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Lateral Integration of VCSEL with Slow Light Amplifier/Modulator

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Abstract: We propose a novel lateral integration scheme of VCSEL and slow light devices with a Bragg reflector waveguide. The modelling shows compact slow light SOA/modulator can be efficiently coupled with a VCSEL by trench structure.

1. Introduction

High speed and low power consumption VCSELs have been attracting much interest for optical interconnects in data center, supercomputers and so on.We still need new challenges in VCSEL photonics for increasing the speed of modulation, increasing the output power and integrating new functionalities. There have been reports on VCSEL-based functional devices such as modulator-integration with VCSEL and VCSEL-based amplifiers [1, 2]. However, there have been difficulties in their integration because their vertical integration causes the instability of coupled cavities and strong optical feedback to a VCSEL, and so on. On the other hand, we proposed and demonstrated VCSEL-based slow light devices [3]. By slowing light, we are able to miniaturize various waveguide devices.

In this paper, we propose a novel integration scheme of VCSEL and slow light devices with a Bragg reflector waveguide to provide us the integration of new functionalities.

2. Lateral coupling scheme

The proposed integration structure of VCSEL and slow light devices is shown in Fig. 1. The vertical emission is inhibited by a top-DBR whose reflectivity is nearly 100%. Lateral optical confinement is formed using an oxide and a shallow trench structure, which leads to a leaky traveling wave. Thus the lateral optical coupling from VCSEL to slow light device takes place. It is noted that the group velocity of coupled light in the Bragg reflector waveguide can be slow down [3], thus we are able to integrate compact slow light devices with a VCSEL. The coupled light is amplified or modulated in a slow light SOA or in a slow light electro-absorption modulator, respectively. The same active region can be used by foreword bias or by reverse bias operation. The output can be taken from a slow light device by decreasing its top-DBR reflectivity.

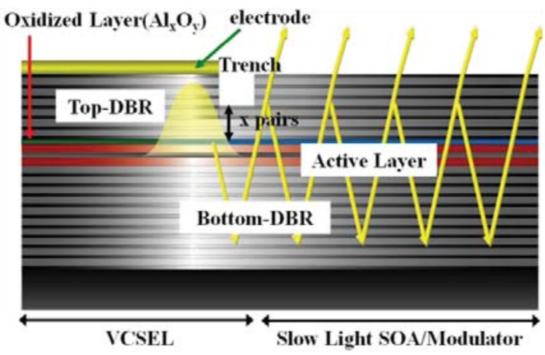

Fig. 1. Schematic structure of a novel integration of VCSEL and slow light devices.

We calculated the coupling efficiency from a VCSEL to a slow light waveguide with Bragg reflectors. We used a mode-matching method (FIMMWAVE, Photon Design Co.). First, we calculated the lateral coupling efficiency from a VCSEL to a passive slow light waveguide. Figure 2 shows the calculated intensity distribution in the lateral direction when the trench width of 1μm and the remaining DBR-pairs in the trench is 8 pairs. It shows lateral coupling from VCSEL to a slow light waveguide. The definition of the coupling efficiency is the same as the slope efficiency defined in lasers. Figure 3 shows the calculated coupling efficiency as a function of the remaining DBR-pairs in the trench (the trench depth). We are able to obtain a high coupling efficiency of more than 50%, however, a noticeable of radiation loss (3dB) is caused in the trench, which gives penalty in thresholds and slope efficiencies. Further optimizations are under study for reducing the radiation loss.

3. Modeling results

We carried out the modeling of a slow light SOA laterally integrated with a VCSEL. The injection current in a slow light SOA is below the threshold so that the lasing action of the SOA is avoided. We assumed triple 980 nm QWs in the active region. Figure 4 shows the calculated intensity distribution in the lateral direction. With increasing the injection current, the intensity in the SOA spread in the lateral direction. The radiated power from the SOA can be increased by making the SOA longer. The top DBR pairs is optimized to 15 to increase the SOA gain. The absorption coefficient of p-DBR(Top) and n-DBR(Bottom) are assumed as $10cm^{-1}$, $5cm^{-1}$, respectively. Figure 5 shows the SOA gain as a function of injection current density. The SOA length is assumed as 50 um,

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which enables the direct coupling to a multi-mode fiber. The result shows a possibility of a SOA gain of more than 15 dB, enabling a few tens mW of output power from our SOA-integrated VCSEL. But the influence of the gain saturation is not considered in this calculation model.

Next, we carried out the modeling of a slow light electro-absorption modulator. The number of the top DBR pairs in the modulator section is 25. The other parameters are the same as the case of the SOA. Figure 6 shows the calculated intensity distribution with different absorption coefficients of QWs in the modulator section. We assumed the absorption coefficient as 200cm^{-1} and 1200cm^{-1} for non-biased and reverse-biased operation, respectively [4]. With increasing the absorption coefficient in the modulator, the lateral penetration of the intensity is decreased. We found that the scattering at the trench deteriorates the extinction ratio. Thus we need to screen this scattering at the boundary. Figure 7 shows the insertion loss and the extinction ratio as a function of the screening length at the boundary. The modulator length is 50µm. It shows a possibility of extinction ratio over 5dB for a compact slow light modulator integrated with a VCSEL.

4. Conclusion

We proposed a novel lateral integration scheme of VCSEL and slow light devices. The coupling efficiency can be over 50%. We presented the feasibility of compact slow light SOA and modulator integrated with a VCSEL. Our novel approach enables us to avoid the reflection from the integrated devices back toward to a VCSEL for stable operation. The lateral coupling scheme can make VCSELs have new functionalities.

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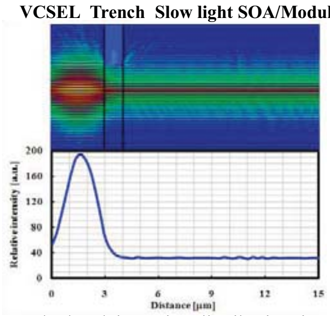

Fig. 2. Calculated intensity distribution in the lateral direction when the trench width of 1µm and the remaining DBR-pairs in the trench is 8 pairs.

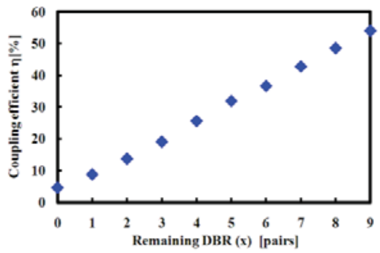

Fig. 3. Calculated coupling efficiency as a function the remaining DBR-pairs in the trench (the trench depth).

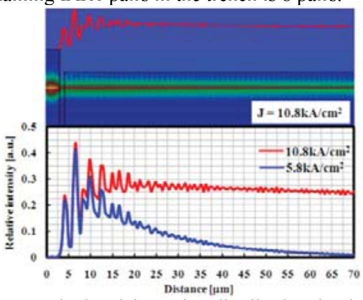

Fig. 4. Calculated intensity distribution in the lateral direction. With different injection current density.

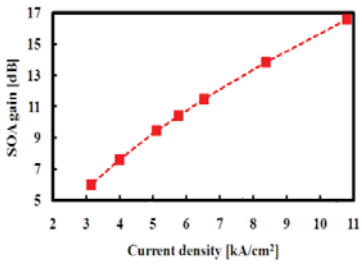

Fig. 5. SOA gain as a function of injection current density.

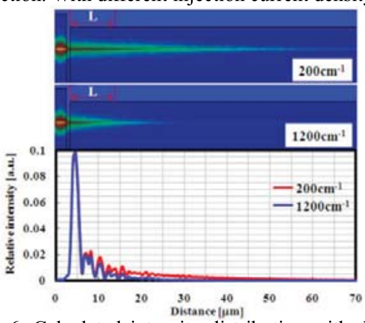

Fig. 6. Calculated intensity distribution with different absorption coefficients of QWs in the modulator section.

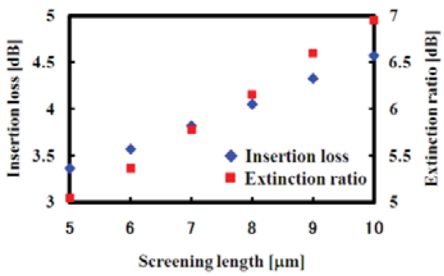

Fig. 7. Insertion loss and extinction ratio as a function of the screening length at the boundary.