Low Polarization Sensitive Semiconductor Optical Amplifier Co-Integrated with Passive Waveguides for Optical Datacom and Telecom Networks

Student Paper

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ABSTRACT

For device application in Datacom and Telecom networks, low polarization sensitive (PS) SOAs with easy fabrication process co-integrated with passive photonic circuits are highly essential. In this work, a low polarization sensitive SOA based on a bulk active layer is designed, fabricated and characterized. The results of the present work focus on the investigation of low polarization ridge waveguides with bulk active layer. In the proposed structure, the SOA is integrated with other passive waveguides, therefore exhibiting its potential application to be integrated in a photonic integrated circuit. The low polarization sensitivity of bulk SOA is proven for a wide range of input power (-25 dBm to 10 dBm) and wavelength for network-device applications. Characterizations of an SOA with length of 1.5mm co-integrated with 2.3 and 0.8 mm passive waveguides indicate 17 dB net gain with a polarization dependent gain (PDG) between 0.3dB and 3dB at 1588nm wavelength and 125 mA bias current for different input optical powers.

Keywords: Semiconductor optical amplifiers, low polarization sensitivity, Bulk, and polarization dependent gain.

1. INTRODUCTION

Semiconductor optical amplifiers (SOAs) integrated with passive devices are attractive for optical Datacom and Telecom systems due to their high gain with small footprint and broad bandwidth operation. Polarization insensitive operation of the SOAs is essential in enabling transparent operation in all optical communication networks operating in broadband communication wavelength range. Approaches to achieve polarization insensitive (PI) SOAs have already been demonstrated with strained multi-quantum well (MQW) [1] and strained-bulk buried and ridge waveguide (WG) structures [2-5]. However, the realization of high gain PI MQW SOA has so far required growing technologies where high precision is needed to engineer the energy bands (for a desired wavelength emission band) [1]. Researchers have also realized SOAs based on bulk active layers but with buried waveguide structure [2],[3]. However, here tapering and window regions are required to improve the coupling loss and facet reflectivity [3], making co-integration with integrated passive circuits even harder.

In this paper we report bulk ridge-type PI SOA for 1.55µm wavelength co-integrated with passive waveguides. The designed size of the bulk active region renders them polarization insensitive over large current and wavelength ranges, while relaxing the fabrication process based on simple single-step grown unstrained active layers. This will also improve the SOAs reliability. Experimental results of SOAs co-integrated with passive waveguides show low PI operation and 17 dB net gain at different bias currents and input optical powers.

2. Structure, Design and Fabrication

To achieve low PDG SOA, a layer stack was grown consisting of an unstrained core of Q1.55 InGaAsP surrounded by a Q1.25 cladding, with a total InGaAsP thickness of 500 nm. The thickness of the cladding and core layers are optimized thereby the confinement factors of TE- and TM-polarization are almost the same which allows to achieve low PDG SOA. The SOA was then fabricated following the standard generic integration platform process offered by SMART Photonics B.V. [6]. An active layer structure is grown using metalorganic chemical vapour deposition (MOCVD) which is patterned and etched to leave the active layer structure where needed. The islands are regrown with a Q1.25 waveguiding layer, after which high resolution lithography and dry-etching is applied to pattern the waveguides. A passivating dielectric layer is deposited as well as a planarizing polymer, prior to metallization. To reduce facet reflections, a dielectric AR coating is deposited. A schematic of the fabricated structure is shown in Figure 1.

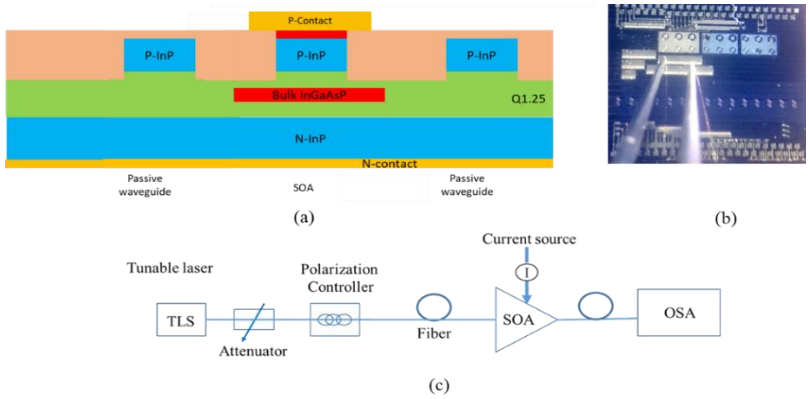

Figure 1: (a) Cross-sectional view of the low PDG bulk SOA co-integrated with butt-coupled waveguides. The SOA consists of a bulk InGaAsP active core embedded in the 500 nm thick InGaAsP (Q1.25) waveguide. (b) The fabricated chip. And (c) the measurement setup.

3. Characterization of low polarization sensitive bulk SOA

The low polarization sensitive bulk SOA have been assessed using the set-up shown in Fig. 1(c). Optical spectra of the amplified spontaneous emission (ASE) of a 1.5 mm long SOA for bias currents varying from 40 to 120 mA are shown in Fig. 2(a). Due to the band-filling effect, an increasing of the bias current results in a blue shift. The wavelength corresponding to the peak power shifts from 1621 nm to 1585 nm, for 20 mA and 125 mA, respectively. Additionally, the ASE peak power increases from -64 dBm to -36 dBm as well. Above 125 mA bias current, the gain of the SOA equals the total losses (including AR facets), which in turn makes it start lasing. This can be avoided by optimizing the AR coating further. Hence, at this step, the highest possible bias current used for the SOA is 125 mA.

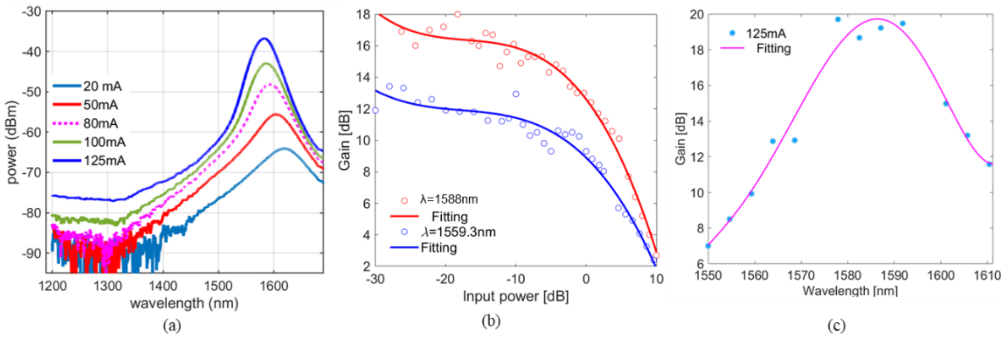

Figure 2. Amplified spontaneous emission collected at the output facet of the ridge-bulk SOA for currents of 20, 50, 80, 100, and 125 mA at temperature of 20 ℃. Fig. 2(b) Chip gain (the highest value of gain considering different polarization) versus input power for the ridge-bulk SOA at bias current of 125 mA and for two wavelength: 1588nm and 1559.3 nm.

To characterize the gain and polarization performance of the ridge-bulk SOA versus the input power, a tunable laser is connected to the input of the SOA using a tapered fiber via a polarization controller. The output optical spectrum is collected at the output facet of the SOA using a tapered fiber. We record the spectrum for different input powers varying from -20 dBm to 15 dBm. The bias current of the SOA is set to 125 mA. We change the polarization states to measure the highest (the best case) and lowest (the worst case) gain of the SOA, respectively. Fig. 2(b) shows the SOA gain at two different wavelengths: 1588nm (the wavelength corresponding to the peak power of ASE for 125mA bias current) and 1559.3nm which is different from the peak wavelength. As shown the gain at 1559.3 nm is 12 dB whereas the gain of the SOA at 1588nm is 17 dB. Figure 2(c) shows the gain spectrum of the SOA at bias current of 125mA. The peak gain is around 1580nm and the SOA has at least 10dB gain in the broadband interval of 1550nm to 1610nm.

The polarization sensitivity of the chip gain is defined as the absolute value of the difference of the chip gain for the linear TE and TM polarization $\left|\mathrm{TE}_{\mathrm{gain}} - \mathrm{TM}_{\mathrm{gain}}\right| = \left|\Gamma_{\mathrm{TE}} g_{\mathrm{mat,TE}} - \Gamma_{\mathrm{TM}} g_{\mathrm{mat,TM}}\right|$ which $g_{\mathrm{mat,TE/TM}}$ stands for material gain of bulk active layer. Based on the designed layer stack (c.f. Fig. 1(a)), same confinement factor for both polarization is achievable. Since the material gain for both polarization are almost equal, one could expect the low polarization sensitive SOA. Fig. 3 (a) and (b) shows the absolute magnitude of the polarization dependent gain (PDG) versus the input power for the two different wavelength of interests, 1588nm and 1559.3nm. As depicted in the figures below, by increasing the input power at a fixed current (125 mA) the PDG also decreases. This result is in agreement with theoretical simulation of other types of buried hetero-structure based SOAs [2]. Comparison of the two figures suggests that the overall PDG is lower for wavelength of 1559.3 nm compared to 1588nm of half dB. This originates from the fact that the corresponding gain (c.f. Fig. 2(b)) is 4dB lower for 1559.3nm wavelength compared to the peak wavelength.

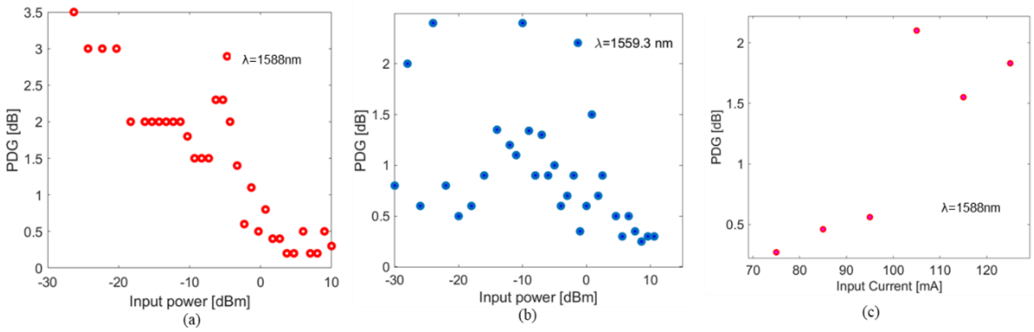

Figure 3. Polarization dependent gain (PDG) of the proposed ridge-bulk SOA vs. input power varying from -25dBm to 10 dBm at bias current of 125 mA versus input power for a wavelength of a) 1588nm and b) 1559.3 nm. (c) PDG vs. bias current for assumed input power and wavelength of -22dBm at 1588nm, respectively.

Moreover, Fig. 3(c) shows the PDG dependence of bulk SOA versus the bias current. Generally speaking by increasing the bias current the SOA gain increases and the PDG increases correspondingly. The PDG is less than 1dB for bias currents lower than 100m. However, at 105mA it increasers abruptly to 2.1 dB and then decreases to 1.5 dB at 110mA. Further theoretical investigation which we will consider in future is needed to understand more about its behaviour.

4. CONCLUSIONS

A low polarization sensitive ridge waveguide bulk SOA co-integrated with passive waveguide is realized with easy fabrication process and demonstrated. The SOA module exhibits polarization dependent gain in the range from 3 dB to 0.3 dB as function of the input power. Moreover, it exhibits a large gain of 17 dB for input bias current of 125 mA. Results also show that SOA has even lower polarization sensitivity for wavelengths away from the peak of ASE, though its gain decreases to 12 dB. The proposed bulk ridge-type PI SOA is well suited for integration with passive waveguides which allows to utilize these active components in more sophisticated circuits such as wavelength selective switches (WSS) where the integration of actives (which act as gain element or booster or gate) and passive components (arrayed waveguide gratings which act as multiplexers and de-multiplexers) on-chip are needed.

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