Design characterization of an Erbium-Doped Fiber Ring Laser using a circulator and a filter for C and L band amplification

Debolina Brahma,* Sanchita Goswami and Sambhunath Biswas

Department of Electronics and Communication Engineering, Heritage Institute of Technology, Kolkata 700107, India

Received February 03, 2014; accepted March 24, 2014; published March 31, 2014

Abstract—Design characterization of a wavelength division multiplexed erbium doped fiber ring laser using an ITU-T signal source at −30dBm/channel input signal level, a splitter, 980nm and 1480nm pumping lasers in a bidirectional pumping scheme with 250mW pump powers and two double pass EDFAs with 10m and 20m lengths at room temperature, a circulator and a gain flattening filter (GFF). An average gain of 34.45dB and noise figure of 8dB (maxima) is on optimization to provide a uniform gain over 70nm.

Gain clamped two stage L-band EDFA or dual pumped double pass EDFA cascades show a high gain and low noise figure (NF) [1], while another similar approach utilizes an optical splitter to provide distributed pumping from a single pump laser, a substantial gain of 17dB with NF below 6.7dB within the 36nm L band range (1570-1605nm) [2-3] is obtained. However, L-band EDFAs have lower power conversion efficiency (PCE) and quantum conversion efficiency (QCE) values compared to C-band EDFAs for some novel hybrid configuration [4]. For long haul communication systems, wavelength division multiplexing (WDM) and dense-wavelength division multiplexing (DWDM) are being used along with EDFAs to amplify the signal over the C and L band [5-7]. The EDFA gain spectrum is wavelength dependent. As a result, different channels have different amplifications. It shows temperature dependent multichannel gain and noise figure distortion which becomes a limiting factor in temperature uncontrolled environments. One novel dual core EDFA in parallel configuration presents an overall flat gain over the ultra wideband region [8-9].

In this novel work an erbium doped fiber ring laser network is configured. It comprises two double pass EDFAs which are being pumped bi-directionally and are coupled together by a circulator into a filter for gain flattening. Gain flattening filters (GFF) are used to optimize the output gain.

Some of the equalization techniques involve the use of long fiber Bragg gratings [10] as band rejection filters and employment of Mach-Zehnder optical filters [11] in multi-wavelength fiber amplifier cascaded systems [12]. The system is also analyzed in terms of gain and noise figure variations with amplifier length, temperature and pump power.

The system is modelled according to the works of Giles and Desurvire [13]. We use the GainMaster^{TM} simulator manufactured by Fibercore Ltd to design the network. The system consists of a tunable laser source (TLS) which provides 60 channels with 100GHz channel spacing and −30dBm/channel input signal power distributed according to ITU standards with the central wavelength at 1552.52nm (depicted in Fig.1). An optical isolator with an isolation of 20dB, insertion loss of 0.2dB and input and output return losses of 60dB and 55dB, when introduced along with the TLS, restricts the backward reflection of ASE into the signal source. A 4:1 optical splitter, with input and output return losses of 60dB and 25dB, directivity of 50dB, and 40% splitting ratio provides two parallel pathways. These two pathways comprise different erbium doped fibers EDF-I and EDF-II, both double pass EDFAs, each of which is pumped by a 980nm laser in co-direction and a 1480nm laser in counter-direction. EDF-I has a numerical aperture of 0.22-0.25, cut-off wavelength of 870-970nm, absorption of 3.3μm at 980nm and 5.4μm at 1550nm, with a saturation parameter of 1.60×10^{16}/ms. Similarly, EDF-II has a cut-off wavelength of 900-970nm, numerical aperture of 0.21-0.23, absorption of 11μm at 980nm and 13μm at 1550nm, with a saturation parameter of 3.88×10^{15}/ms. The two pathways constitute the fiber ring which is then coupled with a circulator with a return loss, isolation and directivity of 60dB, 40dB and 55dB, respectively. This circulator feedbacks the signal reflected by the filter back into the system.

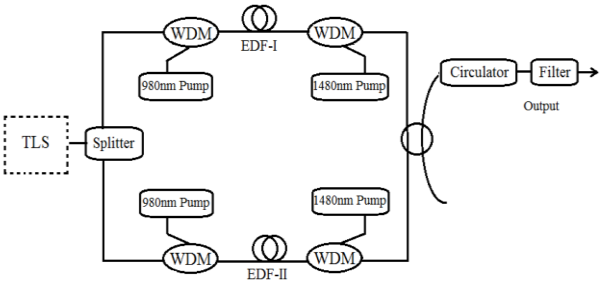

Fig. 1. Schematic of EDFA ring configuration with a gain flattening filter.

---

[*] E-mail: debolina.brahma90@gmail.com

As depicted in Fig. 2, the system optimization is done to obtain a maximum, minimum and average gain of 38.76dB, 13.94dB and 32.72dB, respectively, over 70nm (1545-1615nm). The amplifier lengths EDF-I and EDF-II are kept constant at 10m and 20m respectively while the pump and signal power levels are stabilized at 150mW and −30dBm/channel, respectively (at 25°C). In such conditions, a gain tilt of −17.42dB, power and quantum conversion efficiencies is found to be 22.36% and 35.72%. This optimized configuration shows an encouraging NF below 8dB.

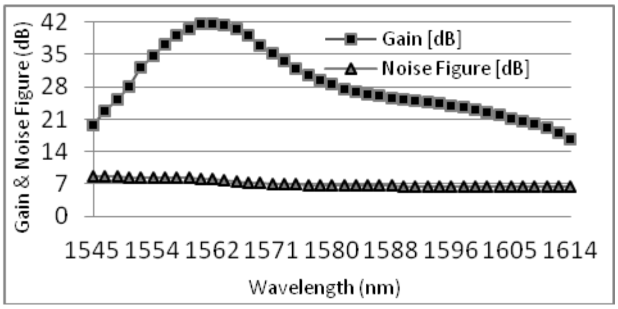

Fig. 2. Optimized gain and noise figure spectra of an EDFA ring laser system.

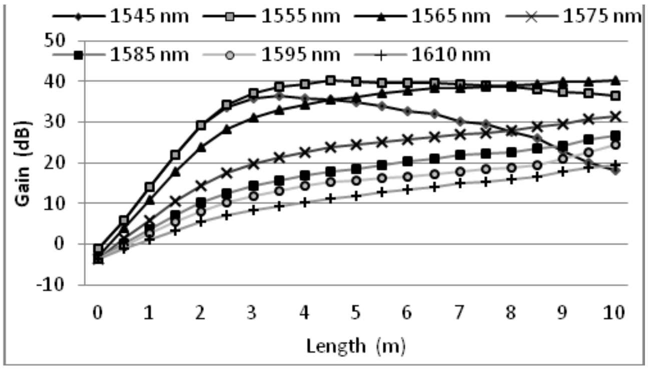

Fig. 3. Gain versus EDF-I length for different input channels.

From Fig. 3 we obtain the gain dependence of the system on the amplifier length of EDF-I for the 20m EDF-II length, 150mW pump power and -30dBm/channel signal level. As obtained from the Fig. 3, for signal channels in the C-band, gain rises to a maximum of 41.27dB and then falls as we increase the length. It reaches this maxima at 4m EDF length, which is the optimized EDF-I length when the system is designed for the C-band. For signal channels in the L-band, this rise is much steadier. Thus the overall optimized length obtained for EDF-I is nearly 10m over the 70nm bandwidth. By compromising on the C-band channels, higher gains in the L-band can be obtained at higher EDF-I length, which is a setback in terms of system capacity. After a certain length of fiber we can notice a fall in the gain at certain wavelengths. It is so because no more inversion occurs, leading to a rise in ASE (backward ASE, particularly). Thus to invert the entire fiber length to obtain a higher gain at higher EDF lengths we require higher pump power.

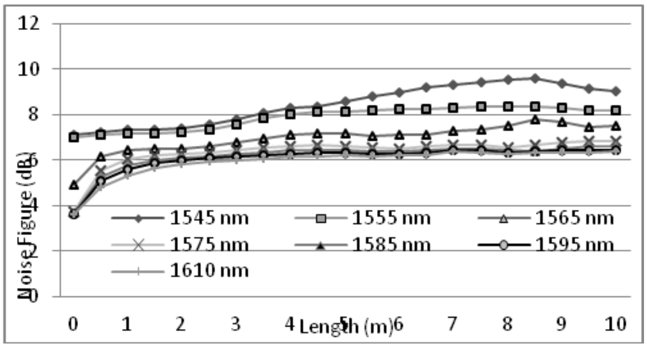

Fig. 4. Noise Figure versus EDF-I length for different input channels.

The noise figure characteristic in Fig. 4, remains almost constant for channels in the L-band, while for the C-band, at lower wavelength it increases with EDF-I length. As the noise figure increases in the C-band, gain decreases over an increase in the EDF length. Up to the 10m EDF length, the noise figure remains below 8dB. Studies show almost no dependence of gain and noise figure on the length of EDF-II, therefore it can be varied over large lengths to provide desirable output power.

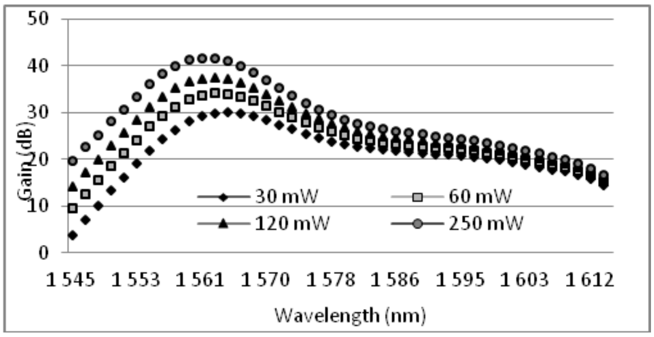

Fig. 5. Gain spectra variation for different pump powers.

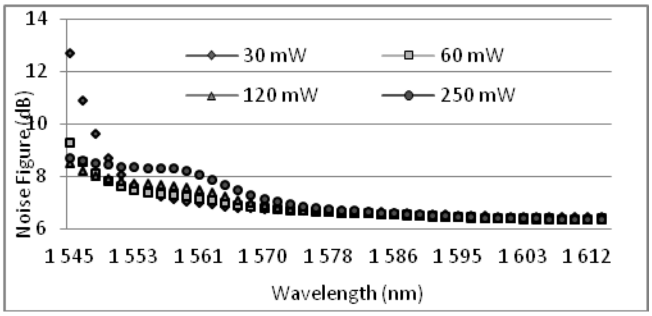

Fig. 6. Noise Figure spectra variation for different pump powers.

The system analysis is done in terms of gain and NF at different pump powers in Figs. 5 and 6. Pump powers can be varied to optimize EDFA gain. It is possible to obtain higher gains about 41.27dB, with an average gain and gain tilt of 34.45dB and -15.62dB, respectively, on increasing the pump powers to 250mW, but with a certain disadvantage of non-uniformity. As interpreted from the Fig. 5, gain flatness improves with a decrease in the pump power. The noise figure in Fig. 6 has a steep fall from 13dB to less than 7 dB with an increase in pump powers from 30mW to 250mW. An increase in the pump power helps inversion, thereby increasing stimulated emission.

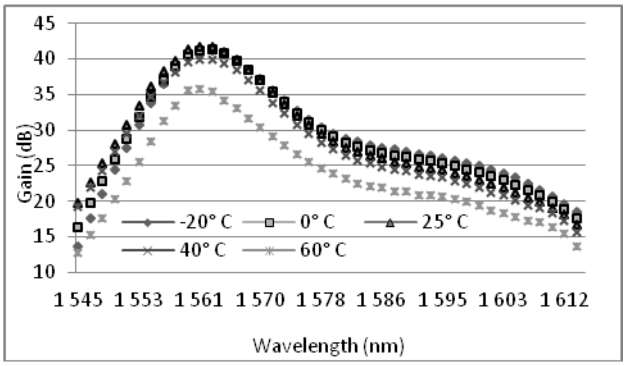

Fig. 7. Gain spectra dependence on temperature.

The gain spectrum was optimized at 25° C, with other parameters remaining constant in Fig. 7. Both absorption and emission cross-sections are wavelength dependent as well as linear functions of temperature. It has been reported that fluoride fiber amplifiers (EDFFAs) are more temperature sensitive as compared to alumino-silicate amplifiers (EDFSAs) counterparts in a multichannel wavelength-multiplexed transmission system [14]. The system depicts a large variation in gain with a temperature, which can be disadvantageous for WDM systems.

In conclusions, an erbium doped fiber ring laser system has been designed and its characteristics are presented after obtaining the simulation results. The system provides an overall gain of 34dB over 70nm (C and L band) with gain tilt, average gain and N.F as 34.45dB, -14dB, below 8dB, respectively, at 250mW pump power. The gain variation with EDF-I length shows 10m as the optimum length. Also, the inclusion of a filter reduces the non-uniformity and provides a flat-gain of 20.2dB. This is a novel configuration that gives a high average gain and low noise figure among fiber ring configurations.

The authors would like to acknowledge the Department of Electronics and Communication Engineering, Heritage Institute of Technology, Kolkata 100107, India, for their support and encouragement. We would also like to acknowledge the help provided by Somnath Pain.

References

[1] S.W. Harun, H. Ahmad, Opt. Laser Techn. **35**, 645 (2003).
[2] C.L. Chang, L. Wang, Y.J. Chiang, Opt. Comm. **267**, 108 (2006).
[3] N.M. Yusoff, A.F. Abas, S. Hitam, M.A. Mahdi, Opt. Comm. **285**, 1383 (2012).
[4] R. Anthony, R. Lahiri, S.N. Biswas, Inter. J. Comp. App. **44**(14), 1 (2012).
[5] J.H. Lee, W.J. Lee, N. Park, IEEE Phot. Techn. Lett. **10**(12), 1721 (1998).
[6] R. Anthony, S.N. Biswas, Elseviers Proc. Techn. **4**, 92 (2012).
[7] A.H.M. Husein, F.I. El-Nahal, Optik **123**, 586 (2012).
[8] Y.B. Lu, P.L. Chu, A. Alphones, P. Schum, IEEE Photon. Technol. Lett. **16**(7), 1640 (2004).
[9] S.K. Liaw, C.K. Huang, Y. L. Hsiao, Laser Phys. Lett. **5**(7), 543 (2008).
[10] R.K. Varshney, P.J. Lemaire, J.B. Judkins, V. Bhatia, T. Erdogan, J.E. Sipe, IEEE J. Lightwave Techn. **14**, 58 (1996).
[11] J.Y. Pan, M.A. Ab, A.F. Elsefare, R. E. Wagener, IEEE Photon. Technol. Lett. **7**, 1501 (1995).
[12] S. Pain, M. Biswas, S. Biswas, Phot. Lett. Poland **5**(3), 106 (2013).
[13] C.R. Giles, E. Desurvire, IEEE J. Lightwave Techn, **9**(2), 271 (1991).
[14] J. Kemtchou, M. Dhamel, P. Lecoy, IEEE J. Lightwave Techn. **15**(11), 2083 (1997).