Design and Analysis of Polarization Insensitive O-Band Bulk SOA for active-passive photonic circuits

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Abstract: We design and numerically analyze low polarization sensitive bulk-SOA in the O-band suitable for co-integration with passive waveguides/circuits. Low polarization dependent gain (<1.5dB) is achieved with 20dB average gain and 11dBm output saturation power.

1. Introduction

Photonic integrated transceivers operating at O-band (1310 nm) are currently commercialized for the Datacom optical interconnects. As the traffic in data centers is steadily growing, higher capacity WDM photonic transceivers and switches are investigated to face the required capacity and lower the power consumption. The increase of the number of channels/data rate in transceivers is limited by the required optical power at the receiver, while scaling the port count of the photonic switch is limited by the on-chip loss. Therefore, monolithically integration of polarization independent (PI) O-band SOAs with passive circuits (splitter, coupler, filters, etc..) will enable sophisticated photonic circuits with the required on-chip amplification, such as PI SOA based amplified WDM receivers and PI SOA based loss-less large port photonic switches. So far several types of polarization insensitive (PI) SOAs based on quantum well active layer, strained bulk and square shape buried bulk have been designed and fabricated. However, realization of high gain PI MQW SOA requires high precision growing technologies to engineer the energy bands [1-3]. Moreover, SOAs based on buried bulk active layer require tapering and window regions to improve the coupling loss and facet reflectivity, which makes harder the co-integration with passive waveguides. SOAs based on bulk active layer in ridge waveguide structure experimentally was proposed by Holtmann [4], but they are not suitable for co-integration with passives. Moreover, a theoretical and numerical investigation of PI SOA based on bulk active layer for waveguide working around 1300nm is missing. Despite the reported O-band SOAs, polarization insensitive operation and active-passive co-integration of SOAs with passive components to realize sophisticated photonic circuits have not been demonstrated. In this paper, we study, analyze and optimize the design of PI SOAs based on bulk active layer working in O-band with appropriate layer-stack suitable for direct integration with passive waveguide to design photonic integrated circuits in O-band.

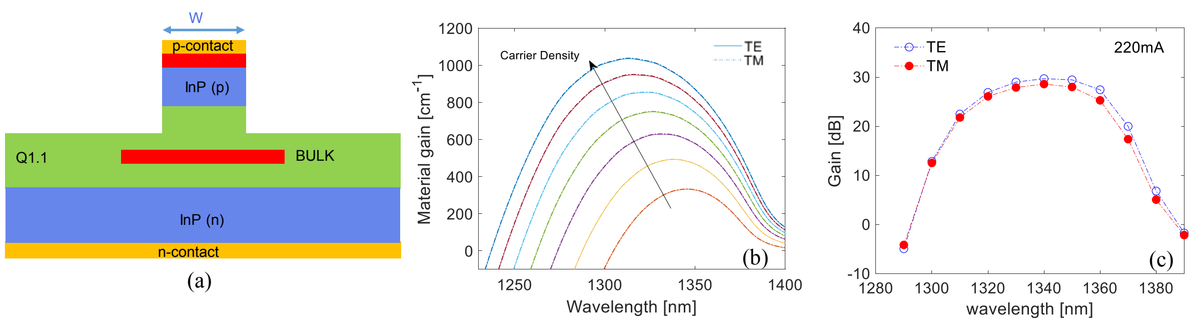

Fig. 1. (a) Travelling waveguide structure of SOA with bulk active layers. (b) Material gain vs. wavelength for TE (solid line) and TM-mode (dash line) for different bias currents (carrier densities) up to 100mA. (c) Gain for TE- and TM-mode at input power of -15dBm.

2. Design and numerical investigation of O-band bulk SOA

We have designed a layer-stack based on unstrained bulk active layer which makes it compatible for the co-integration with passive waveguide for the fabrication of complex functionalities. The gain of an SOA is $e^{(\Gamma g_m-\alpha)l}$, where G is the modal (net) gain, Γ is modal confinement factor of TE/TM, α is the material losses, g_m is material gain, and l is the SOA length. The polarization dependent gain could be described as $PDG = G_{TE}/G_{TM} = e^{(\Gamma_{TE}g_{TE}-\Gamma_{TM}g_{TM})l}$. To achieve low PDG in the SOA, we designed a layer-stack consisting of an unstrained core of Q1.3 InGaAsP (with thickness of 90nm) surrounded by a Q1.1 cladding, with a total InGaAsP thickness of 400 nm, as indicated in Fig. 1(a). This designed layer-stack for SOA can be integrated with a passive waveguide layer-stack with exactly the same layers without the bulk layer [5] The designed size of the bulk active layer (90 nm) renders it polarization insensitive over wide wavelength and current ranges, while relaxing the fabrication process based on simple single-step grown unstrained active layers which improves the SOAs performance reliability. Also, relatively large size of bulk area based on ridge waveguides decreases the model reflectivity without using window region. A schematic of the analyzed O-band SOA is shown in Fig. 1(a). The ridge waveguide keeps the mode away from the etched area, confining the light in the middle of the bulk layer. The width of ridge waveguide *W* is chosen to be 2 µm to optimize number of modes and waveguide loss. As the active layer is bulk, the material gain for both modes are approximately the same, c.f. Fig. 1(b), which originates from the degeneracy of the band structure around bandgap for heavy- and light-hole. The material gain is self-consistently calculated by solving several equations including the current continuity, the Poison, the photon rate, the heat flow and the capture/escape balance equations. As indicated, the material gain enhances by increasing the carrier density or bias current. Then, the net gain characteristics of SOAs is calculated by solving time domain travelling wave equations using slowly varying envelope approximation approach [7]. The gain spectrum of the SOA for both TE- and TM-mode is shown in Fig. 1(c) for bias current of 220mA. Over the whole spectrum, the SOA is polarization independent (PDG ranges between 0 and 2.5dB) and the gain of TE-mode is higher than the TM-mode, since the material gain for TE- mode is higher than the TM one. The gain maximum is around 1340 nm and the gain 3-dB bandwidth is around 40nm. Moreover, the PDG level for shorter wavelengths is lower and almost zero around 1290 nm because the confinement factor for TE is almost equal to TM at shorter wavelength.

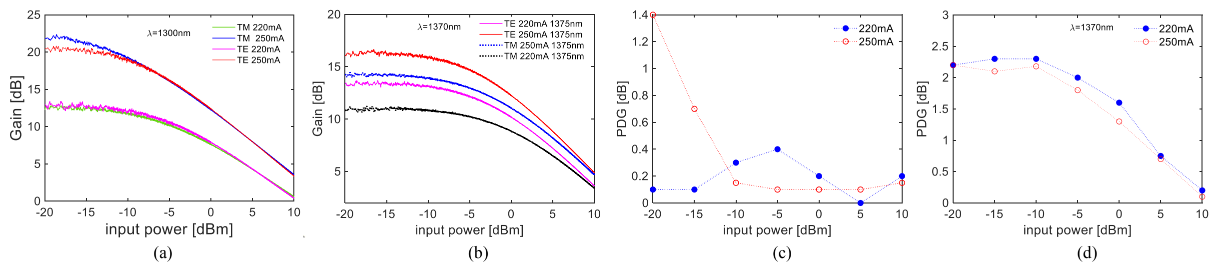

Fig. 2. Gain saturation properties of SOA with length of 1500µm at (a) 1300nm and (b) 1370nm for two bias current of 220mA and 250mA. (c) and (d) shows corresponding PDG versus input power for both wavelengths and currents.

The gain saturation characteristics of the bulk SOA are shown in Fig.2 (a) and (b) where the gain is plotted versus input power for two different bias currents of 220mA and 250mA at two different wavelengths 1300nm and 1370nm. At 1300nm the linear gain SOA for 220mA and 250mA are around 13dB and 20dB, respectively, and saturates around -5dBm. The same behavior occurs for gain saturation characteristics at 1370nm in Fig. 2(b). The SOA output saturation power at 1300nm is around 7dBm and 11dBm for 220mA and 250mA bias currents, respectively. Similarly the output saturation power of SOA at 1370nm increases from 10dBm to 11dBm by increasing the current from 220mA to 250mA. Figure 2(c) and (d) show the corresponding PDG versus input optical power of the bulk SOA for two different wavelengths and bias currents. By increasing the input power, the PDG level decreases, although there are some fluctuations in the PDG level, especially for 1300nm, which is due to the spontaneous emission noise. The PDG level for 1300nm is lower compared to 1370nm, which is due to the fact that the confinement factor is the same for both polarization at 1300nm.

In conclusion, O-band PI SOA based on bulk active layer suitable for active-passive monolithically integration with passive is designed and numerically investigated for the first time. Results indicate low PDG, high output saturation power and high gain operation of the SOAs. This work has been supported by the European ICT project QAMeleon funded under Horizon 2020.

3. References

[1] Nkanta, J., et al. "Low polarization-sensitive asymmetric multi-quantum well semiconductor amplifier for next-generation optical access networks." Optics letters OSA 38.16, pp-3165-3168, 2013.

[2] Zali, A., "Low Polarization Dependent MQW Semiconductor Optical Amplifier with Tensile-Strained-Barrier Design for Optical Datacom and Telecom Networks", 22nd International conference on transparent optical networks (ICTON), Italy 2020.

[3] Zali, A., et al., "Low polarization sensitive semiconductor optical amplifier co-integrated with passive waveguides for optical datacom and telecom networks", Proc. 22nd European Conference on Integrated Optics, 2020.

[4] Holtmann, Ch., et al. "Polarization independent bulk active region semiconductor optical amplifiers for 1.3µm wavelengths." Photonic Technology Letters, IEEE 8.3, pp-343-345, 1996.

[5] Hazan, J., et al. "Towards an Integration Technology Platform at 1300nm: Ridge Waveguide Design", 24th annual Symposium of the IEEE Photonics Benelux Chapter – VU Amsterdam, Netherlands, 2019.

[7] Bonifacio, R., et al. "The slowly varying envelope approximation revisited." Optics communications 101.3-4, pp-185-187, 1993.