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LOSSLESS INTEGRATED ACTIVE SPLITTERS FOR OPTICAL NETWORKS

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Abstract
We discuss the latest results in the European Union RACE II project LIASON to specify and develop "lossless" splitters in integrated optics, combining an erbium-doped planar amplifier and a passive 1xN cascaded y-junction splitter.

Introduction

The great success of optical telecommunications in trunk-line applications has led to the expectation that this will be repeated in local loop applications, with unprecedented bandwidth being delivered to the homes and offices of consumers. This scenario presents many challenges, for designers of systems and components to realise these systems. The potential rewards for meeting these challenges are great; for the service providers and device fabricators, the widespread adoption of local optical networks will create a huge market.

In an economic climate which demands immediate returns on investment, the components used in these systems must be extremely low in cost, with no margin allowed for potential expansion of services. To achieve low cost, components must be suited to mass production, which makes integrated optics very attractive. We describe here the status of a project to develop an integrated, optically transparent "lossless" splitter in ion-exchanged waveguides in glass for CATV and PONs applications, potentially suitable for wavelength-division-multiplexed [WDM] and bidirectional systems. The technical and cost specifications are reviewed, and the pros and cons of the particular realisation discussed. We present experimental results and theoretical predictions based on a detailed amplifier model, and examine the prospects for meeting the device specifications.

The LIASON Collaboration

The work described here has been carried out by the LIASON consortium, whose partners between them have substantial experience in rare-earth-doped fibre and planar waveguides, in high performance passive waveguide devices and in analogue and digital optical systems. In particular, the LIASON project builds on the experimental and commercial passive devices, including 1xN splitters and "dense WDM" structures, developed by Corning Europe over the last few years. Given this knowledge base, it is a natural development to look into the possibility of incorporating gain through erbium-doping, and extend the range of potential devices.

The LIASON device is a "lossless" splitter, in which a 1xN splitter is integrated on a monolithic substrate with an upstream optical amplifier which compensates for the signal power reduction due to splitting. Fig. 1 shows a sketch of the concept: note that pump/signal multiplexing and demultiplexing functions are also integrated, and that part of the substrate is not doped with erbium, to reduce signal reabsorption losses.

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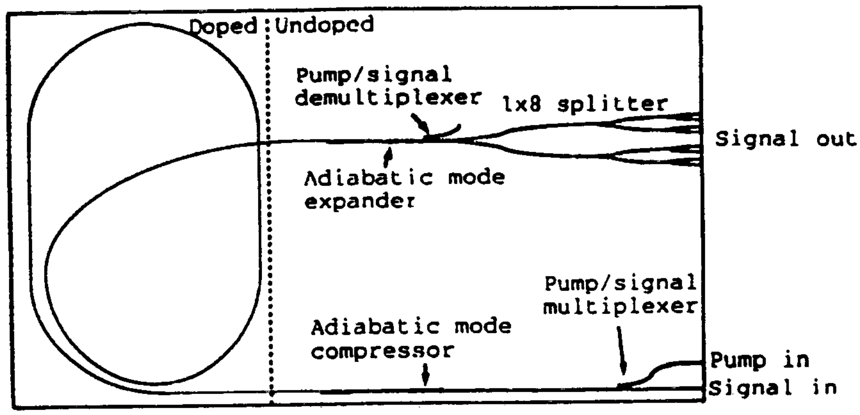

Figure 1: Concept for LIASON "lossless" splitter

Ion-exchanged waveguides in a composite glass host have a number of advantages over other realisations. The background propagation losses are as low as or lower than in other planar systems, and a wide variety of glass compositions can be explored to optimise the erbium spectroscopy. On the other hand, bulk doping has the drawback that it takes an impractical pumping level to saturate the erbium inversion over the area of the signal mode, because the effective inversion increases approximately as the logarithm of the pump power. Because the amplifying erbium transition is in a quasi-3-level system, this results in high levels of signal reabsorption by the ground state population, lowering the gain and raising the noise figure.

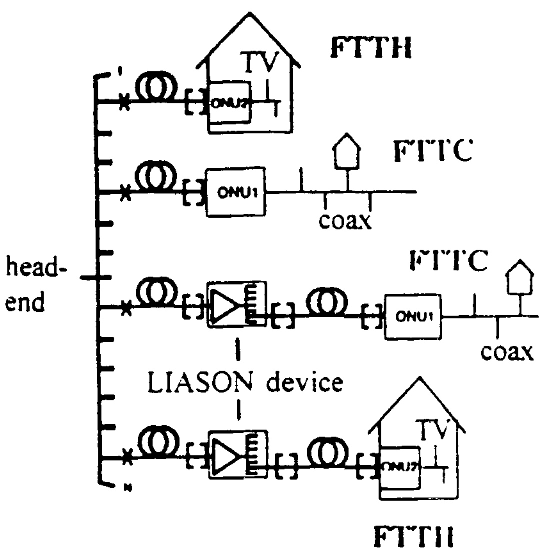

Figure 2: CATV application for lossless splitter

The use of Tl^{-} exchange minimises this problem. Tl^{+} exchange leads to a high maximum index change of about 0.1, which makes very tightly confined waveguides possible. The amount of pump power required to reach a given saturation decreases roughly in proportion with the cross-sectional area of the mode.

Applications and Specifications

Two local loop applications have been envisaged within the LIASON project, in analogue CATV systems (fig. 2) and in digital PONs (fig. 3) [FTTH = fibre-to-the-home: FTTC=fibre-to-the-curb: ONU = optical network unit][1]. The specifications for the LIASON device in these two systems are shown in table 1. As one looks from left to right in the table, the specifications become progressively more demanding: for the 1x16 CATV application, even a perfect erbium-doped fibre amplifier would be hard-pressed to meet them. The polarisation-dependent loss requirement of 0.05 dB is too stringent for commercial fibre components.

Both PONs and CATV applications are significant in their potential to boost the incursion of fibre into the local loop, and because each device serves a small number of individual customers the lossless splitters must be low cost.

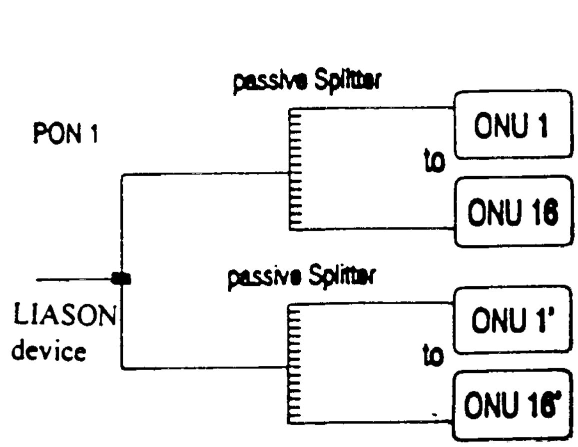

Figure 3: PONs application for lossless splitter

	PON 1x2	CATV 1x8	CATV 1x16
Splitting "loss"	3 dB	9 dB	12 dB
Noise figure at given fibre-to-fibre gain	< 10 dB (5dB gain)	<5.6 dB (0dB gain)	<5.3 dB (0dB gain)
Internal reflection	<-23 dB	<-46 dB	<-49 dB
Gain slope	-	<0.1 dB/nm	
Polarisation-dependent loss	-	<0.05 dB	
Unit cost/kECU	<2.6	<1.75	<4.2

Table 1: Specifications for lossless splitter performance

high volume products. The cost of erbium-doped optical amplifiers is dominated by the pump laser, and the cost figures given in table I are achievable only if the pump laser costs drop substantially. Successful applications of erbium-doped amplifiers in the local loop will certainly drive pump prices down because the market will be enormous compared to that for trunk line applications.

Host selection

To keep device fabrication costs to a minimum, the lossless splitters must be as small as possible. This requires short amplifier lengths, which in turn implies high dopant concentrations to achieve a given level of gain. It is well-known that ion-ion interactions between erbium ions, as shown in fig. 4, can diminish amplifier efficiency, particularly when exacerbated by clustering, with locally elevated dopant levels.

Through Judd-Ofelt analysis as in table 2, it can readily be shown that it is not possible to pick a host in which the parasitic ESA transition (see fig. 4) is reduced in strength relative to the desirable transitions. The deleterious effect of ion-ion interactions can be minimised only by seeking hosts in which the spectral overlap is small.

We have made fundamental spectroscopic measurements of the signal emission/absorption and the ESA transitions in a variety of silicate glass hosts. We have chosen a borosilicate host which combines reasonably high emission cross-sections at 1550 nm, as required by the systems applications, with low spectral overlap and thus relatively weak ion-ion interactions. Predictions based on a detailed amplifier model confirm our expectation that this is the most promising of our candidate host glasses for use with high dopant concentrations.

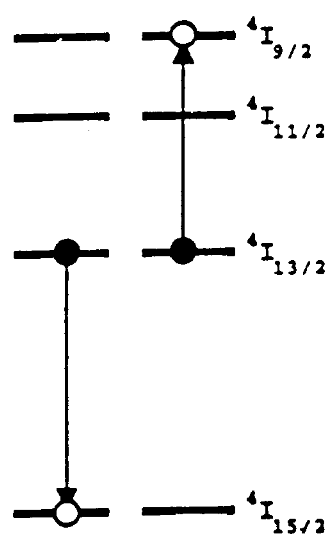

Figure 4: Ion-ion interaction: 2 ions in metastable $^4I_{13/2}$ state interact with net loss of 1 excitation

Current performance

In fig. 5 we show the most recent detailed gain performance measurements, along with the predictions of the amplifier model[7]. This model incorporates the effects of clustering and uniform upconversion, and the predictions are in reasonably close accord with the data. Net gain levels are about 6-8 dB for the maximum pump

Transition	U_2^2	U_4^2	U_6^2
980 nm Pump: $^4I_{15/2} \rightarrow ^4I_{11/2}$	0.0	0.0	0.4
1550 nm Emission: $^4I_{13/2} \rightarrow ^4I_{15/2}$	0.0	0.1	1.4
1700 nm ESA: $^4I_{13/2} \rightarrow ^4I_{9/2}$	0.0	0.0	0.7

Table 2: Judd-Ofelt coefficients for Er^{3+} transitions; note dominance of third term

powers used.

Recent improvements, which have not yet been fully characterised, include reduced losses and smaller mode sizes, and adiabatic tapers to improve the mode matching for fibre coupling whilst preserving the tight mode confinement necessary for good amplifier performance.

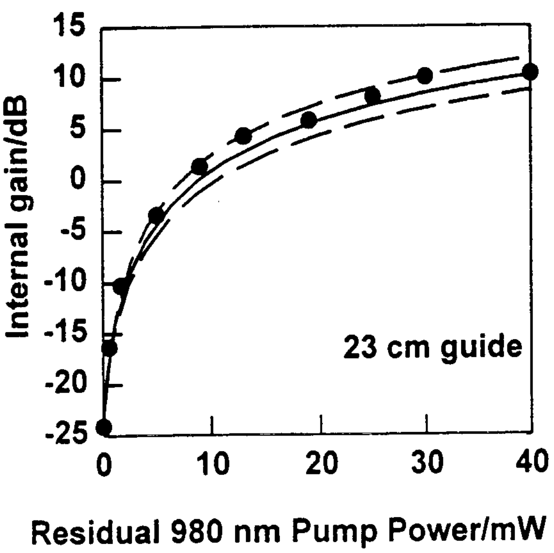

Figure 5: Recent amplifier performance. Erbium concentration 4×10^{19} cm^{-3}

Fig. 6 shows predictions for gain as a function of modal radius and propagation loss. Current performance is good enough for the PONs application, but in order to make the CATV applications practical, further improvements in the waveguide fabrication are required. Note that here we have assumed a concentration 2.5x greater than used thus far with no change in fluorescence lifetime or clustering fraction.

Future prospects

The optically transparent lossless splitters envisioned here lend themselves to bidirectional operation, so that upstream signals for e.g. video-on-demand may be sent from users to the head end. This low data-rate signal may be within the erbium amplification band, so that losses in the splitter are compensated, or it may be in the 1300 nm band, with integrated multiplexers to bypass the amplifier section. Systems studies are underway to consider the implications of these new applications on the device specifications and cost requirements.

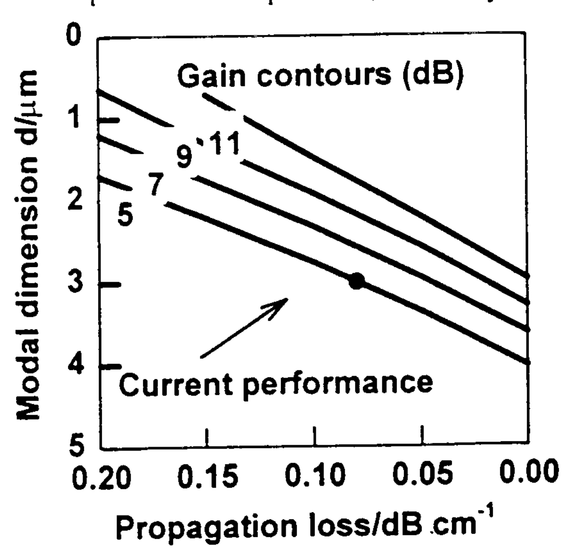

Figure 6: Predicted amplifier gain, as a function of mode size ($1/e^2$ intensity modal radii d×√2d) and propagation loss; pump 60 mW at 1480 nm

Conclusion

Detailed specifications have been derived for lossless splitters employed in PONs or optical CATV networks. We have made good progress towards realising lossless splitters for digital PONs applications, and we have identified the problems involved in meeting the specifications for CATV applications. We have established some general guiding principles for selection of host glasses and waveguide design in planar amplifiers.

Acknowledgements
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