Novel Concept for Polarization Splitting in InP Platforms

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ABSTRACT

A novel concept for the monolithic integration of a polarization beam splitter (PBS) on InP platforms is presented. The device is utilizing a waveguide integrated 1x2 power splitter, a variable optical attenuator (VOA) and a semiconductor optical amplifier (SOA) both based on multiple-quantum wells (MQWs). The separation of TE- and TM- polarized light is resulting from the power splitter and the different absorption and amplification coefficients in MQW-VOA and MQW-SOA. By engineering the power-splitting ratio and the MQW structure a high polarization extension ratio (PER) of above 20 dB for both polarizations over more than 40 nm optical bandwidth can be achieved.

Keywords: PBS, InP integration, VOA, SOA, polarization multiplexing, polarization diversity, photodetector

1. INTRODUCTION

Polarization control is a key element for today's polarization multiplexed optical networks and interferometric sensor systems. For the implementation of polarization demultiplexing at the receiver, a polarization beam splitter (PBS) and optionally a polarization rotator are needed. One option to implement the polarization demultiplexing stage is based on discrete polarization components, usually implemented in free-space optics [1]. The other approach is based on monolithically integrating the polarization components together with the receiver in a photonic integrated circuit (PIC) [2-3]. Monolithic InP-based PICs offer compelling solutions for large scale photonic integration, while also providing the same inherent scalability that has benefited Si-based integrated electronics. For monolithic integration, challenges are associated with active/passive integration, optical isolation and on-chip polarization handling [3]. The current designs of the PBS can be categorized into two types, mainly mode coupling and mode evolution. The mode-coupling-based PBS [4-6], utilizing the mode beating behaviour determined by device geometry and operating wavelength, is inherently fabrication sensitive and wavelength dependent, while also often an active element (e.g. thermal tuning heater) needs to overcome the fabrication mismatches. The mode-evolution-based PBS has a relatively long device length, required to achieve adiabatic transition [7]. Recently, a new concept for polarization divers detection has been proposed in [8] by making use of the properties of MQWs to detect TE and TM polarized light separately. Although a much smaller footprint proposed by this design, the speed of MQW-PD is mainly limited by the transit time in the MQW structures.

In this work, a novel design for polarization splitting is proposed. The polarization splitting with high PER can be achieved by utilizing separately absorbed/amplified signals in MQW-VOA/SOA. Since the MQW-SOA/VOA sections can be integrated together with lasers by using the same epitaxy layers, no extra regrowth step is needed for integration of the proposed PBS. This device has several interesting features for monolithic InP-integrations, offering the polarization diverse detection not only for telecommunications applications e.g. polarization diverse coherent receivers [2-4], but also for sensing and imaging applications, such as optical coherence tomography (OCT) imaging and interferometric sensing [9, 10].

2. DESIGN AND DISCUSSION

Figure 1 shows the schematic structure of the proposed device. The input signals, consisting of a mixed TE- and TM- polarized signal, are split into two arms depend on the design application by less than 50%. The splitter can be realized by using an optical element such as a directional coupler or a multi-mode interference coupler.

The signal in the upper arm passes through a monolithically integrated VOA. The TE polarized signal is absorbed by the VOA while the TM passes through the VOA and therefore will remain in the arm having low-loss. These losses are mainly due to the joints of the different epitaxial stacks. The loss for TM-polarized signal is expected to be less than 2.5 dB. By improving the butt-joint technology a total loss of less than 2 dB is achievable for the TM signal. The PER for the TM signal in this arm can be engineered by choosing an appropriate design of the MQW-VOA. A PER above 20 dB for above 40 nm optical bandwidth can be achieved. Figure 2 (left) shows the polarization dependent loss (PDL) measured for a VOA integrated with a high-speed PD while the PDL measured for the PD is <0.5 dB [11]. As shown in Fig. 1, the other part of the incoming signals (e.g. 10%) will be coupled into the lower arm. The TE-polarized signal will be amplified in the SOA while the TM signal passes through the SOA having approx. the same loss as the TM signal in the upper arm. In this arm a weaker TM signal helps to achieve a higher PER. Therefore, the higher PER for the TE signal can be enhanced by engineering the coupling ratio of the power splitter and the net gain in the SOA. Figure 2 (right) shows an example for the net gain of the MQW-SOA integrated with a high speed PD. The TE signal can be amplified for more than 20 dB, including the coupling loss in the joint section, over an optical bandwidth of 40 nm in this arm.

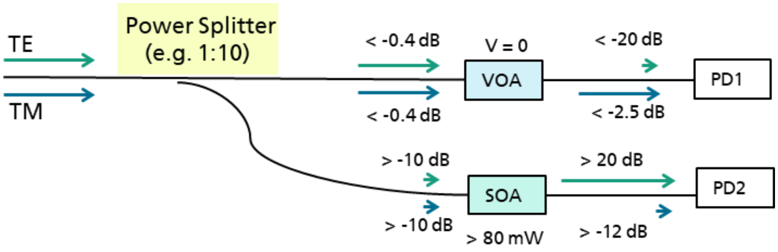


Figure 1.Proposed PBS based SOA and VOA integration with polarization independent PDs and estimated power penalties and PER in each arms for both polarization-states

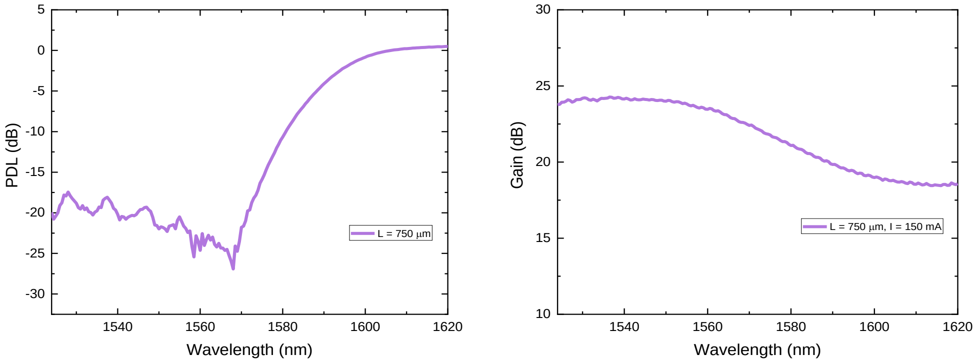
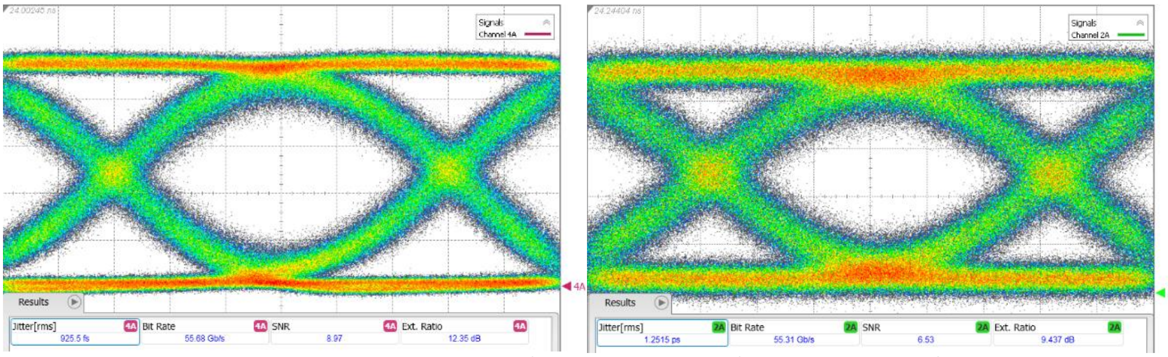


Figure 2. PDL measurement (left) of the integrated VOA, gain spectrum (right) of the integrated SOA using -15 dBm input signals; with the high-speed PD measured at room temperature.

The optimized power consumption of the MQW-SOA should be taken into account to achieve higher PER. According to Fig. 1, a weaker signal in the lower arm would be desired to achieve a higher PER for both polarizations as well as a lower insertion loss at the upper port. Therefore, the pre-amplified signal quality using SOAs integrated with high-speed PDs was investigated, especially if the detected data signal shows bit pattern effects. The results are derived from pseudorandom binary sequence (PRBS) measurements. Fig. 3 (left) shows the generated optical 56GBd NRZ signal with a pattern length of 2^{31}-1 detected by the optical input of a Keysight sampling oscilloscope. The measurement result of a photodetector chip without integrated SOA is presented in Fig.2 (right). For detecting the electrical signal of the photodetector chip, a RF probe head with a bias-T and the electrical input of the sampling oscilloscope with 70 GHz bandwidth was used. For the measurement, a SHF electrical pattern generator feeding an optical modulator with TE-polarized light at 1550 nm is used [12]. The generated optical 56 GBd NRZ signal with a pattern length of 2^{31}-1 was detected by the optical input of a Keysight sampling oscilloscope. In Fig. 2 (right) the signal quality is slightly worse for the photodetector chip even for high optical input powers, because of discrete RF components needed to connect the photodetector chip to the oscilloscope. Measurement results of a photodetector chip with a monolithically integrated SOA are presented in Fig. 4. The eye diagrams do not show any degradation due to bit pattern effects and the detected signal quality is the same as for a photodetector without SOA. Since the resonance frequency of the SOA is in the range of 1 GHz, it becomes clear that for a 56 GBd PRBS signal with a 2^{31}-1 pattern length, no bit pattern effects can be observed for the photodetector chip with monolithically integrated SOA. The measurement confirms, if the SOA is driven below its saturated regime, the patterning effects even above 56 GBds due to carrier fluctuations are expected to be small [12]. Therefore, the presented PBS scheme only shows no pattern effects for data signals with high symbol rates above the carrier lifetime frequency of the SOA gain material or below the carrier lifetime frequency.



Jitter[rms] 4A: 925.5 fs
Bit Rate 4A: 55.68 Gb/s
SNR 4A: 8.97
Ext. Ratio 4A: 12.35 dB

Jitter[rms] 2A: 1.2515 ps
Bit Rate 2A: 55.31 Gb/s
SNR 2A: 6.53
Ext. Ratio 2A: 9.437 dB

Figure 3. MZM generated 56 GBd NRZ optical signal used for the measurement (left); 56 GBd RF signal from a waveguide integrated photodetector without SOA for 0 dBm optical input power (right)

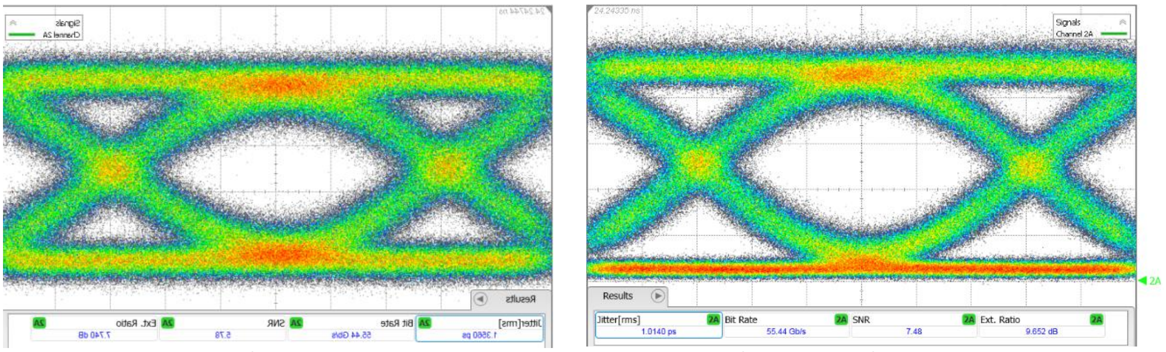


Figure 4. 56 GBd RF signal from a photodetector with monolithically integrated SOA for -15 dBm (left) and 0 dBm (right) optical input power

3. CONCLUSIONS

We presented a new PBS design based on the monolithic integration in InP technology. This device proposes a new polarization diversity network using the property of MQW-VOA and MQW-SOA. The separation of TE- and TM- polarized light is resulting from the 1x2 power splitter and the different absorption and amplification coefficients in MQW-VOA and MQW-SOA. By further improving the MQW structure and power-splitting ratio, a high PER for both polarization above 20 dB and 40 nm of optical bandwidth with an insertion loss of less than 2 dB can be achieved. The presented PBS can be integrated together with the lasers and uses the same epitaxy layer stack. Therefore, no extra regrowth step is needed. The concept offers a key component for next generation telecommunication devices and photonic sensors.

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