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PROGRESS TOWARDS THE ULTIMATE ERBIUM-DOPED FIBRE AMPLIFIER

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The erbium-doped fibre amplifier (EDFA) has developed at a startling speed since its announcement in 1987. The EDFA 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, high efficiency, low noise and potential multichannel operation with low interchannel crosstalk. Expected applications are as fibre power-amplifiers in transmission systems and distribution networks, as signal repeaters in point-to-point optical links, as fibre pre-amplifiers in amplifier/receiver combinations and as distributed fibre amplifiers for soliton propagation.

As a result of its almost ideal amplifier performance and its wide applicability in telecommunications systems, the development of the amplifier as a component has been extremely rapid, to the point where today the EDFA can be considered as almost mature. Inevitably, therefore, further scope for major improvements is limited. However, there are a number of areas where enhanced performance may be expected in the future and which remain the subject of intensive worldwide investigation.

Pump Efficiency

Factors which have emerged as important in achieving maximum gain for minimum pump power (max. dB/mW) are fibre numerical aperture, erbium concentration and confinement, and background loss. Unfortunately, these factors are interrelated; it is found that increasing the numerical aperture increases the fibre background loss, especially for high erbium concentrations. The best reported result of 11dB/mW [1] was for a fibre made by the VAD process. Results which exceed this value have yet to be reported, although fibres made in our laboratory using the MCVD fabrication process have achieved 8.9dB/mW. However, it should be recognised that a trade-off exists between gain efficiency and noise figure [2] owing to backward-travelling ASE which saturates the input to the amplifier. We calculate that amplifiers with gain efficiency in excess of 10dB/mW will have noise figures exceeding 4dB.

High Output Power

The search for EDFA's with output power in excess of +20dBm depends largely upon the availability of a sufficiently-powerful and practical pump source. Approaches vary from the use of multiple-diode lasers [3], to the adoption of Nd:YAG mini-lasers [4] and Nd^{3+}-doped fibre lasers [5]. The latter two emit at a wavelength around 1.06μm and can give output powers in excess of 1 Watt, thus showing considerable potential as pumps for EDFA's with output power approaching +30dBm. To exploit this pump wavelength requires an erbium/ytterbium co-doped fibre [6].

Flat Gain Spectrum

A number of schemes have emerged to flatten the unequal EDFA gain spectrum which causes problems in multichannel WDM transmission systems. Some progress can be made with choice of fibre materials, particularly Al_20_3 co-doping and the use of ZBLAN fibres, although the most promising approach appears to be the use of an internal compensating filter within the amplifier [7]. This approach has the merit that the gain spectrum can be shaped and flattened without loss of pump efficiency and dynamic range. However, for long amplifier chains involving large numbers of EDFA's, a form of spectral AGC will be required to precisely balance individual channels across a wide spectral range.

Planar EDFA's

Although the planar waveguide approach to erbium-doped amplifiers is attractive particularly for lossless splitting of a signal into a large number of output ports, the search for a planar amplifier is plagued by erbium concentration effects which result in a large loss of radiative quantum efficiency once the erbium concentration exceeds a few hundred ppm. This effect limits the length of the amplifier to around a metre. The search continues to find a glass host which is able to accept a high level of erbium doping from which amplifiers of a few mm in length can be fabricated.

In conclusion, some areas remain for improvement before the ultimate EDFA is achieved. As the EDFA matures, attention is now switching to areas where obvious gains can be made, for example low-loss components (isolators, WDM couplers), system control and engineering issues.

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