15m of high Al-EDF, respectively, as shown in Fig. 2(a). The forward/backward pump powers were 620/145mW. The fiber lengths and pump powers were selected to optimize the overall gain, NF, and gain flatness. The gain in the L-band was found to be 19.4±1.4dB and 20.9±4.8dB at RT for the P-EDF and the high Al-EDF, respectively. The gain of the high Al-EDF drops significantly beyond 1605nm, which is typical for conventional L-band aluminosilicate EDFAs [8]. However, the P-EDF maintains a relatively high gain and provides a 2.8dB improvement in gain at 1615nm over the high Al-EDF, indicating that P represents an effective co-dopant to improve the L-band gain bandwidth. The average NF was less than 5dB in both cases.

Next, we measured the temperature dependent gain and NF for the two EDFs over the temperature range -60 to +80 ºC. At -60ºC, the P-EDF provided a 4.6dB improvement in gain at 1615nm over the high Al-EDF, as shown in Fig. 2(b). The TDG coefficient, expressed in dB/ºC, was calculated as the slope of the linear regression fit between the gain and the corresponding temperature [9], as shown in Fig. 3(a). In the 40nm bandwidth from 1575 to 1615nm, the TDG coefficient varied from -0.006 to -0.044 dB/ºC for the P-EDF and from 0.006 to -0.025 dB/ºC for the high Al-EDF, which is similar to that of a previously reported conventional L-band EDFA [10]. In the wavelength range 1585 to 1615nm, the TDG coefficient of the high Al-EDF slightly decreased and then increased, while the TDG coefficient of the P-EDF kept decreasing with a more significant change. Ideally, a combination of these two EDFs would be used to flatten the TDG coefficient over this 30nm bandwidth. The hybrid configuration was optimized using 15m of P-EDF and 5.5m of high Al-EDF. The hybrid EDF achieved 20.2±3.7dB gain and 4.2dB average NF at RT, and 21.6±2.7dB gain and 3.7dB average NF at -60ºC, as shown in Fig. 2(a)-(b). The NF was less than that of the single EDF configuration. The TDG coefficient varied from -0.008 to -0.032 dB/ºC, as shown in Fig. 3(a). In the wavelength range from 1585 to 1615nm, the TDG coefficient had a negligible variation of 0.005dB/ºC, contributing to a constant overall gain increase as the temperature decreases. As the temperature changes, the relative gain variations referenced to RT are shown in Fig. 3(b)-(d). The P-EDF has an increased gain variation as the wavelength increases, with a +3.7 to -2.5dB variation at 1615nm. In the high Al-EDF, there was a zero-gain variation near 1580nm and a relatively larger gain variation at longer wavelengths. The hybrid EDF maintains a flat gain variation from 1585 to 1615nm at different temperatures, indicating a less temperature-sensitive gain flatness.

4. Conclusions

We demonstrate that P-EDF is beneficial in extending the longer wavelength limit of L-band gain compared to a conventional Al-EDF. We report a method to improve the thermal performance of L-band EDFAs by concatenating a length of high Al-EDF with a length of P-EDF. In the hybrid configuration, we achieved a flattened TDG coefficient from 1585 to 1615nm, and a lower NF over the temperature range -60 to +80°C. To the best of our knowledge, our study extended to a longer wavelength of 1615nm in the L-band as compared to previous temperature dependent EDFA studies [10,11].

Acknowledgements

The data for this work can be accessed at https://doi.org/10.5258/SOTON/D1992.

5. References

[1] A. J. G. Ellison, D. E. Goforth, B. N. Samson, J. D. Minelly, J. P. Trentelman, D. L. McEnroe, and B. P. Tyndell, “Extending the L-band to 1620 nm Using MCS Fiber,” in OFC 2001, (OSA, 2001), paper TuA2.

[2] S. Tanaka, K. Imai, T. Yazaki, H. Tanaka, T. Yamashita, and M. Yoshida, “Ultra-Wideband L-band EDFA Using Phosphorus Co-Doped Silica-Fiber,” in OFC 2002, (OSA, 2002), paper ThJ3.

[3] L. Qian, D. Fortusini, S. D. Benjamin, G. Qi, P. V. Kelkar, and V. L. d. Silva, “Gain-flattened, extended L-band (1570–1620 nm), high power, low noise erbium-doped fiber amplifiers,” in OFC 2002, (OSA, 2002), paper ThJ4.

[4] A. Mori, T. Sakamoto, K. Kobayashi, K. Shikano, K. Oikawa, K. Hoshino, T. Kanamori, Y. Ohishi, and M. Shimizu, “1.58-um Broad-Band Erbium-Doped Tellurite Fiber Amplifier,” IEEE J Lightwave Technol 20, 822-827 (2002).

[5] N. K. Thipparapu, Y. Wang, S. Wang, A. A. Umnikov, P. Barua, and J. K. Sahu, “Bi-doped fiber amplifiers and lasers [Invited],” Opt. Mater. Express 9, 2446-2465 (2019).

[6] J. A. Bebawi, I. Kandas, M. A. El-Osairy, and M. H. Aly. “A Comprehensive Study on EDFA Characteristics: Temperature Impact,” Appl. Sci 8, 1640 (2018).

[7] F. A. Flood, “L-Band Erbium-Doped Fiber Amplifiers,” in OFC 2000, (OSA, 2000), paper WG1.

[8] L. Qian and R. Bolen, “Erbium-Doped Phosphosilicate Fiber Amplifiers: A comparison of configurations for the optimization of noise figure and conversion efficiency,” Proc. SPIE, Photonic Applications in Devices and Communication Systems, 59702V (2005).

[9] Y. Wang, N. K. Thipparapu, S. Wang, P. Barua, D. J. Richardson, and J. K. Sahu, “Study on the temperature dependent characteristics of O-band bismuth-doped fiber amplifier,” Opt. Lett. 44, 5650-5653 (2019).

[10] Y. Im, K. Oh, S. H. Chang, K. Kim, and D. J. DiGiovanni, “Reduction of Temperature-Dependent Gain in L-band EDFA Using Antimony-Aluminum Codoped Silica EDF,” IEEE Photon. Technol. Lett 17, 1839-1841 (2005).

[11] F. A. Flood, “Comparison of Temperature Dependence in C-Band and L-Band EDFAs,” IEEE J Lightwave Technol 19, 527-535 (2001).