are simultaneously obtained: reduced cost (short fabrication time, high reproducibility and low power consumption during operation); compactness; stability; speed (operation at least at 40 Gb/s); use simplicity (by avoiding the differential mode and by limiting the tunable SOA number); tolerance to input signal fluctuations (high input power dynamic range (IPDR) and low polarization dependence); quality of the output signal. The hybridization concept as used for PLC (planar lightwave circuit) is particularly attractive due to its capability to integrate different functions on the same platform, and so to achieve very compact sub-systems. Up to now, such a SOA-MZI [13] has shown 10 Gb/s low consuming wavelength conversion and 40Gb/s wavelength conversion in differential mode [14]. Anyway, it requires a quite complicated technological process whose risk increases with the number of functions to be integrated. In opposition, monolithically integrated all-active devices are fabricated with the simple and reproducible technological process of the standard SOA [17]. Thanks to the input signal SOA's, an IPDR higher than 15 dB [17] has been shown at 10 Gb/s and good performance at 40 Gb/s in differential mode [18]. Anyway the price of the technological simplicity is the use complexity due to the differential mode and to the tuning of at least two "not functional" input SOA's. Up to now, monolithically integrated active-passive devices with a butt-joint based technology have been also extensively fabricated, following different schemes (butt-joint with buried passive waveguide [15], butt-joint with deep ridge passive waveguides [16]), with up to 40 Gb/s wavelength conversion, exclusively in differential mode [15]. Anyway, the fabrication of butt-joint based devices is a long and difficult process including at least three epitaxial steps [16] with finally similar performance as the all-active device.

For these reasons, a new active-passive device has been recently fabricated, associating the realization simplicity and the high IPDR of the all-active one, with the active-passive device operation simplicity added to the standard mode operation simplicity at 40 Gb/s: thanks to an evanescent coupling between the active and the passive waveguides, the 4-SOA's MZI (Figure 2) has been realized with the single SOA technology. A long and highly confined conversion SOA design has been chosen to shorten the response time and achieve 40 Gb/s standard mode operation on the C-band [19]: a low penalty and floor free BER has been simultaneously measured on the 4 tributaries (obtained after demultiplexing), as well as an 8dB IPDR by controlling the input SOA current. This device belongs at the same time to a new component generation, flexible and modular, and to a mature technology, simple and reproducible. It is particularly promising for high bit rate future all-optical 3R regenerators.

4. Conclusion

Among SOA based devices for optical processing, XPM based interferometers are particularly attractive due to their functionality on one hand and their regenerative properties on the other hand. Different technological approaches have been presented to evaluate their suitability for insertion in system: while the hybrid integration presents the main advantage to allow integration of diversified functions for subsystem implementation, monolithically integrated active-passive evanescent coupling SOA-MZI assembles the interests of the technology simplicity and maturity, the design modularity and the use simplicity including standard mode 40 Gb/s operation.

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ThX2 **2:30 PM**

160Gb/s to 10Gb/s OTDM Demultiplexing Using a Traveling-wave Electroabsorption Modulator

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We demonstrate for the first time direct 160Gb/s to 10Gb/s demultiplexing using one electrically-gated electroabsoprtion modulator. No indication of an error floor was observed. The power penalty for the worst channel is less than 1.5dB.

1. Introduction

Demultiplexing is one of the most essential issues in realizing optical time division multiplexing (OTDM). While fiber-based technology has been demonstrated up to 640Gb/s [1], semiconductor-based technology is more attractive due to its compactness, efficiency, and integration possibility. At 160Gb/s, several approaches have been reported using GT-UNI [2], SOA-MZI [3-4], or PD-EAM [5]. One problem is the fact that error floors are commonly present and a second problem is that these demultiplexing schemes require high quality optical pulses as the gate signal, which increases the complexity and the cost. An alternative approach is to use electrically gated electroabsorption modulators (EAMs). For 160Gb/s to 10Gb/s demultiplexing, the gating window should be less than 6ps at a 10GHz repetition rate. This is a quite stringent requirement, and so the reported demonstrations [6-7] all drive the EAM at 40GHz to get a short enough gating window. An extra stage of either optical [6] or electrical [7] demultiplexing is required to demultiplex the data down to 10Gb/s. We have recently demonstrated 80Gb/s to 10 Gbit/s demultiplexing using a standing-wave enhanced EAM [8]. In this work, we extend the bit rate up to 160Gb/s using a traveling-wave EAM (TW-EAM) driven by two microwave tones.

2. Device Characteristics

The TW-EAM used in this work as a high-speed optical demultiplexer has traveling-wave electrodes that can extend the active device length without sacrificing the bandwidth. A longer device length favors higher extinction ratio, higher saturation power and lower driving voltage. The active region of our TW-EAM consists of 10 tensile-strain wells (InGaAsP, 0.35%, 120nm) and 11 compressive-strain barriers (InGaAsP, 0.57%, 70nm). The active device length is 300 μm. For the TM polarization, the modulation efficiency can be as high as 30dB/V in the 0 to 1V reverse bias region and the total static extinction ratio can be over 50dB [9]. The traveling-wave operation of the TW-EAM was demonstrated with a 40GHz optical pulse genera-

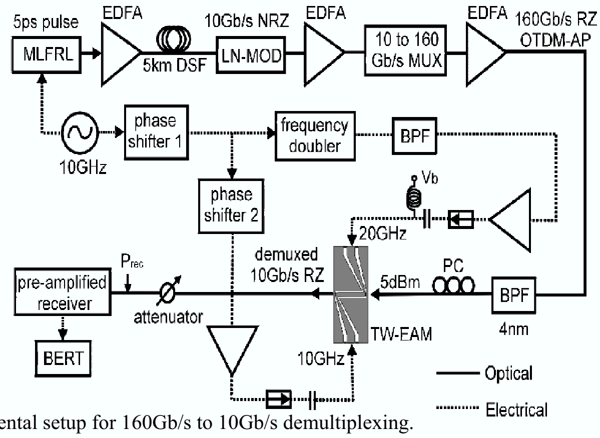

Fig. 1: Experimental setup for 160Gb/s to 10Gb/s demultiplexing.

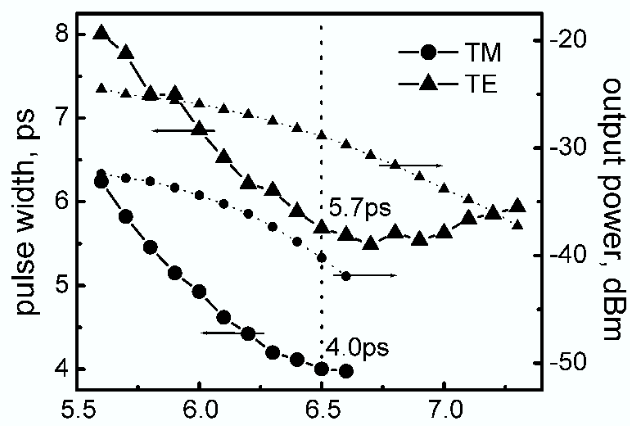

Fig. 2: Pulse width and output power of 10GHz pulses generated using TW-EAM driven by two microwave tones.

tion experiment and confirmed with a theoretical model [10].

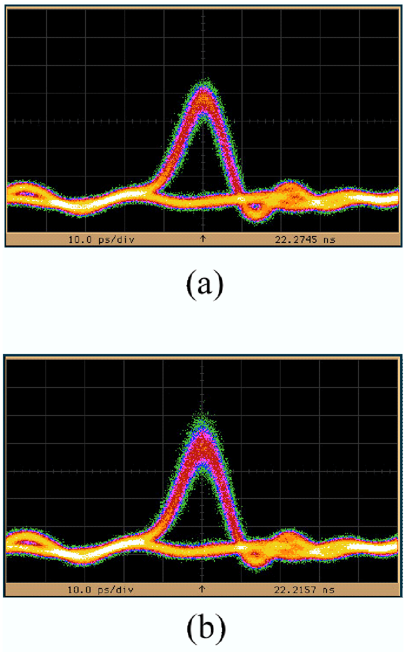

Fig. 3: 10Gb/s eye diagrams (a) back to back; (b) demultiplexed from 160Gb/s

3. Demultiplexing Experiment

To generate a short enough gating window for 160Gb/s to 10Gb/s demultiplexing, the TW-EAM is driven by two microwave tones, 10GHz (24.6dBm) and 20GHz (23.4dBm), respectively from the two ends of the traveling-wave electrodes, as shown in Fig. 1. This is a unique configuration for the TW-EAM where the microwave loss that might occur if the two tones were combined with a coupler can be eliminated. Two electrical isolators are used to protect the amplifiers, though it is not absolutely necessary depending on the design of the amplifiers. When the relative phase between the two tones is adjusted properly, the combined microwave driving signal becomes "pulse-like" with a repetition rate of 10GHz. The microwave swing around the pulse peak can be faster than that of the 10GHz sinusoidal wave and hence shortens the gating window. The side effect is that the peak-to-peak microwave swing will be reduced which might degrade the dynamic extinction ratio. However, since our TW-EAM has a very high modulation efficiency, deterioration in performance was not observed. Fig. 2 shows the 10GHz optical pulse generation results with 2dBm CW input at 1555nm. From this figure, the bias voltage of the TW-EAM for the 160Gb/s demultiplexing is chosen to be 6.5V with a pulse width of 5.7ps for the TE polarization and 4.0ps for the TM polarization. At this bias, the output power of the TM polarization is more than 10dB lower than that of the TE polarization. Therefore, the TE polarization is adopted to ensure the signal to noise ratio even though the gating widow is much shorter for the TM polarization.

As shown in Fig. 1, 10GHz, 5ps optical pulses at 1555nm are generated from a mode-locked fiber ring laser. These pulses are boosted by an EDFA and then sent into 5km of dispersion-shifted fiber for nonlinear pulse compression. The pulse width after compression is around 2ps. The 10GHz pulse train is modulated with 2^{31}-1 PRBS using a $LiNbO_3$ modulator and then optically multiplexed to 160Gb/s with passive delay lines and couplers. Note that the 160Gb/s RZ signal is multiplexed with alternating polarization since single polarization multiplexing will lead to the closure of the demultiplexed 10Gb/s eye and an error-free operation was not possible. This can be attributed to the relatively long tails of the compressed pulse and the fact that the gating window of the TE polarization is only 5.7ps so that inter symbol interference occurs. Phase shifter 1 is used to synchronize the gating window with the channel to be demultiplexed while phase shifter 2 is used to adjust the relative phase between the 10GHz and the 20GHz driving signals.

Fig. 3 shows both the 10Gb/s back-to-back and the demultiplexed eye diagrams. Although the demultiplexed eye is a little bit noisier than the back-to-back eye, it is still clear and open. The bit error rate curves and the receiver sensitivities for the 16 channels are shown in Fig. 4. It is evident from this figure that no indication of an error floor is observed. Note that the slope of the demultiplexed curve is almost the same as that of the back-to-back curve. The power penalty of the 16 channels is quite low and varies from 0.7dB to 1.4dB. This variation is attributed to the imperfection of the optical multiplexer which is in part limited by the resolution of our sampling equipment. These results demonstrate that the TW-EAM can be a compact and high-performance optical demultiplexier up to 160Gb/s.

4. Conclusion

Direct 160Gb/s to 10Gb/s OTDM demultiplexing using one electrically gated TW-EAM is reported for the first time with low power penalty and no error floor. The presented scheme is significantly more compact than other approaches where multiple stages or very short optical gating pulses are required. We believe that the current limitation of alternating polarization multiplexing can be removed if the quality of the transmitter pulse can be improved.

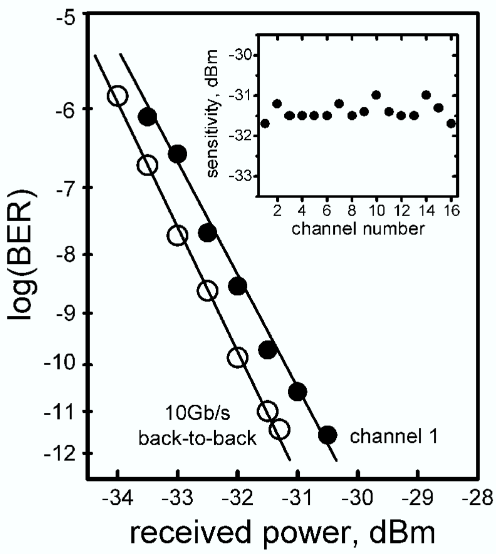

Fig. 4: BER curves and receiver sensitivities for 160Gb/s to 10Gb/s demultiplexing

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ThX3 2:45 PM

Operation Margin of All-Optical Regenerator at 40-Gbit/s by SOA-Based Polarization Discriminated Switch

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We have experimentally investigated the operation margin of all-optical regenerator by SOA-based polarization discriminated switch at 40 Gbit/s. The tolerances against power variance and timing deviation of the input data signals were evaluated in detail.

1. Introduction

All-optical signal processing, such as a wavelength conversion, optical regeneration functions (re-amplification, re-shaping and re-timing) and optical demultiplexing, will be an essential technologies that can provide flexibility and scalability in future all-photonic network. To realize these functions efficiently, all-optical switches employing a semiconductor optical amplifier (SOA) in an interferometer, such as an SOA-Mach Zehnder interferometer (MZI) [1-3], an SOA-delayed interferometer [4] and an SOA-one-arm MZI which is so called "ultrafast nonlinear interferometer (UNI)" [5-8], have been extensively investigated at the bit rate of 40 Gbit/s or higher. Since UNI employing one SOA has a structural simplicity that intrinsically assures good balance in both gain and phase in the one-arm MZI, it is easy to be tuned at the optimized condition and to stabilize the regeneration performance. Although the development during these ten years has born a lot of variations of all-optical regenerators and has verified their potential high bit-rate operability, there exists another hurdle to be passed before employing them in practical use. In the real transmission line in the fields, various kinds of impairment factors, such as ASE noise from concatenated EDFAs, chromatic dispersion, polarization mode dispersion (PMD) and nonlin-