OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 2, No. 8, August 2008, p. 455 - 458

An efficient and flat-gain Erbium-doped fiber amplifier in the region of 1550 nm to 1590 nm

S. W. HARUN*, M. C. PAUL[a], M. PAL[a], A. DHAR[a], R.SEN[a], S. DAS[a], S. K.BHADRA[a], N. S. SHAHABUDDIN[a], H. AHMAD[b]

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.*

A flat gain erbium-doped fiber amplifier (EDFA) operating in the 1550 nm to 1590 nm region is demonstrated. The EDFA uses only a15m EDF as opposed to a standard L-band EDFA which requires significantly longer EDF lengths. The EDF is fabricated using a Modified Chemical Vapor Deposition process in conjunction with a solution doping technique. The NA, cut-off wavelength and erbium ion concentration of the fiber are obtained at 0.15, 998 nm and 900 ppm respectively. The gain of the EDFA is flattened to a level of about 12 dB with a gain variation of less than 3 dB over a range from 1550 to 1590 nm with a 1480nm pump at 90mW. This amplifier operates on the energy transfer of the quasi-two-level system, whereby the C-band energy acts as a pump for the population inversion required for gain at the longer wavelength. The noise figure at the flat gain region varies from 6 to 8.5 dB.

(Received June 25, 2008; accepted June 30, 2008)

Keywords: Erbium-doped fiber amplifier, Flat-gain EDFA, L-band EDFA, High concentration EDF

1. Introduction

Dense wavelength division multiplexing (DWDM) transmission systems are attractive because of their large and flexible transmission capacity. Erbium doped fiber amplifiers (EDFAs) are key components for the construction of these DWDM transmission systems. Unfortunately, the inherent wavelength dependence of the gain and noise characteristics of EDFAs that makes WDM multistage transmission systems suffer from an unbalanced signal to noise ratio (SNR) of the channels. Normally, channels whose wavelength experiences the least gain are degraded more by the amplifier spontaneous emission (ASE) noise. To date, several techniques have been proposed to overcome this difficulty [1-3]. One of these solutions is to incorporate an optical filter after or between the EDFAs as to obtain simultaneous gain equalization. However, in WDM based optical access networks with the add/drop function, this technique does not always operate effectively because each channel generally passes through a different number of EDFAs in the multi-stage system. Therefore, it is best that the EDFA itself has flat amplification characteristics that provide equal amplification for all channels.

Recently, IsoGain™ Erbium-doped fibers (EDFs) [4], which have a unique core composition have been introduced to obtain a substantially flattened wavelength response. The EDFA requires around 14 m of this fiber to obtain flattened amplification in the C-band region. 4 or 5 times longer length of the EDF as in the case of the C-band is required to operate in the L-band region. In this paper, a compact EDFA is demonstrated that provides a flat amplification characteristic with a substantially shorter length of EDF as compared to the conventional design of the L-band EDFA. The EDF used in this experiment is fabricated from a Modified Chemical Vapor Deposition (MCVD) process in conjunction with a solution doping technique. This amplifier operates within a wavelength region of 1550 to 1590 nm using only 15m of EDF as opposed to the standard L-band EDFA, which requires more than 50 m of EDF.

2. Fabrication of the EDF

The EDF used in this experiment is fabricated by combining the MCVD process and the solution doping technique [5-7]. The MCVD process is used to deposit a silica soot layer containing index raising dopants such as GeO_2 and P_2O_5 for the core. The solution doping technique involves soaking the porous soot layer with a solution of erbium ions containing codopants such as $AlCl_3$ and $ErCl_3$ in suitable proportions. The composition, porosity and homogeneity of the deposited soot layer along with its uniformity along the length of the tube play a critical role in determining the erbium concentration and associated optical characteristics in the fabricated preforms and fibers.

The preform fabrication involved the deposition of a porous core layer of selected composition inside a silica substrate tube at a suitable temperature as done in the MCVD process. The deposition was carried out using a ‘forward method’. In this method the oxy-hydrogen burner moves along the direction of the reactant’s flow containing $SiCl_4$ and O_2 within the tube as done conventionally so that soot particles are deposited downstream of the burner and the partial consolidation of porous layer can be formed concurrently with the deposition. The temperature is maintained between 1400 and 1500°C in this process. The refractive index of the aluminosilicate-based core glass is varied by changing the porosity of silica layer along with the $AlCl_3.6H_2O$ solution concentration. The porosity of the layer is controlled through proper selection of the burner speed and temperature during presintering.

Doping of erbium ions into the unsintered core layer is done by solution doping technique. The soot of the core layer is soaked in alcoholic/aqueous solution of a mixture of a suitable concentration of $ErCl_3.6H_20$ and $AlCl_3.6H_2O$ to obtain the desired quantity of erbium ions. Further processing involves the dehydration and sintering of the porous deposition under a controlled atmosphere to form a clear glassy layer containing the erbium ions. The dehydration is carried out at high temperatures by adding Cl_2 along with the input oxygen. Sintering is then performed in the presence of O_2 and He at high temperatures. The tube is then collapsed in a few passes of the burner at a high temperature of above 2000^0C to form a preform. A fiber of 125 micrometers in diameter is drawn at temperature of around 2000^0C using the conventional fibre drawing technique. In this process, the objective is to obtain the fibre core with an Er-ion concentration of 900 ppm as to produce a highly doped fibre.

3. Result and discussion

The refractive index (RI) profiles and the geometry of the fibres were measured by refracted near field (RNF) technique by an optical fiber analyzer. Figure 1 shows the measured RI profile of the fabricated fiber. As shown in this figure, the core diameter of the fiber is 5.2 micrometers and a numerical aperture (NA) of 0.15. The refractive index of the core and cladding are obtained at 1.4635 and 1.4563 respectively. The NA is evaluated from these RI values. The cut-off wavelength of the fiber is calculated to be approximately 998 nm according to standard equation, $\lambda_c = \frac{2\pi}{2.405} a\sqrt{n_1^{\;2} - n_2^{\;2}}$, where a, n_1 and n_2 are the core radius, core and cladding refractive index respectively. Figure 2 shows the loss characteristics of the fiber which peaks at around 980 and 1530nm. By using the absorption peaks at 980 and 1530 nm, the erbium concentration of this fiber is calculated and measured to be around 900 ppm.

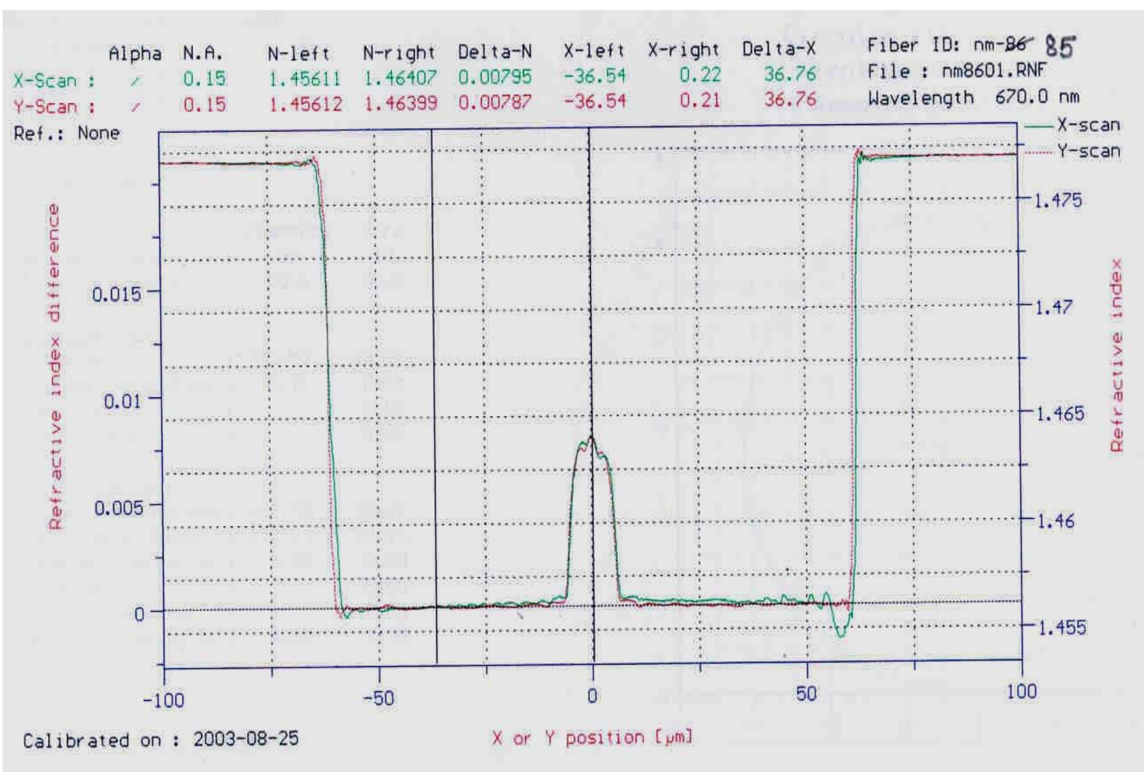

Fig. 1: Refractive index profile of the fabricated EDF

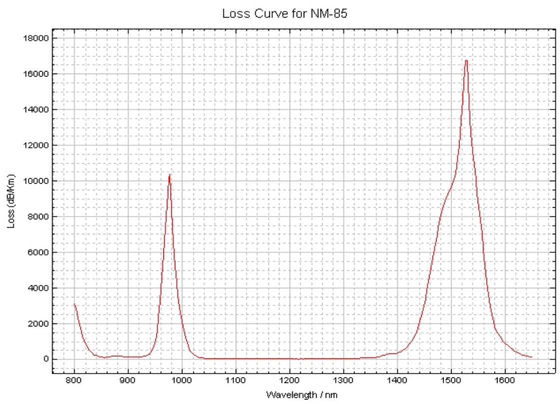

Fig. 2: Loss characteristics of the EDF

The experimental set-up used for the EDFA is shown in Figure 3. As shown in the figure, instead of the commonly used 980 nm pumping laser and due to the cut-off wavelength which is slightly higher than 980 nm, the 1480 nm laser diode is used to pump the EDF. The forward pumping scheme is used in the experiment as to reduce the noise figure. A WDM coupler is used to combine the test signal and the 1480 nm pump from the laser diode. The gain and noise figure of the amplifier are characterized using a tunable laser source (TLS) in conjunction with an optical spectrum analyzer (OSA). The EDF length and pump power are varied in this experiment.

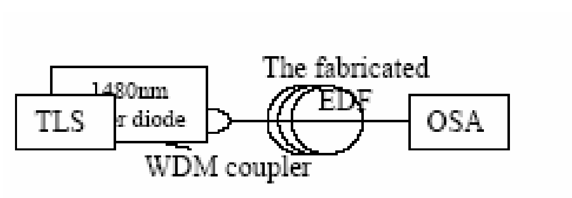

Fig. 3: Experimental set-up for characterizing of EDFA

Fig. 4 shows the ASE spectrum of the amplifier at various 1480 nm pump power. The EDF length is fixed at 15 m. The ASE power rises as the pump power increases as in the figure. At a pump power of 40 mW, the ASE from the initial part of the fiber that peaks at around 1530 nm is reabsorbed at the end part of the fiber, which then re-emits an ASE at 1560 nm. This is due to the energy transfer of the quasi-two-level system, whereby the 1530 nm energy acts as a pump for the population inversion in the generation of the ASE at the longer wavelength as shown in Fig. 4.

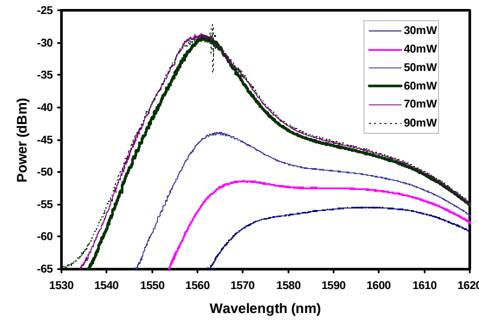

Fig. 4: ASE spectra at 1480nm pump power varies from 30 to 90 mW.

At the maximum pump power, the ASE spectrum is shifted to a longer wavelength region as the EDF length is increased. Figure 5 shows the gain and noise figure spectra of the EDFA at various EDF lengths. The input signal and pump powers is fixed at 0 dBm and 90 mW, respectively. As expected, the gain spectrum increases and is shifted to a longer wavelength as the EDF length increases from 10 to 15 m. However, For the EDF length of 25 m, the gain drops due to incomplete population inversion. A higher pump power is required as to increase the gain. At 15 m of EDF, the gain is flattened to a level of about 12 dB with a gain variation of less than 3 dB over 40 nm that spans from 1550 to 1590 nm. The noise figure at the flat gain region varies from 6 to 8.5 dB. The highest noise figure is obtained with a shorter EDF length of 10 m as in Figure 5. This could be due to the shorter length of the EDF which provides lower overall gain and also increases the ASE output which in a way affects the noise figure.

This EDFA is compact due to the shorter EDF length, and as such is suitable for applications in WDM system which has a higher input signal power due to a large number of channels. The gain characteristics is flat at 0 dBm and is very useful in a power booster configuration.

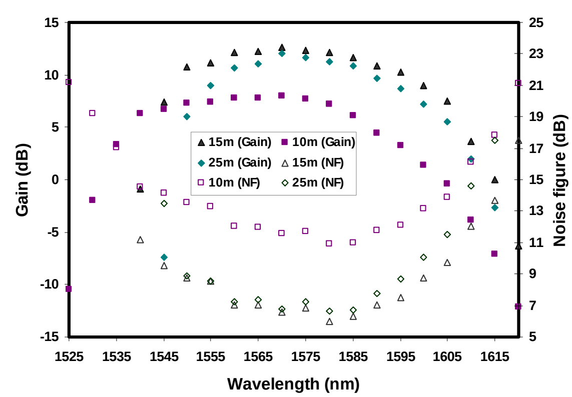

Fig. 5: Gain and noise figure characteristics of the EDF at different lengths

4. Conclusion

A flat-gain EDFA has been demonstrated using only a 15 m short length of EDF which is for operation in the1550 nm to 1590 nm region. This is opposed to the standard L-band EDFA, which requires more than 50 m of EDF. The EDF is fabricated using a Modified Chemical Vapor Deposition process in conjunction with a solution doping technique. The fabricated EDF has a NA, cut-off wavelength and erbium ion concentration of the fiber of 0.15, 998 nm and 900 ppm respectively. The EDFA has a flattened gain of about 12 dB with a gain variation of less than 3 dB over a range of 40 nm. The noise figure at the flat gain region varies from 6 to 8.5 dB.

References

[1] J. M. Oh, H. B. Choi, D. Lee, S. J. Ahn, S. J. Jung, S. B. Lee, , IEEE Photon. Technol. Letts. **14** (9), 1258 (2002).

[2] R. K. Varshney, B. Nagaraju, A. Singh, B. P. Pal, A. K. Kar, Optics Express, **15** (21), 13519 (2007).

[3] H. S. Kim, S. H. Yun, H. K. Kim, N. Park, B. Y. Kim, IEEE Photon. Technol. Lett. **10**, 790 (1998).

[4]www.fibercore.com/isogaindownload.pdf?PHPSESSID =e34627a5fe664e1d84697f48d9b3022e.

[5] R. Sen, T. Bandyopadhyay, S. K. Bhadra, K. Dasgupta, M. C. Paul, ‘A method for fabricating rare earth doped optical fibre’, PCT WO 02/060830 A1

[6] M. Pal, R. Sen, M. C. Paul, S. K. Bhadra, S. Chatterjee, D. Ghosal, K. Dasgupta , Opt. Commun. **254**, 88 (2005).

[7] M. Chatterjee, R. Sen, M. Pal, M. Naskar, M. Paul, S. Bhadra, K. Dasgupta, D. Ganguli, T. Bandyopadhyay, A. Gedanken, R. Reisfeld, Acta. Opt. Sin. **23**, 35 (2003).

*Corresponding author: swharun@um.edu.my