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The Erbium-Doped Planar Amplifier: from Laboratory to Local Loop

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I review the status of research into planar erbium-doped waveguide amplifiers, highlighting the challenges and prospects through examination of a typical application.

Introduction

The erbium-doped fibre amplifier (EDFA) was invented at the University of Southampton in 1987 [1], and rapidly recognised as a very significant advance. The first commercial EDFAs were available only four years later, making possible fully transparent transoceanic cables with unprecedented bandwidth and expanding the scope of land-based optical networks. Despite their unsurpassed performance, however, EDFAs remain expensive components whose cost must usually be shared among hundreds or even thousands of customers in order to make their use economically viable. They are thus to be found as head-end power amplifiers or booster amplifiers in trunk lines and submarine cables, but not in applications in the local loop.

It is to the local loop that integrated optical components are potentially well-suited. All-optical communication systems demand a variety of functions at the user end, for which the main requirement is low cost, and moderate performance is acceptable. For high-volume, complex, multichannel components such as multiplexers and splitters, integrated optics offer the advantages of mass production through photolithographic techniques and highly reproducible performance. These devices can benefit from incorporation of gain to offset insertion and splitting losses.

Research into erbium-doped planar amplifiers (EDPAs) is underway at a number of industrial and academic laboratories, and publications date from 1990. However, no commercial device exists and none seems imminent. Possible reasons might include technical problems or lack of suitable markets. I will examine these possibilities, and discuss one project aimed at developing practical devices for use in the local loop.

The Status of Research into Erbium-Doped Planar Amplifiers

It is still possible to summarise world-wide EDPA research in a few pages; table I shows the approaches which have been used to make waveguide amplifiers. Other systems are under investigation but have not progressed beyond planar waveguides or spectroscopic studies. Elaborate lasers and amplifiers have been made [2] using flame-hydrolysis-deposited SiO_2-on-Si or Er^{3+}-diffused $LiNbO_3$, but here I consider only simple, broadband single-pass amplifiers.

In comparison to EDFAs, EDPAs have tended to require rather high pump power levels, but otherwise their performance is good. EDPA optical path lengths are shorter than those in EDFAs and their propagation losses higher, so that erbium concentrations are necessarily greater. High dopant levels lead to problems of clustering and uniform upconversion, which degrade the performance. This continues to preclude the short lengths of highly doped amplifier which would have great appeal for use in integrated optics.

Host material	Waveguide Fabrication	Papers
Bulk-doped phosphate glass	Ion-exchange	11
Flame-hydrolysis SiO_2-on-Si	Reactive ion etching	10
Erbium-diffused $LiNbO_3$	Ti-diffusion/Proton exchange	10
Bulk-doped silicate glass	Ion-exchange	9
Sputtered silicate glass	Reactive ion etching	5
Sputtered Y_2O_3 films	Ion beam etching	4
PECVD SiO_2-on-Si	Reactive ion etching	4
Ion-implanted sputtered Al_2O_3	Reactive ion etching	3

Table I: Experimental EDPA systems

While there has been much discussion of the fabrication and performance of EDPAs, little has been written about the technical specifications for practical devices, and the research generally lacks specified technological goals. This perhaps reflects an expectation that the technology will not enter the market place anytime soon. Nevertheless, some existing EDPA systems appear to be capable of meeting the technical specifications for the applications discussed below. This is in contrast to semiconductor optical amplifier devices, which suffer from high insertion and polarization-dependent losses and short excited state lifetimes.

The Status of the Optoelectronics Market

In so far as integrated optics based on insulating dielectrics are concerned, market demand is rather limited. Several companies offer passive devices such as 1xN splitters based on silica-on-silicon waveguides or ion-exchanged waveguides in bulk glasses, and a well-developed range of high frequency signal-processing devices is available in lithium niobate.

While fibre optic trunk lines and EDFAs have been installed piecemeal into existing telecommunications networks, EDPAs can be an economic proposition competitive with "bulk" spliced fibre solutions only if there is a large demand for highly functional devices. For such demand to materialise 1550 nm photons must be present in the local loop. It is not cost-effective to replace existing copper coax networks with fibre, given the limited current demand for truly broadband services which renders the huge potential bandwidth increase irrelevant. On greenfield sites, however, the costs of fibre and coax are comparable, and the enhanced service quality of optical systems makes them the obvious choice. The optical access line project (OPAL) in the former East Germany is making extensive use of fibre networks, and represents a major market for passive integrated optics - some thousands of ion-exchanged splitters have been ordered for deployment over the next few years.

Government support, in the promotion of the "information superhighway" in the United States, in the European Union RACE programme and in other projects in countries such as Singapore and Japan, will doubtless bring enhanced opportunities for the deployment of integrated optical components, and may encourage companies to develop products they would otherwise see as too risky for backing with scarce research funds.

Ultimately, the future of EDPAs will probably be tied closely to the development of fully optical broadband networks, and the need for compact, loss-compensated components in the local loop and in all-optical switching matrices. The availability of EDPAs will facilitate provision of enormous bandwidth to individual consumers, and play an important part in making the information revolution a reality. However, if these devices are not forthcoming, decisions on operating wavelengths and system designs may close the window of opportunity. The challenge facing EDPA developers is to adapt their already successful technologies to meet immediate needs (which may not exploit the full EDPA potential) cost-effectively.

The RACE 2109 LIASON project: targetted development of an EDPA

Within the European Union RACE programme (Research and technology development in advanced communications technologies in Europe), project LIASON has been funded to develop lossless 1xN splitters for use in the subscriber loop of optical networks. Applications are envisaged in analog CATV and digital PONs. In current CATV scenarios, the optical network power budget runs out at the kerb; incorporation of a lossless splitter allows the optical line to run onto the customer premises. For PONs system in OPAL, a 1x2 "lossless splitter" permits exploitation of the full capacity of optical line terminations in rural areas.

Technical and cost specifications for some of these applications are shown in table II [3]. Note the demanding 0.05 dB PDL requirement for CATV, which is unlikely to be met easily in any system, whether based on fibre or integrated optics. The cost requirements are also rather stringent; for large production volumes (in multiples of 10000 to 100000) they are feasible, but will depend crucially upon the availability of high power pump laser diodes (coupled pump powers 60-70 mW) at moderate cost. Although the PONs application demands the simplest device from a technical point of view, it is unclear whether the demand from the OPAL system can be high enough to bring the price down to a competitive level.

The LIASON concept builds on the extensive experience of its various partners in systems applications of optical networks, EDFAs and rare-earth spectroscopy in glasses and the commercial development and fabrication of high performance passive ion-exchanged splitters and multiplexers. The LIASON devices will be ion-exchanged waveguides in silicate glass hosts, with an upstream erbium-doped section to compensate the power reduction due to splitting up to 16 ways in a downstream, undoped section of cascaded y-junctions.

The LIASON realisation is handicapped by the bulk doping, which gives rise to deleterious reabsorption losses in the 3-level erbium system, lowering the gain and increasing the noise figure. However, careful host selection and characterization in combination with detailed modelling indicate that the required performance is attainable for at least some of the applications. This is provided the modal sizes and propagation losses in the amplifier section can be made small enough; good progress is being made in this direction.

The level of integration in the generation of LIASON devices under development is quite modest, but still represents a major simplification over a fibre-based solution, incorporating as it will on one chip pump/signal multiplexer, amplifier, pump/signal demultiplexer and 1xN

	PON 1x2	CATV 1x16
Splitting "loss"	3 dB	12 dB
Noise figure at given fibre-to-fibre gain	< 10 dB (5dB gain)	<5.3 dB (0dB gain)
Internal reflection	<-23 dB	<-49 dB
Gain slope	-	<0.1 dB/nm
Polarisation-dependent loss	-	<0.05 dB
Unit cost/kECU	<2.6	<4.2

Table II: Specifications for Lossless Splitters

splitter. Potential enhancements to take advantage of the integration and photolithographic fabrication technique include gain-flattening and provision for bidirectional operation, perhaps involving additional signals in the 1300 nm band.

Conclusion

While EDFAs have achieved technological maturity and commercial success, EDPAs remain a matter for laboratory research. EDPAs are potentially highly competitive for large-volume applications where economies of scale and the advantages of easy mass production become significant, and they can make significant contributions to the "information revolution". Technically, they can probably meet or exceed the relevant specifications for applications such as lossless splitters. EDPAs are thus suitable for deployment in the local loop, but at present pump laser costs they will be viable only in volumes of many thousands. Major programmes such as OPAL currently provide the kind of market necessary to make EDPAs a commercial reality; in the future, various national "information superhighways" may help move them from the laboratory to the local loop.

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