Polarization-Independent Photodetector with Integrated Optical Preamplifier and 60 GHz 3 dB Bandwidth

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Abstract: An InP-based photodetector monolithically integrated with a semiconductor optical amplifier is presented. The chip operates in the O-band and is polarization-independent. Eye pattern measurements at 56 GBaud confirm the lower detection limit of signals with -13 dB optical power compared to a photodetector without preamplification.

1. Introduction

High-speed short-reach optical interconnects are necessary to meet the ever-increasing capacity demand in data centers. The ITU-T G.9806 recommendation for higher speed optical access systems advises the use of O-band transmission schemes to mitigate dispersion effects [1]. Amplification at the receiver side increases the receiver sensitivity and therefore allows for reduced power consumption at the transmitter side while remaining the link power budget [2, 3]. Operating the laser at lower power levels results in an overall reduced power consumption for the entire optical interconnect.

Currently, avalanche photodiodes (APDs) amplify the signal inside the photodiode for short reach transmission links with slower symbol rates. The figure of merit of APDs is the external responsivity-gain-bandwidth product (eRGBP), being the gain-bandwidth product (GBP) multiplied with the external responsivity [4]. A worldwide overview indicates that APDs are limited by their GBP to 56 GBaud [4]. Contrary to APDs, signal amplification with a semiconductor optical amplifier (SOA) does not reduce the detection bandwidth [2]. Discrete SOAs, however, can result in bulky receivers [2]. In InP, monolithic integration of an SOA and the photodiode [5] is possible, allowing for smaller packages. In [6] an InP monolithic SOA-UTC with O-band operation was demonstrated. The polarization dependent loss (PDL), however, was approx. 5 dB, and the bandwidth was only 33 GHz.

We demonstrate an InP-based SOA-PD with < 1 dB PDL and 60 GHz bandwidth, thus overcoming the drawbacks of the implementation in [6] and enabling 56 GBaud direct detection for intra datacenter communication.

2. Design and Fabrication

The PIC consists of a fiber matched spot size converter (SSC), an aluminum-based tensile strained multiple quantum well (MQW) SOA and a high-speed photodetector (Fig. 1). The chips have been fabricated on a 3-inch InP wafer. Semi-insulating InGaAsP/InP waveguide layers and the doped SOA and detector layers are grown by a two-step MOVPE process with selective area regrowth. The wafers were fabricated using standard photolithography, dry (RIE and ICP) and wet etching techniques. Photoresist and SiNx served as etching masks. The waveguide integrated SOA comprises an MQW layer stack and heterostructure contact layers in order to reduce the contact resistance for low power consumption. The waveguide integrated pin-photodiode comprises an InGaAs absorption layer and heterostructure contact layers in order to allow high responsivities and high bandwidths and operation in the O-band as in [7]. The optical facet of the chips is AR coated to reduce insertion loss and to avoid back reflections into the transmission link.

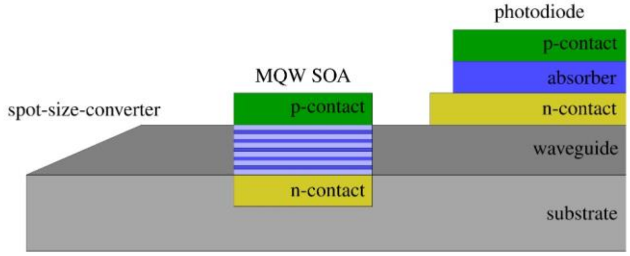


Fig. 1. Cross-sectional view of the monolithically integrated SOA-PD chip

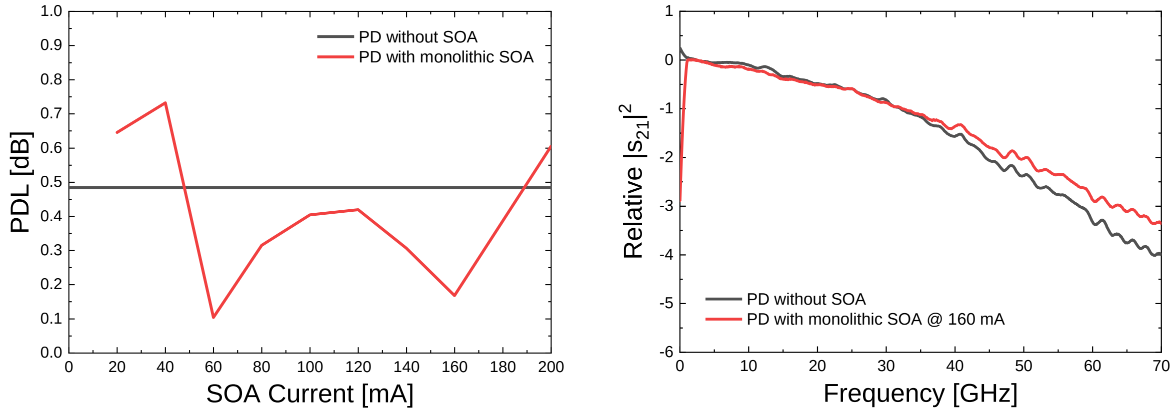


Fig. 2. Polarization-dependent loss at a wavelength of 1320 nm (left) and RF response of the photodetector with and without SOA (right)

3. Measurement Setup and Results

The SOA-PD is investigated in the O-Band and compared with a conventional PD from the same wafer. The photodetector has an external responsivity of 0.57 A/W and a polarization-dependent-loss below 1 dB at 1320 nm (Fig. 2 left). The SOA-PD has an external responsivity-gain of 24 A/W and also a polarization-dependent-loss below 1 dB at 1320 nm, being stable below 1 dB for currents of 200 mA. The frequency response of the PDs is measured with a vector network analyzer and shown in Fig. 2 right. As expected, the RF responses with and without integrated SOA are similar. The major difference is below 1 GHz and can be attributed to the resonance frequency of the SOA. This may introduce bit-pattern effects, which could not be observed in our eye patterns, though. The current of the SOA is set to 200 mA with a voltage of 1.94 V throughout this manuscript, unless noted otherwise.

A 40 km transmission experiment is performed to investigate the signal quality. The transmitter part of the setup (Fig. 3) consists of a tunable laser source, a 56 GBaud Mach-Zehnder modulator (MZM) and a bit pattern generator. The bit pattern generator generates a non-return-to zero (NRZ) signal, which is modulated onto the light with a wavelength of 1320 nm with the MZM. The generated 56 GBaud NRZ signal is shown in Fig. 4. Although the photodetector has a bandwidth of 60GHz, a modulation with higher order formats or symbol rates was not possible without pre-distortion and post-compensation due to the approx. 35 GHz bandwidth of the MZM. The optical NRZ signal is send through the polarization controller and a variable optical attenuator (VOA), emulating an optical fiber, into the SOA-PD and PD chips. The electrical signals are measured with an RF probe and a sampling oscilloscope. The measurements are performed without pre-distortion or post-compensation by digital signal processing. First, the photodetector without pre-amplification is investigated (Fig. 5 a), where the ROP is reduced to achieve a low SNR of 4. The SOA reduces the necessary ROP by 13 dB while retaining good eye quality (Fig. 5 b).

To analyze the transmission through a real fiber and the polarization dependence, a measurement using a fiber spool with a length of 40 km was carried out. The input polarization state is set with a polarization controller is set to maximum and to minimum photocurrent. The result for the optimum polarization with a photo current of 1.40 mA is shown in Fig. 5 c), while the suboptimal result with a photo current of 1.16 mA is shown in Fig. 5 d). These results underline the low polarization-dependent-loss of below 1 dB of the photodetector PIC with integrated SOA and show that the performance decrease due to suboptimal polarization settings is neglectable.

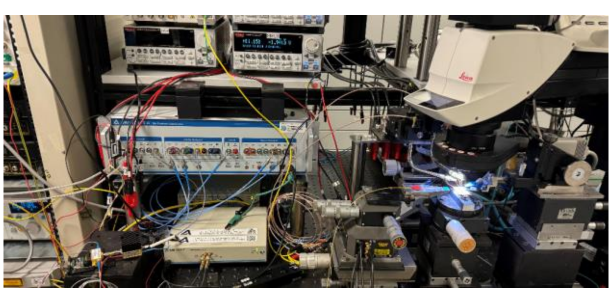


Fig. 3. Photograph of the setup for the eye pattern measurements

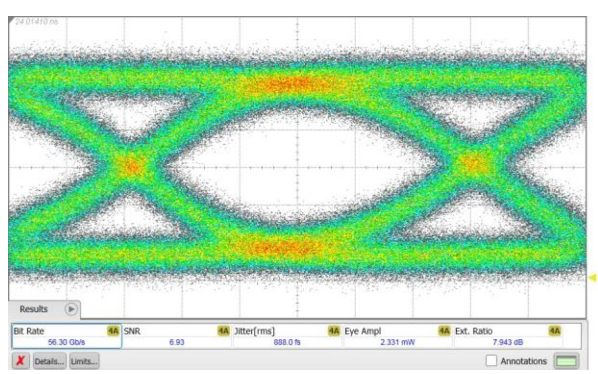


Fig. 4 MZM generated 56 GBaud NRZ signal, measured with an optical sampling oscilloscope

Fig. 5 a) Chip w/o preamplifier, polarization adjusted for maximum photocurrent, ROP (– 4 dBm) adjusted to low SNR of 4

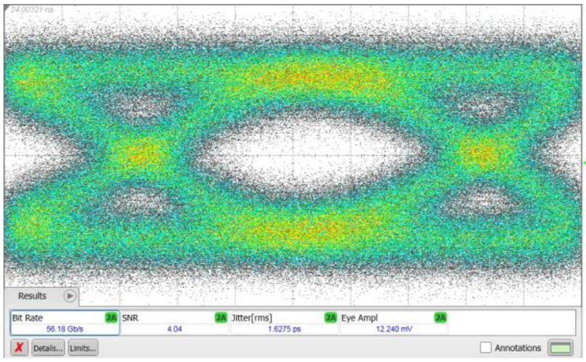


Fig. 5 b) Chip with preamplifier, polarization adjusted for maximum photocurrent, ROP (– 17 dBm) adjusted to low SNR of 4

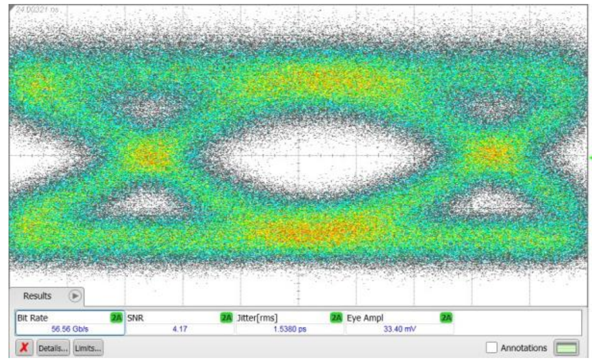


Fig. 5 c) Same as b), after 40 km, no adjustments to ROP of -15 dBm

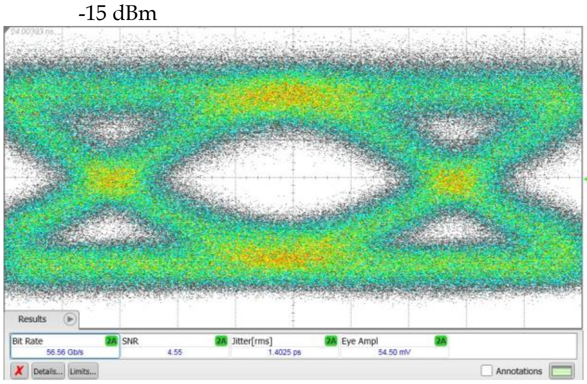
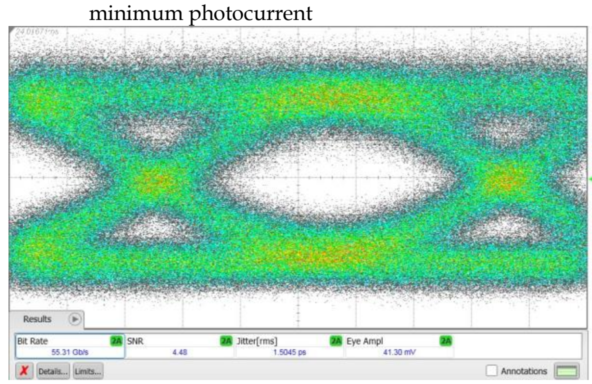


Fig. 5 d) Same as c), but with polarization adjusted for minimum photocurrent



4. Conclusion

An O-band photodetector with integrated semiconductor optical amplifier is presented. The polarization dependent loss is below 1 dB, and the 3 dB RF bandwidth is 60 GHz. The optical preamplifier reduces the required optical power by ~13 dB at 56 GBaud. Transmission through 40 km of fiber without pre-distortion or post-compensation does not lead to eye quality degradation.

The chip is a next step towards high-speed receiver architectures of intra-datacenter interconnects. We expect that the data rate for the presented photodetector chip can be extended up to 128 GBaud PAM-4, if a better modulator is used.

References

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