



**HAL**  
open science

# Original Amplifier For Mode Division Multiplexing Based On Dual Core Erbium-Doped Fibre And Asymmetric Long-Period-Grating Converters

Vipul Rastogi, Ankita Gaur, Pierre Aschieri, Bernard Dussardier

► **To cite this version:**

Vipul Rastogi, Ankita Gaur, Pierre Aschieri, Bernard Dussardier. Original Amplifier For Mode Division Multiplexing Based On Dual Core Erbium-Doped Fibre And Asymmetric Long-Period-Grating Converters. Conference on lasers and electro-optics, european quantum electronics conference (CLEO-Eur/EQEC 2015), IEEE, Jun 2015, Munich, France. hal-01171074

**HAL Id: hal-01171074**

**<https://hal.science/hal-01171074>**

Submitted on 2 Jul 2015

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Original Amplifier For Mode Division Multiplexing Based On Dual Core Erbium-Doped Fibre And Asymmetric Long-Period-Grating Converters

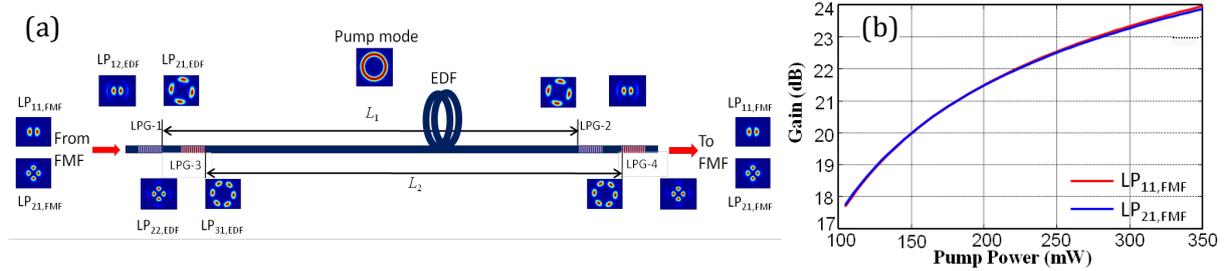
Vipul Rastogi,<sup>1</sup> Ankita Gaur,<sup>1</sup> Pierre Aschieri,<sup>2</sup> and Bernard Dussardier<sup>2,\*</sup>

<sup>1</sup>Department of Physics, Indian Institute of Technology, Roorkee, 247 667, India

<sup>2</sup>Université Nice Sophia Antipolis, CNRS, LPMC, UMR 7336, 06108 Nice CEDEX 2, France

An original concept of a Few-Mode Erbium Doped Fibre Amplifier (FMEDFA) based on a dual-concentric-core Erbium Doped Fibre (EDF) and paired mode converters is proposed for amplification of the LP<sub>11</sub> and LP<sub>21</sub> mode groups at 1530-nm wavelength with controlled Differential Modal Gain (DMG). As a proof of concept, we propose an EDF scheme that amplifies eight modes (including two polarizations and two orientations) of two mode-groups LP<sub>11</sub> and LP<sub>21</sub> input from a Few-Mode Fibre (FMF), with more than 20 dB of gain each. This concept is scalable to more mode groups and interesting for Mode Division Multiplexing (MDM).

The EDF has a dual concentric core structure: It consists of a central core (radius  $r < a$ ) with index difference  $\Delta n_1$ , and a ring core ( $b < r < c$ ) with relative index difference  $\Delta n_2 > \Delta n_1$  with respect to pure silica cladding. A trench ( $a < r < b$ ) with same index as silica separates the central and ring cores. The ring core is doped with Er<sup>3+</sup> ions and works as the amplifying core. The schematic of the proposed amplifier is shown in Fig. 1(a). For the sake of clarity the LP mode-groups are often referred to as LP modes. The mode intensity profiles shown in Fig. 1(a) correspond to the fibre parameters chosen so that in the wavelength range of interest there is no resonance between the central core and the ring core for the desired sets of modes. There is sufficient mode spacing between the effective indices ( $> 5 \times 10^{-4}$ ) of the modes to avoid mode coupling due to micro-bending [1]. Among the modes shown in Fig.1(a), LP<sub>12,EDF</sub> and LP<sub>22,EDF</sub> can be identified as core mode as their energy is mostly confined in the central core, whereas LP<sub>21,EDF</sub> and LP<sub>31,EDF</sub> have their energy mostly confined in the ring and can be identified as ring modes.



**Fig. 1** (a) Schematic of the FMEDFA. FMF: few-mode input and output fibres, EDF: Er<sup>3+</sup>-doped dual core fibre, LPG-i : asymmetric long pitch gratings (paired as 1-2 and 3-4), L<sub>1,2</sub>: amplifying lengths for both mode-groups. (b) Variation of gain vs. pump power for L<sub>1</sub>=17.8m (LP<sub>11,FMF</sub> mode group) and L<sub>2</sub>=16.6m (LP<sub>21,FMF</sub> mode group). Gain (DMG) = 20 dB (0 dB) at 150 mW pump power. EDF parameters:  $\Delta n_1 = 0.018$ ,  $\Delta n_2 = 0.02$ ,  $a = 4.5 \mu\text{m}$ ,  $b = 6 \mu\text{m}$  and  $c = 9 \mu\text{m}$ .

The input LP<sub>11,FMF</sub> and LP<sub>21,FMF</sub> modes of the line FMF excite the LP<sub>12,EDF</sub> and LP<sub>22,EDF</sub> core modes of the EDF. By using paired asymmetric long period grating (ALPG) converters, the LP<sub>12,EDF</sub> and LP<sub>22,EDF</sub> core modes excite the LP<sub>21,EDF</sub> and LP<sub>31,EDF</sub> ring modes, respectively. The asymmetric structure of the paired ALPG converters allows for the conversion of any mode symmetry to any other. We use a 4.3-cm long ALPG with a grating period of  $\Lambda_1 = 479 \mu\text{m}$  to couple light from LP<sub>12,EDF</sub> to LP<sub>21,EDF</sub> and a 9.6-cm long ALPG with a grating period of  $\Lambda_2 = 198 \mu\text{m}$  to couple LP<sub>22,EDF</sub> core modes to LP<sub>31,EDF</sub> ring modes for amplification. The ALPG refractive index modulation is  $3 \times 10^{-4}$ . After amplification, each ring mode is coupled back to its corresponding core modes via the corresponding paired ALPG. We choose the LP<sub>02,EDF,p</sub> pump mode of EDF for amplification. The EDF parameters are chosen to equal the overlap of the LP<sub>02,EDF,p</sub> with each LP<sub>21,EDF</sub> and LP<sub>31,EDF</sub> modes. The gain for each mode group is independently decided by the distances L<sub>1,2</sub> between the in- and out-coupling paired ALPGs. A suitable choice of L<sub>1</sub> and L<sub>2</sub> is used to achieve any desired DMG value.

Numerical simulations show that for 150 mW pump power injected in the LP<sub>02,EDF,p</sub> mode and 30  $\mu\text{W}$  in each signal channel, more than 20 dB is achieved for both modes groups, and that DMG is less than 0.69 dB if L<sub>1</sub> = L<sub>2</sub> = 17.8 m. For example, this residual DMG can be minimized by optimizing L<sub>1</sub> and L<sub>2</sub> : DMG = 0 dB (150 mW) with L<sub>1</sub> = 17.8 m and L<sub>2</sub> = 16.6 m (Fig1(b)). Alternatively, by equally exciting all the supported pump modes of the EDF (instead of only LP<sub>02,EDF,p</sub>) with a total of 168 mW power leads to gain > 20 dB and DMG < 0.71 dB only for equal amplifier length > 20.7 m. Here also, L<sub>1,2</sub> optimization allows for DMG control.

## References

- [1] S. Ramachandran, J. W. Nicholson, S. Ghalmi, M. F. Yan, P. Wisk, E. Monberg, and F. V. Dimarcello, "Light propagation with ultralarge modal areas in optical fibers," *Opt. Lett.* **31**(12), 1797-1799 (2006).
- [2] R. Slavik, "Coupling to circularly asymmetric modes via long-period gratings made in standard straight fiber," *Opt. Comm.* **275**(1), 90-93(2007).