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APPROACHING THE OPTIMUM ERBIUM-DOPED FIBRE AMPLIFIER (EDFA)

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ABSTRACT

EDFAs are now established as key components for future high-speed communication networks. Research is therefore aimed at optimising the amplifier design. Current issues are optimal pump efficiency, spectral gain-shaping, material constraints and choice of pump wavelength.

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The EDFA[1] is now established as a key component for future high-speed, silica-based optical fibre communication networks operating at a wavelength of 1.55μm. Its major attributes are high-gain[2], high-efficiency[3,4], low-noise[5] and potential multichannel operation[6] with low-crosstalk.

Fibre amplifier performance is determined by a number of parameters. These include pump wavelength[7,8], fibre core parameters such as NA[9] and λ_{cutoff}[10,11], the host glass[12-15], dopant concentration[16-19] and distribution within the fibre core[20], as well as the amplifier configuration. Each of these parameters has been the subject of intensive worldwide investigation.

Two preferred pump wavelengths[7,8] have been identified which are free of excited-state absorption (ESA). These are the 980nm and 1.48μm bands and, as a result of careful fibre optimisation, maximum efficiencies[3,4] of 11.0dB/mW and 5.1dB/mW have been quoted for these two wavelengths respectively. Unfortunately, the pump band located at 800nm suffers from low-pump absorption cross-section and significant ESA[21]. Nevertheless, careful choice of fibre parameters and pumping at the edge of the band (827nm) to minimise ESA has allowed a pump efficiency of 1.3dB/mW to be obtained[22].

Erbium is a three-level system and therefore for most èfficient operation it is essential to maximise the pump intensity in the region of the dopant[20]. There are several ways in which this can be achieved . High NA amplifier designs are common, since they allow the pump spot size to be reduced and so increase the pump intensity. For realistic fibre NAs, the amplifier pump efficiency exhibits a quadratic dependence on NA[9]. Provided the fibre is operating in the single-mode region, reducing the fibre cutoff wavelength is also advantageous, since this effectively localises the dopant in the centre of the pump field and, for a large range of cutoffs, also maximises the pump intensity, thus further improving efficiency[10,11]. Finally, the dopant itself can be confined close to the core centre[20].

When operating under deep saturation in the power amplifier mode, up to 93% quantum efficiency[18] and 77% absolute pump-to-signal conversion efficiency[19] have been respectively obtained for the two preferred pump wavelengths (980nm and 1.48μm). These results indicate that the amplifier is operating as a near-perfect photon convertor and little further improvement is possible.

Amplifier performance is also influenced by the glass-host. Of the silica-based host glasses, the germano-silicate type is known to exhibit a narrow spectral bandwidth with a concomitant high gain efficiency[12,13]. Conversely, silica-based glasses co-doped with alumina exhibit a broadened gain spectrum and will be important in WDM applications[6,12,13]. The host glass also affects the maximum usable erbium concentration before detrimental concentration effects are observed[16-19]. For the fibre types quoted, maximum concentrations are typically in the range 50-500 ppm Er^{3+}. Other glass types are currently under investigation with a view to increasing the amplifier gain bandwidth and/or allowing higher dopant concentrations. These include multicomponent glasses[14] and fluoride glasses (ZBLAN)[15]. The latter glass doped with 1000ppm of Er^{3+} gives a gain of 17.5dB (55mW pump) and a gain bandwidth of some 40nm. However, issues of strength and incompatibility with silica-based optical components will have to be addressed in the future.

The gain spectrum obtained in Al_2O_3 co-doped fibres, although broad (>35nm), is typically irregular and this limits its application in WDM systems. However, the gain spectrum can be flattened by careful choice of pump wavelength, power and fibre length[23], or by "gain-shaping"[24], using an optical filter incorporated within the amplifier length. Both techniques provide amplifiers characterised by gains in excess of 25dB and 3dB- bandwidths in excess of 30nm for pump powers of less than 50mW. Alternatively, by concatenating amplifiers with different gain spectra the gain available to two channels can be actively controlled[25]. However, this technique is likely to be limited in the number of channels it can compensate.

A greater understanding of spectroscopy of erbium[12,13,26,27] has contributed significantly to the advances outlined above and allowed improved amplifier modelling. Comprehensive numerical models have now been developed[28], as well as simpler, but more restricted, analytic solutions[29]. These models will undoubtedly facilitate future improvements in amplifier performance.

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