# DIODE-PUMPED, PLANAR LOSSLESS SPLITTER AT 1.5μm FOR OPTICAL NETWORKS

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*Abstract* We demonstrate the first planar lossless splitter at 1.5 μm. The ion-exchanged waveguide circuit in Er/Yb codoped silicate glass achieved 1x2 lossless splitting at 1537 nm with a 980 nm laser diode pump.

*Introduction* The increasing need for cost-effective extension of broadband digital and CATV 1.5 μm optical networks from the curb to businesses - or even the home - has made the development of planar lossless splitters highly desirable. Such devices must combine splitting ratios up to 1x16 with noise figures as low as 5dB [1]. These demanding specifications require a low-loss waveguide fabrication technology suitable for mass reproduction at low cost. The technology must also allow the realisation and integration of passive splitters with amplifying sections capable of achieving net gains from 3 to 13 dB, all under laser diode pumping. Since ion-exchange has been a long-standing, reliable technique used in the fabrication of passive splitters, there have been substantial efforts to use this technology to demonstrate Er-doped waveguide amplifiers at 1.5 μm. Already, net gains of 6dB [2] and 7 dB [3] have been reported in Er and Er/Yb codoped waveguides, respectively. To this date, however, there have been no reports of the integration of both active and passive components to realise a truly lossless splitter.

In this paper, we demonstrate the first planar lossless splitter at 1.5 μm. The device comprises a 1x2 splitter fabricated by thallium-ion exchange in an Er/Yb codoped silicate glass, and achieves lossless splitting at 1537 nm when pumped by a laser diode. The results illustrate the potential of ion-exchange technology to realise planar devices for broadband fibre-to-the-home telecommunication systems.

*Device Fabrication* Figure 1 shows a diagram of the device. The substrate material was a borosilicate glass uniformly codoped with 5% $Yb_2O_3$ and 3% $Er_2O_3$ by weight. The 38 mm long 1x2 splitter was made by thallium-ion exchange and comprised a 17.3 mm long straight section followed by a 20.7 mm long splitting section. The resulting waveguides had $1/e^2$ intensity dimensions of 6x5 $\mu m^2$. The waveguide fabrication process included a special step to taper the ends of the waveguides to expand the modal dimensions up to 8x7 $\mu m^2$ over a distance of a few mm. This step was crucial to achieving low insertion losses at 1.5 μm while maintaining tight mode confinement in the majority of the gain section, thus avoiding reduction in the net gain.

*Device Characterisation* Figure 2 shows the apparatus used to measure the net gain of the lossless splitter. A tuneable laser diode was used as the 1.5 μm signal and a 980 nm laser diode as the pump source. The pump and signal were combined at the device input through a fibre WDM. At the device output, the signal was separated from the pump with a second fibre WDM and detected. The signal net gain, G, was calculated as

$$G = 10 \log[(P_{out} - P_{ASE})/P_{in}] \qquad (1)$$

where $P_{out}$ is the output signal power from one splitter arm, $P_{ASE}$ the output amplified spontaneous emission power from one arm with no input signal, and $P_{in}$ the reference signal power measured through the system without the device. Figure 3 shows the net gain in dB vs. wavelength for both output arms. For this measurement, the pump power was 100 mW and the signal power was -22 dBm. As the figure shows, lossless splitting was achieved both around 1537 nm and 1543 nm.

We have not yet measured the noise figure (NF) for this device; figure 4 shows the measured NF for a straight channel waveguide in a substrate codoped with 5% $Yb_2O_3$ and 2% $Er_2O_3$ by weight. The waveguide mode had dimensions of 6.5x4 $\mu m^2$ and a length of 3.3 cm. The noise figure was measured using the polarisation-nulling technique [4] with copropagating pump, and signal powers of -22.5 and -2.5 dBm. From figure 4, the NF was ~7.5 dB with net gain of 2 dB at 1537 nm.

*Discussion* Three key factors have allowed us to achieve lossless splitting with a laser diode pump. The first is Er/Yb codoping, which allows efficient use of the laser diode pump in a short length, even in a borosilicate glass. The second is the fabrication of low-loss waveguides with very tight modal confinement. This is important not only to achieve high pumping intensities, but also to reduce the signal reabsorption effects within the mode tails that arise because of the uniform doping of the substrate. The third factor is the tapering of the waveguide ends to achieve low insertion losses and increase the net gain of the overall system.

In this device, the active and passive waveguiding regions have not been separated. Consequently, the pump power in each arm of the splitter suffers roughly a 3dB decrease, thus limiting the gain achievable in each arm. In addition, the waveguides are multimoded at 980 nm, which leads to different pumping conditions in each splitter arm, and hence slightly different gains at the two outputs, as shown in figure 3. These problems will be improved in future devices by separating the gain region from the splitting region. We have already measured net gains of 7dB at 1537 nm using similar pump powers in a 3.8 cm long straight waveguide of similar dimensions. With a net gain of 7 dB, the separation of the active and splitting regions should readily allow the demonstration of a 1x4 lossless splitter. This improvement would also reduce the noise figure of the device, bringing the design target of 5 dB within reach for a 1x4 splitter. We have developed the capability to separate active and passive regions by fusing doped and undoped glasses, and are currently working on implementing these improvements. Further work will include integration of a pump/signal multiplexer, as well as the splitter, on an undoped region of the dual-glass substrate.

Finally, it is worth noting that the net gain of 7 dB referred to above compares favourably with that achieved elsewhere [2], which used two laser diode pump sources in a double-pass configuration and required an Er/Yb co-doped phosphate glass. Our results confirm recent indications [5] that an Er/Yb silicate host with its superior chemical durability is an attractive alternative.

*Conclusion* We have demonstrated the first planar lossless splitter at 1.5 μm. The present 1x2 device is aimed at digital applications [1]; we are confident that improvements in the Er/Yb concentration ratio and device layout will lead to 1x8 lossless splitters with good noise figures, which would be ideal for analog CATV applications. These results demonstrate that ion-exchange technology is a strong contender to yield active planar components for broadband telecommunication systems.

**Acknowledgements**
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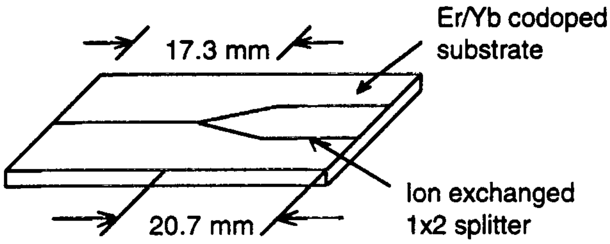


Figure 1. Planar lossless splitter

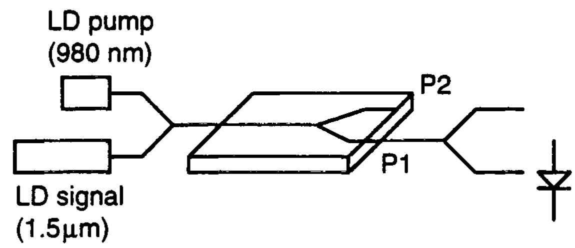


Figure 2. Gain measurement apparatus

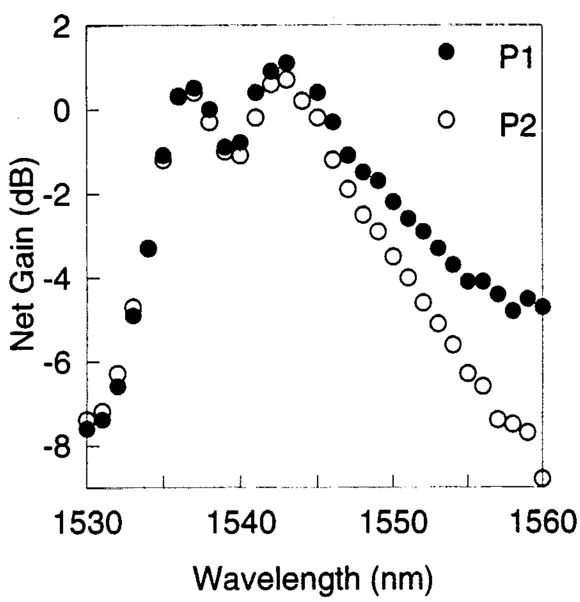


Figure 3. Gain measurement

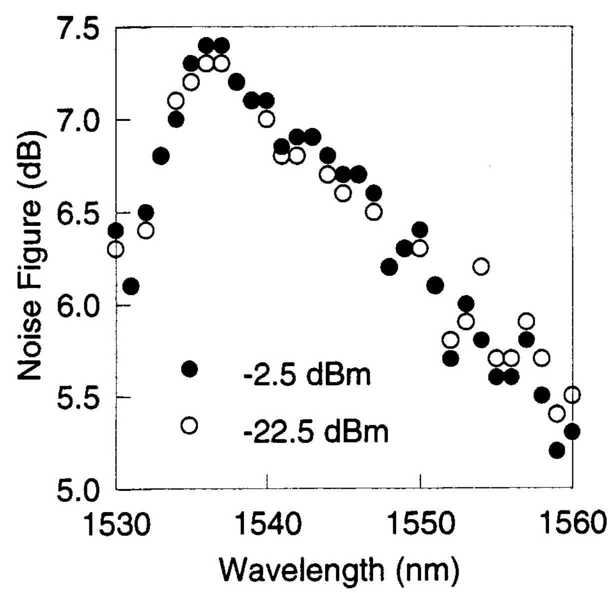


Figure 4. Noise figure measurement as a function of signal power.

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