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

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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 LP₁₁ and LP₂₁ 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 LP₁₁ and LP₂₁ 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 Δn_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 Er³⁺ 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_{12,EDF} and LP_{22,EDF} can be identified as core mode as their energy is mostly confined in the central core, whereas LP_{21,EDF} and LP_{31,EDF} have their energy mostly confined in the ring and can be identified as ring modes.

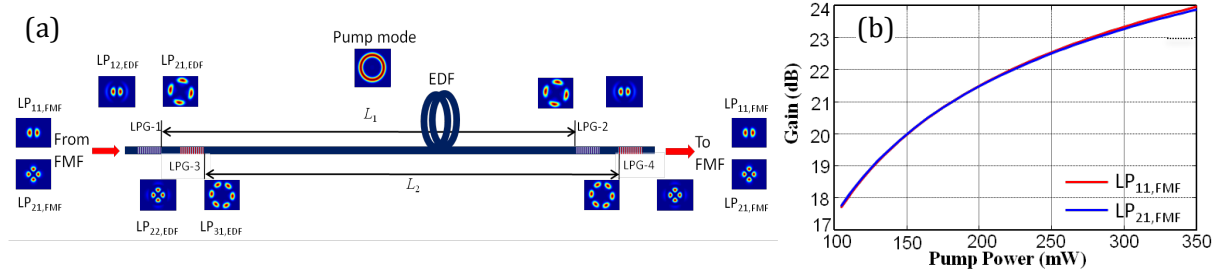


Fig. 1 (a) Schematic of the FMEDFA. FMF: few-mode input and output fibres, EDF: Er³⁺-doped dual core fibre, LPG-i : asymmetric long pitch gratings (paired as 1-2 and 3-4), L_{1,2}: amplifying lengths for both mode-groups. (b) Variation of gain vs. pump power for L₁=17.8m (LP_{11,FMF} mode group) and L₂=16.6m (LP_{21,FMF} 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_{11,FMF} and LP_{21,FMF} modes of the line FMF excite the LP_{12,EDF} and LP_{22,EDF} core modes of the EDF. By using paired asymmetric long period grating (ALPG) converters, the LP_{12,EDF} and LP_{22,EDF} core modes excite the LP_{21,EDF} and LP_{31,EDF} 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_{12,EDF} to LP_{21,EDF} and a 9.6-cm long ALPG with a grating period of $\Lambda_2 = 198 \mu\text{m}$ to couple LP_{22,EDF} core modes to LP_{31,EDF} ring modes for amplification. The ALPG refractive index modulation is 3×10^{-4} . After amplification, each ring mode is coupled back to its corresponding core modes via the corresponding paired ALPG. We choose the LP_{02,EDF,p} pump mode of EDF for amplification. The EDF parameters are chosen to equal the overlap of the LP_{02,EDF,p} with each LP_{21,EDF} and LP_{31,EDF} modes. The gain for each mode group is independently decided by the distances L_{1,2} between the in- and out-coupling paired ALPGs. A suitable choice of L₁ and L₂ is used to achieve any desired DMG value.

Numerical simulations show that for 150 mW pump power injected in the LP_{02,EDF,p} mode and 30 μW in each signal channel, more than 20 dB is achieved for both modes groups, and that DMG is less than 0.69 dB if L₁ = L₂ = 17.8 m. For example, this residual DMG can be minimized by optimizing L₁ and L₂ : DMG = 0 dB (150 mW) with L₁ = 17.8 m and L₂ = 16.6 m (Fig1(b)). Alternatively, by equally exciting all the supported pump modes of the EDF (instead of only LP_{02,EDF,p}) 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_{1,2} optimization allows for DMG control.

References

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