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Ion-exchanged Planar Lossless Splitter for analog CATV distribution systems at 1.5 μm

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Abstract: We demonstrate for the first time an ion-exchanged, planar lossless splitter pumped at 980 nm in an analog CATV distribution system at 1.5 μm.

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1. Introduction

There is a growing need for cost-effective upgrade of high-split coaxial tree-and-branch analog CATV distribution networks to fiber-coax access networks for provisioning of broadband interactive services on top of the analog CATV distribution. This has made the development of planar Lossless Integrated Active Splitters (LIAS) desirable, since this technology suitable for mass production can reduce the overall network costs. A LIAS in principle is an integrated optical device consisting of an amplifying section followed by a power splitting section. Typically such a LIAS must combine a 10 dB gain with a 1x8 splitting factor, a Noise Figure (NF) < 5.6 dB, a gain-slope between -0.4 and 0.1 dB/nm, internal reflection levels below -46 dB and a Polarization Dependent Loss (PDL) < 0.1 dB for ~ 0 dBm input power [1,2]. Furthermore, to enable an interactive services overlay by WDM techniques [3], reasonable flat gain over a substantial part of the 1.5 μm wavelength window is required. These demanding specifications require a low-loss waveguide fabrication technology. Such technology must also allow the realization and integration of passive splitters with amplifying sections capable of achieving net gains of between 3 and 13 dB using laser diode pumping. To date, thin-film sputtering [4], flame-hydrolysis [5,6], and ion-exchange [7,8] have been employed as fabrication techniques to realize erbium-doped planar waveguide amplifiers at 1.5 μm. Of these technologies, ion-exchange is particularly attractive because it is well-developed and has been used in the fabrication of reliable commercial passive devices. Furthermore, net gains of 6dB [7] and 7 dB [8] have already been reported in Er and Er/Yb codoped ion-exchanged glass waveguides, respectively. Recently, we demonstrated the potential of the ion-exchange technology to realize planar devices for broadband fiber-in-the-loop systems by fabricating a lossless splitter [9]. The configuration of this device was similar to one realized by flame-hydrolysis [5], and comprised a 1x2 splitter fabricated by thallium ion exchange in an Er/Yb codoped silicate glass. In this paper, we report on an improved, fiber-pigtailed device and its performance in a 1.5 μm AM-CATV distribution system.

2. Active waveguide

To evaluate the prospects for lossless splitting, we measured the gain of a prototype waveguide amplifier to be used in the splitter. The prototype amplifier section was a straight waveguide fabricated by thallium-sodium exchange in a borosilicate glass, uniformly codoped with 5% wt Yb_2O_3 and 3% wt Er_2O_3. The fabrication process included a second exchange to bury the waveguide. The resulting waveguide was 3.9 cm long and had $1/e^2$ full-width modal intensity dimensions of 4.2 x 3.3 μm^2 at 980 nm and 6.5 x 5 μm^2 at 1480 nm. Using the fiber of a single-mode 980/1550nm coupler, we measured insertion losses of 3 dB and 3.6 dB at 900 nm and 1400 nm, respectively.

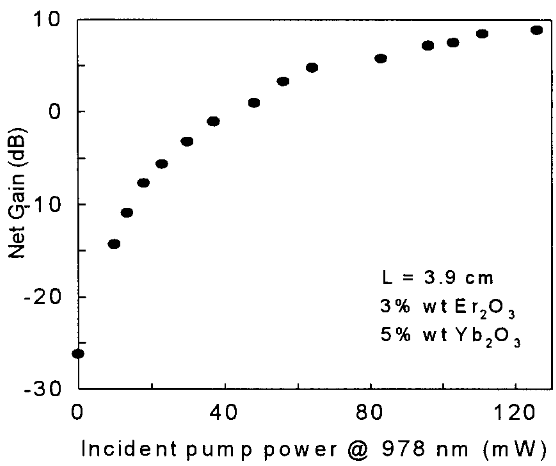

Figure 1.Measured net gain in straight Er/Yb codoped waveguide.

Figure 1 shows the measured net gain for a -30 dBm input signal at 1537 nm versus pump power from a Ti:sapphire laser tuned to 978 nm. The net gain was obtained by measuring the signal throughput with and without the device, taking care to subtract any amplified spontaneous emission. A net gain of 9 dB was achieved with 130 mW of pump power for a gain coefficient of 2.3 dB/cm and a gain efficiency of 0.07 dB/mW. These values are comparable with those achieved in the planar amplifiers fabricated by thin-film sputtering (2.2 dB/cm and 0.07 dB/mW) [4] and flame hydrolysis (0.34 dB/cm and 0.12 dB/mW) [6] using the same pump power. They are better than those achieved in an ion-exchanged waveguide amplifier realized in an Er/Yb co-doped phosphate glass [8] with similar Er- and Yb-concentrations. The achieved gain is sufficient for 1x8 lossless splitting using a commercially available 980 nm pump laser.

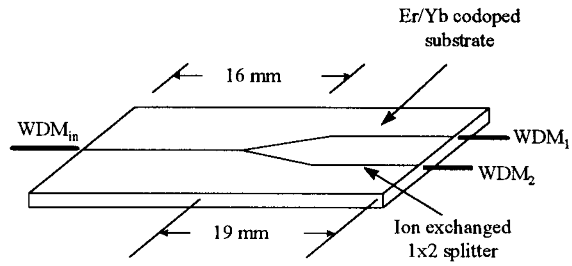

Figure 2. Planar 1 x 2 lossless splitter.

3. LIAS

The 1x2 LIAS as shown in Figure 2 was made with the same fabrication procedure and doping concentrations as the straight waveguide described before. In addition the input and outputs were thermally tapered over 5 mm to reduce the insertion losses of the device at 1.5 μm whilst maintaining tight mode confinement in the majority of the gain section, thus avoiding reduction of the gain. The resulting 3.5 cm-long device comprised a 16 mm-long straight section followed by a 19 mm-long splitting section. The tapering process increased the modal intensity dimensions up to 8x7 μm^2 from the original dimensions of 6x5 μm^2, and brought the insertion loss at 1400 nm down to 2.2 dB from the original value of 3.6 dB. Finally, the tapered input and output ends were pigtailed to 0.98/1.5 μm fused-fiber WDMs.

Before evaluation of the behaviour of the 1x2 lossless splitter in an AM-CATV system, we measured the gain and the Noise Figure (NF), which influence the Carrier-to-Noise Ratio (CNR) in such a system. Furthermore, the Amplified Spontaneous Emission (ASE) slope was also measured to give an estimation of the gain-slope [10], which influences the second order distortion in directly modulated AM-CATV systems. For both these measurements a 1.5 μm tunable laser

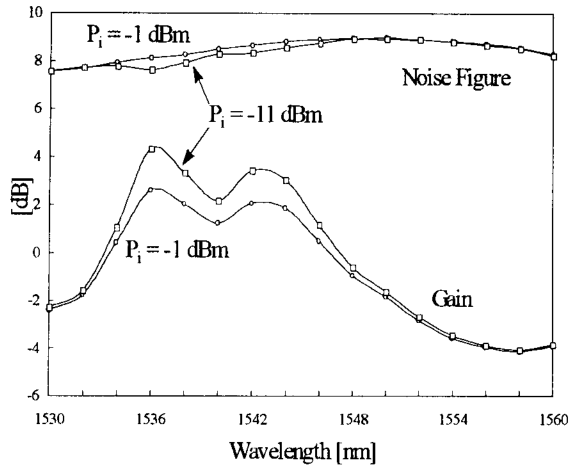

Figure 3. Measured gain and noise figure of the 1x2 LIAS for one of the splitting arms.

source and a 978 nm grating-stabilized 115 mW co-propagating semiconductor pump laser were used. Figure 3 shows the measured gain and noise figure of the 1x2 LIAS (including the 0.98/1.5 μm WDMs) versus wavelength for two levels of input signal power. As the figure shows, lossless splitting with an 8dB noise figure was achieved over the 1535-1547 nm wavelength range even for relatively high input signal power levels. The measured ASE-slope as shown in Figure 4 is not yet within the specified -0.4 up to 0.16 dB/nm range [2] which is equivalent to a CSO of-70 dBc. However, for externally modulated AM-CATV systems, without laser chirp, this specification is not relevant.

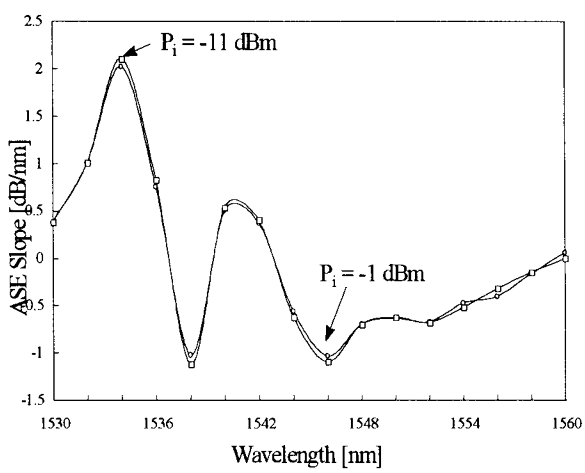

Figure 4. Measured ASE-slope for one of the splitting arms.

4. AM-CATV system measurements

To assess its impact on proper operation of an AM-CATV system, the LIAS was tested in the set-up shown in Figure 5. Both External Modulation (EM) at 1537 nm and Direct Modulation (DM) at 1556 nm were applied. In the EM case the power of the 1537 nm CW laser is impressed with 37 unmodulated carriers according to the German BK450 frequency plan with 5% Optical Modulation Index (OMI) per carrier. The signal is boosted up to 13.8 dBm before it is launched into a 6.6 km long standard single-mode fiber. After this fiber section an attenuator is used to simulate the power-splitting in an access network. In the DM case, the 1556 nm linear laser, with a chirp of

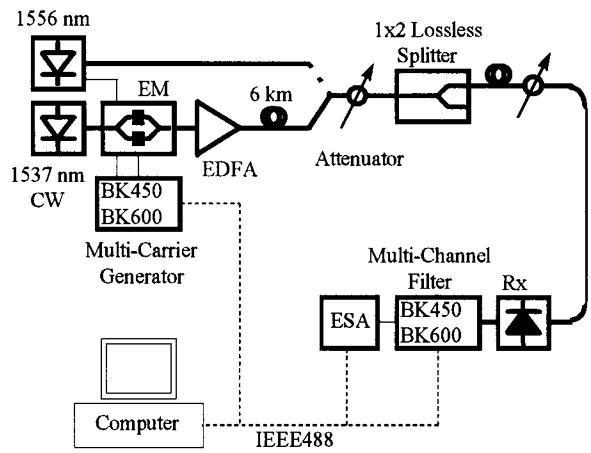

Figure 5. AM-CATV measurement set-up.

100 MHz/mA, is modulated with 50 unmodulated carriers each with 5% OMI according to the German BK600 frequency allocation. The 6 dBm output power of the laser is directly launched into the first attenuator to avoid the fiber-dispersion induced CSO penalty, and thus make the LIAS CSO penalty directly measurable. With this attenuator the input power to the second stage 1x2 lossless splitting is set to -3 dBm. With another attenuator after the 1x2 splitter the input power to the linear receiver is maintained at -3 dBm for the measurements with and without the device. The measured CNR, Composite Second Order (CSO) and Composite Triple Beat (CTB) distortion values are given in Table 1 for the system with and without the 1x2 LIAS. Within the measurement accuracy

no CSO and CTB degradation has been observed when the LIAS is added to the system. Insertion of the LIAS doubled the split count of the system and increased the power budget by 2 dB at 1537 nm. At 1556 nm the LIAS is not lossless; however, this experiment shows that besides gain-slope, which is acceptable at this wavelength, there are no other fundamental problems, e.g. reflections and PDL, in using a LIAS in a directly modulated system within the lossless wavelength range. The extra noise added by the LIAS explains the lower system CNR values in both experiments when it is included in the system. The lower basic CNR in the externally modulated system is caused by a higher source RIN and the noise of the boosting EDFA.

Table 1. AM-CATV system measurement results for External - (EM) and Direct Modulation (DM).

	EM	EM + LIAS	DM	DM + LIAS
CNR [dB]	46	45	51	49
CSO [dBc]	-62	-61	-61	-60
CTB [dBc]	-62	-61	-70	-70

5. Conclusion

We have demonstrated the first use of an ion-exchanged, planar lossless splitter in two AM-CATV systems at 1.5 μm. The 1x2 device achieved lossless splitting with an 8 dB noise figure over the wavelength range of 1535-1547 nm when pumped with 115 mW from a 978 nm laser diode. Although the present device does not fully meet all our target specifications [1,2], it is expected that improvements in the Er:Yb concentration ratio, the use of substrates containing separate active and passive regions made by fusing doped and undoped glasses and some extra filtering will lead to 1x8 lossless splitters with good noise figures and low gain-slopes, which would be ideal for AM-CATV applications. These results demonstrate that ion-exchange technology is a strong contender to yield active planar components for fiber-coax access networks

6. Acknowledgements

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