Asia Communications and Photonics Conference 2021 © Optica Publishing Group 2021

Design of an O-Band Polarization Insensitive SOAs on IMOS for High-Performance Optical Switches

Desalegn Wolde Feyisa, Yuqing Jiao, Zhaowei Chen, Nicola Calabretta, Ripalta Stabile
Institute for Photonic Integration, Eindhoven University of Technology, PO Box 513, 5600MB,
Eindhoven, The Netherlands
d.w.feyisa@tue.nl

Abstract: We report the design of a polarization-insensitive SOA in IMOS-platform with worst-case polarization sensitivity of 0.8 dB over 60 nm bandwidth and 26 dB input power range. 500 μm-long SOA provides 21 dB peak gain.

1. Introduction

All-optical switches will be a crucial technology to consistently increase the capacity of optical communications in data centers to cope with the requirement set by steady traffic growth. High-performance, low-cost, and scalable semiconductor optical amplifier (SOA) based switches are suitable for high-bandwidth and low-latency applications. In SOA-based switches, the polarization sensitivity of SOAs due to geometry asymmetry has always been one of the main problems. These require additional polarization handling circuitry off-chip causing operational complexity or polarization diversity scheme on the chip, which increases the circuit complexity [1]. In multi-quantum well (MQW) SOA, in addition to the geometry-induced confinement factor difference, the asymmetry in TE-like and TM-like field material gain leads to considerable polarization sensitivity variation with current and wavelength [2]. Therefore, achieving good polarization insensitivity over a wide input power range, wide bandwidth and ranges of driving current have always been challenging. Polarization-insensitive (PI) SOA has already been demonstrated using strained MQW [3], thick active layer bulk [4,5], and strained active bulk layer [6]. The thick bulk-active layer approach makes the confinement factor similar for both polarizations. However, thick bulk active SOAs may need a high driving current and 3 dB gain bandwidth, and output saturation power may decrease with increasing thickness. A strained bulk active layer can provide good polarization insensitivity, wide gain bandwidth, and high-output saturation power required at low driving current meeting requirements for switch applications.

The indium phosphide membrane on silicon (IMOS) platform has already demonstrated low-loss and compact passives thanks to the index contrast of the membrane platform [7]. High-performance MQW C-band polarization-dependent SOAs have already been demonstrated on this platform. Hence, investigating PI-SOA in the membrane platform is motivated to Utilize these positive features of the platform and design components for high-performance and compact optical switches in the platform. We specifically target O-band SOA design for an optical switch in intra-data center communication.

In this work, we present an O-band PI-SOA design suitable for optical switching applications on the IMOS platform for the first time. We use a strained, thin, bulk-active layer to achieve polarization insensitivity. We investigate polarization sensitivity variation as a function of the wavelength, input power and current density. Finally, we anticipate the peak gain of the designed SOA and the gain bandwidth.

2. Polarization insensitive SOA (PI-SOA) design

The general requirement for an SOA-based switch is scalability, good signal integrity, high bandwidth and lossless operation. These switch metrics are interrelated and are mainly affected by the performance of the SOA used in the switch. Therefore, achieving good performance in all these metrics requires SOAs to have high input power dynamic range and output saturation power, sufficient gain, wide 3 dB gain bandwidth and low noise figure. The SOA design in this work addresses these requirements.

We used tools from PhotonDesign (Harold and PICWAVE) to model PI-SOA. Fig. 1a shows the cross-sectional view of the SOA structure. We add a tensile strain of 0.18% in the thin bulk active layer (red area in fig. 1a) to increase material gain for the TM field and balance the confinement factor difference caused by geometry asymmetry. We chose a quaternary material (InGaAsP) with a bulk emission wavelength of 1.05 μm (Q1.05) for the separate confinement heterostructure (SCH) to provide sufficient barrier height to provide enough confinement. This provides an adequate conduction band and valence band offsets to confine electrons in conduction and holes in the valence band for better device efficiency. The choice of the SCH dimensions facilitates polarization insensitivity with less strain by influencing the confinement factor. The overall thickness of the active region (core and SCHs) is 300 nm.

The active device is monolithically co-integrated with passive waveguides using the twin-guide approach [8]. In two lateral tapering windows, the active region is laterally tapered to push the field to the waveguide vertically, as shown in Fig. 1 b, c. We optimize the rapid tapering window length, L1=7.2 µm and L2= 25.5 µm, to achieve a coupling efficiency of 90% for TM and 93% for TE. As shown in Fig. 1c, the transition of the TE field from the active region to the waveguide happens before the TM field.

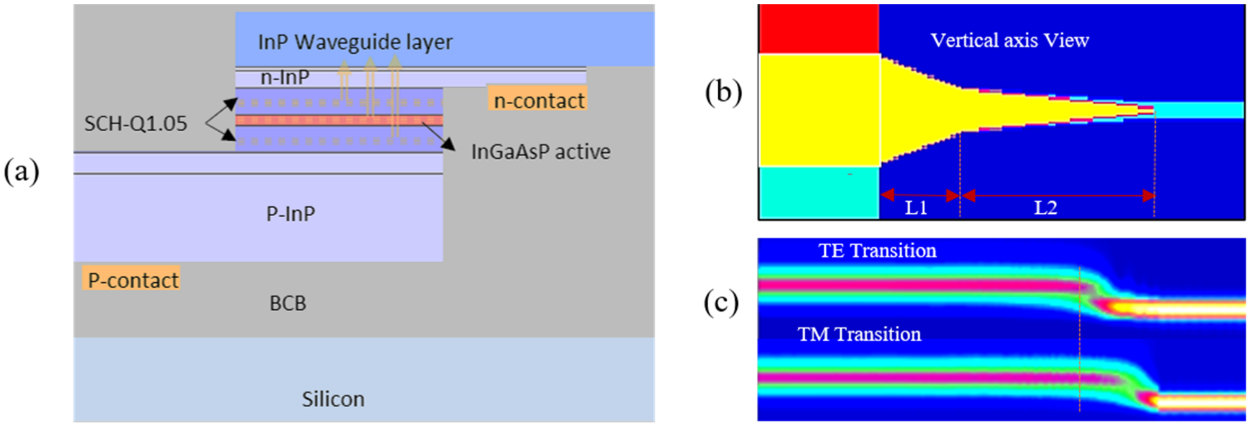

Figure 1a) Device structure full-stack b) Device taper section as seen in the vertical axis c) TE and TM transition from active to passive

2. Polarization sensitivity and gain

The polarization sensitivity is calculated as the absolute value of the difference of TE-like polarization gain (G_{TE}) and TM-like polarization gain (G_{TM}), i.e., $|G_{TE}-G_{TM}|$. Fig.2a plots the polarization sensitivity for input power, from -20 dBm to 6 dBm. We can observe from fig. 2a, the polarization-dependent gain is less than 0.5 dB for the simulated input power range of 26 dB and bias current from 2 kA/cm^2 to 6 kA/cm^2 at the center wavelength λ=1310 nm. The design is optimized at 4 kA/cm^2, and polarization sensitivity is very low near this current density. Polarization sensitivity is slightly higher when we move away from the optimum current. The wobbling in fig. 2a is due to the effect of randomness of noise at low input power and discrete current density step of 2 kA/cm^2 used during the measurement. Polarization sensitivity of less than 0.1 dB is obtained at the optimal driving current points.

Fig. 2b shows polarization sensitivity with varying current density and wavelength with small-signal input power to suppress the input power effect. The design is optimized at 4 kA/cm^2, and the polarization sensitivity is low around this current density. Polarization sensitivity is slightly higher when we move away from the optimal operating point. The worst-case sensitivity of around 0.8 dB is observed for long wavelength and low current or high current and short wavelength. At the optimal design point of wavelength, λ=1310 nm and current, I = 4 kA/cm^2, the polarization sensitivity is around 0.1 dB, as observed from the dark blue areas in fig.2b.

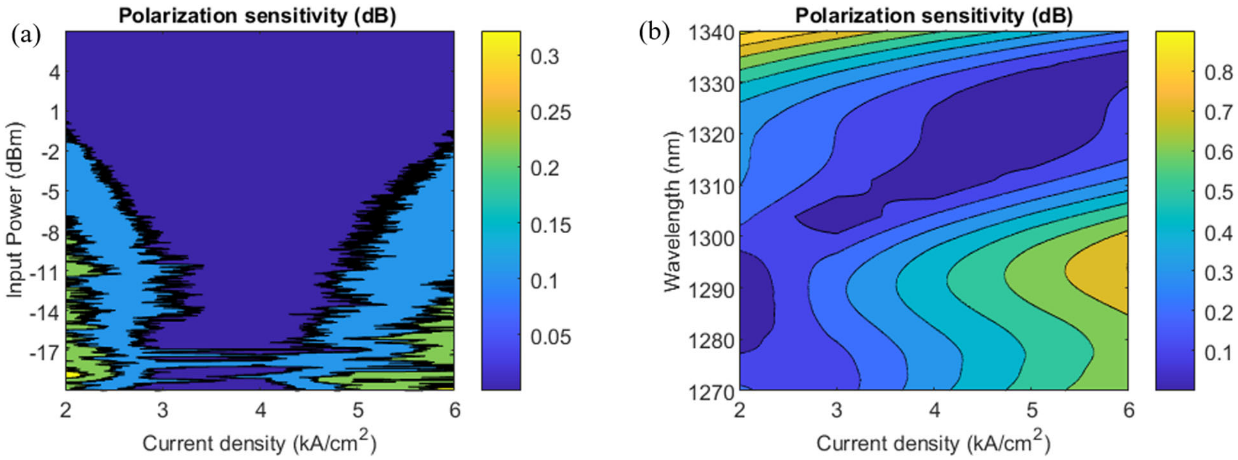

Figure 2 Polarization sensitivity variation. a) With current density and input power at λ=1310 nm. b) With wavelength and driving current.

Fig. 3a shows the gain for SOA length of 300 µm, 400 µm and 500 µm at 6 kA/cm^2 drive current density. With an SOA of 500 µm long, we get an output saturation power of 10 dBm and a linear peak gain of 21 dB. The result for gain shows that we can realize an optical switch with it. For instance, a 16×16 state of the art SOA-based optical switch with 3 SOA cascades in a path has 58 dB path loss in the worst case [9]. If we use the 500 µm long SOA, it can provide around 21 dB gain. Considering a maximum of 1 dB polarization-dependent loss for each SOA, 3 SOAs can provide 60 dB net gain overcoming all on-chip losses.

Finally, the designed SOA has a 3 dB gain bandwidth of around 80 nm at a current density of 4 kA/cm^2 (fig. 3b). Therefore, the SOA can switch the WDM signal, for instance, coming from a CWDM4 transceiver.

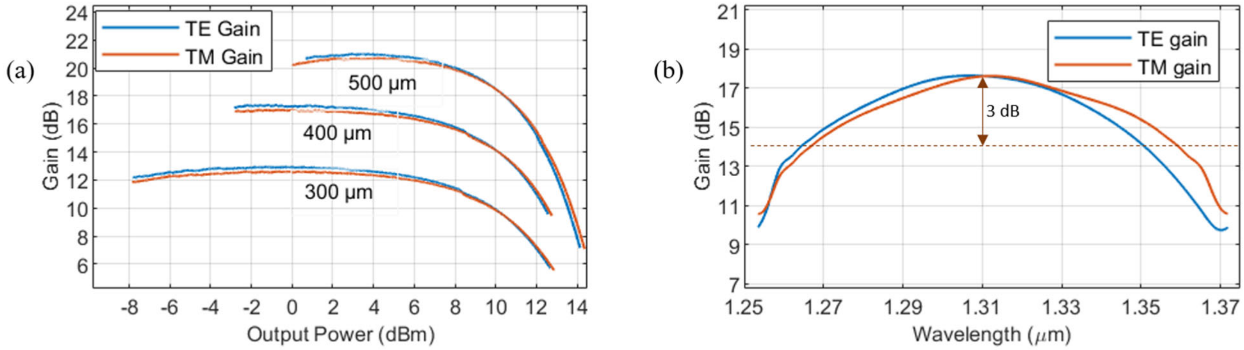

Figure 3 a) Gain versus output power for input power range from -20 dB to 7dB for 300 µm, 400 µm, and 500 µm at 6 kA/cm^2 driving current density. b) Small-signal input gain versus wavelength.

3. Conclusions

We present the design of an O-band polarization-insensitive SOA in the IMOS platform suitable for optical switch applications. The simulation result shows that a 500 µm long device can provide an output peak gain of 21 dB and an output saturation power of around 10 dBm at 6 kA/cm^2 bias current density. The polarization sensitivity shows variation up to 0.5 dB, with varying input power and current density. The effect of current density is also correlated to the varying wavelength ranges. The result shows the worst-case polarization sensitivity is around 0.8 dB, and only 0.1 dB for the best operating condition. The obtained peak gain, output saturation power, polarization sensitivity of gain, and 3 dB gain bandwidth show the suitability of the designed SOA for polarization-insensitive SOA-based optical switch application.

Acknowledgments

This work has been supported by European H2020 ICT TWILIGHT project (contract No. 781471) under the Photonics Public Private Partnership.

3. References

[1] Z. Zhu, X. Li, and Y. Xi, "A Polarization Insensitive Semiconductor Optical Amplifier," IEEE Photonics Technol. Lett., vol. 28, no. 17, pp. 1831–1834, 2016, doi: 10.1109/LPT.2016.2573291.

[2] A. R. Zali, R. Stabile, and N. Calabretta, "Low polarization dependent MQW semiconductor optical amplifier with tensile-strained-barrier design for optical datacom and telecom networks," Int. Conf. Transparent Opt. Networks, vol. 2020-July, pp. 4–7, 2020, doi: 10.1109/ICTON51198.2020.9203186.

[3] L. F. Tiemeijer et al., "Polarization insensitive multiple quantum well laser amplifiers for the 1300 nm window," Appl. Phys. Lett., vol. 62, no. 8, pp. 826–828, 1993, doi: 10.1063/1.108591.

[4] A. R. Zali, R. Stabile, and N. Calabretta, "Design and Analysis of Polarization Insensitive O-Band Bulk SOA for active-passive photonic circuits," CLEO, 2021.

[5] C. Holtmann, P. A. Besse, T. Brenner, and H. Melchior, "Polarization independent bulk active region semiconductor optical amplifiers for 1.3 µm wavelengths," IEEE Photonics Technol. Lett., vol. 8, no. 3, pp. 343–345, 1996, doi: 10.1109/68.481111.

[6] C. Michie, A. E. Kelly, J. McGeough, I. Armstrong, I. Andonovic, and C. Tombling, "Polarization-insensitive SOAs using strained bulk active regions," J. Light. Technol., vol. 24, no. 11, pp. 3920–3927, 2006, doi: 10.1109/JLT.2006.883119.

[7] Y. Jiao et al., "Indium Phosphide Membrane Nanophotonic Integrated Circuits on Silicon," Phys. Status Solidi Appl. Mater. Sci., vol. 217, no. 3, 2020, doi: 10.1002/pssa.201900606.

[8] V. Pogoretskiy, J. van Engelen, J. van der Tol, A. Higuera-Rodriguez, M. Smit, and Y. Jiao, "An integrated SOA-building block for an InP-membrane platform," Opt. InfoBase Conf. Pap., vol. Part F52-I, pp. 4–6, 2017, doi: 10.1364/IPRSN.2017.JW4A.1.

[9] R. Stabile, A. Albores-Mejia, and K. A. Williams, "Monolithic active-passive 16 × 16 optoelectronic switch," Opt. Lett., vol. 37, no. 22, p. 4666, 2012, doi: 10.1364/ol.37.004666.