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Modeling of Slow Light Modulator with Tilt Coupling Scheme

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Abstract

We present the modeling of slow light electroabsorption modulators consisting of Bragg waveguides. The result shows the modulator length can be reduced below 20 μm. We predict a low coupling loss by using a tilt coupling scheme for slow light.

1. Introduction

High-speed short reach applications (-100Gbps) have been attracting much interest. A vertical cavity surface emitting laser (VCSEL) is a key device for short reach optical links. However, the modulation speed of VCSELs is primarily limited by the relaxation oscillation frequency. The integration with an external modulator is one of solutions to go beyond the limit. However, a resonant cavity modulator, which has been only reported for integration with VCSELs, provides us narrow optical bandwidth. On the other hand, slow light has been attracting much interest for reducing the size of various optical devices such as optical amplifiers, optical switches and nonlinear optical devices [1], We have proposed and demonstrated slow light modulator [2, 3] composed of Bragg waveguides [4]. In this paper, we present the modeling of a slow light GaInAs/GaAs electroabsorption modulator with a tilt coupling scheme.

2. Structure of Slow Light Modulator

Figure 1 shows the slow light modulator with Bragg waveguide, which is integrated with a VCSEL. The output light from VCSEL is reflected by a miro-mirror. The reflected light is coupled into the modulator by using a tilt-coupling scheme [3].

Here we carried out a simple model by replacing multilayer Bragg mirrors with a perfect metal mirror [2]. The calculated slow down factor, which is defined as the ratio of the group velocity of slow light versus that in conventional semiconductor waveguides, is shown in Fig.2. The cut-off wavelength is assumed to be 990 nm. The slow-down factor is over 10 in the wavelength range of 980-990 nm. Thus, the electro-absorption effect is enhanced by a factor of more than 10 in this wavelength range and we are able to reduce the length.

3. Modeling Result

The structure is similar to that of VCSELs with a one-wavelength-cavity. Absorption coefficients of 300cm^{-1} and 1200 cm^{-1} are assumed for InGaAs QW absorption modulators with zero-bias and 1V-bias voltages [5]. The device length is as small as 20 μm, which is 10 times smaller than that of conventional electro-absorption modulators. Figure 3 shows the calculated insertion loss and extinction ratio as a function of the wavelength. Even for a 20μm long ultra-compact modulator, we expect an extinction ratio of 7 dB over 972 nm, which will be large enough for short-reach optical links. While the large dispersion of the slow light effect and an increased insertion loss would limit the optical bandwidth of the slow light modulator, we expect optical bandwidth of greater than 5 nm.

An issue is how to couple with slow light in a Bragg waveguide. We proposed a simple and practical method of a tilt-coupling scheme [3]. We assumed that an input beam is 28 degrees tilted from the vertical axis. We carried out the full-vectorial numerical simulation using a film-mode-matching method (FIMMWAVE, Photon Design Co.). Figure 4 shows the calculation model and the calculated intensity distribution. The coupling loss is less than 1.8 dB for TE mode with a 4 μm-spot-size Gaussian beam input. The incident angle is optimized so that the output intensity is maximized as shown in Fig. 5. Figure 6 shows the calculated insertion loss versus wavelength. It is noted that the insertion loss includes the absorption loss enhanced with slow light effect. The coupling loss excluding the absorption loss is 1.8 dB, indicating a possibility of low coupling loss for slow light excitation.

4. Conclusion

We presented the modeling of a slow light GaInAs QW electroabsorption modulator consisting of a Bragg reflector waveguide. The tilt-coupling scheme gives us low coupling loss and enables us to realize a miniature modulator integrated VCSEL.

References

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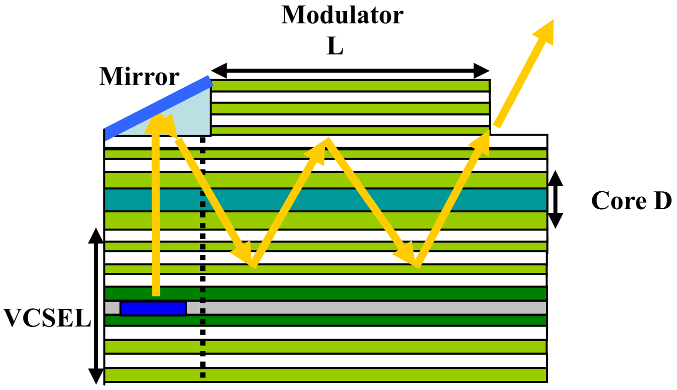

Fig.1 Schematic structure of slow light modulator integrated with VCSEL

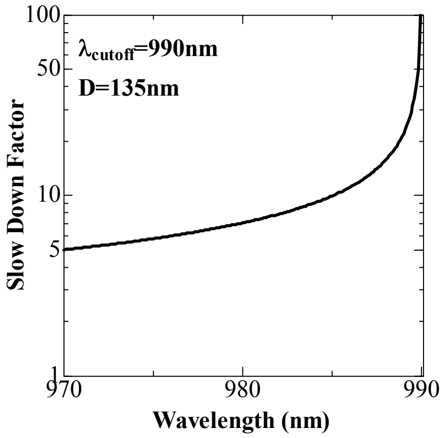

Fig.2 Calculated slow down factor versus wavelength

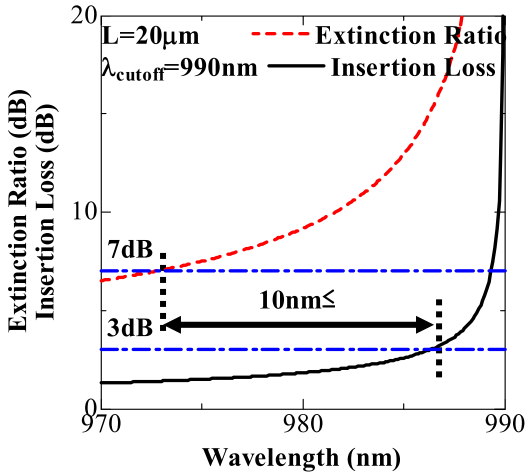

Fig.3 Calculated insertion loss and extinction ratio of Bragg waveguide modulator.

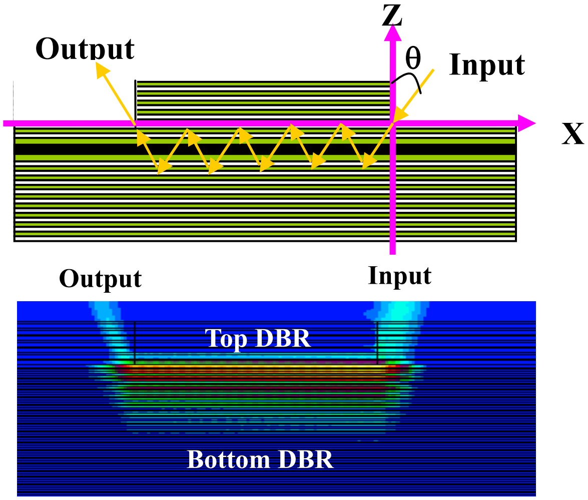

Fig.4 Calculated mode and calculated field distribution of slow light modulator with tilt-coupling scheme.

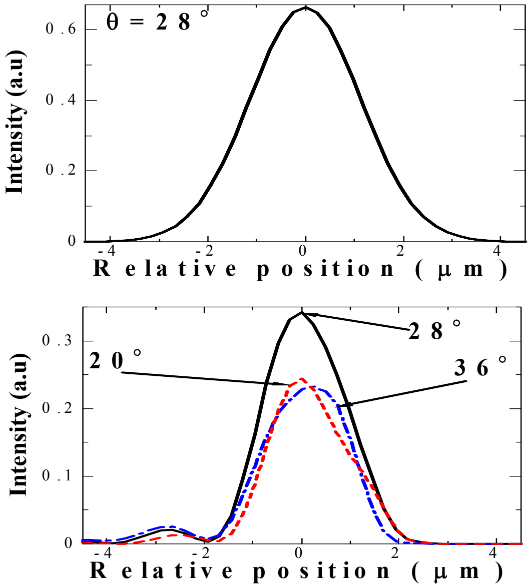

Fig.5 Calculated intensity of input and output intensity for different incident degrees.

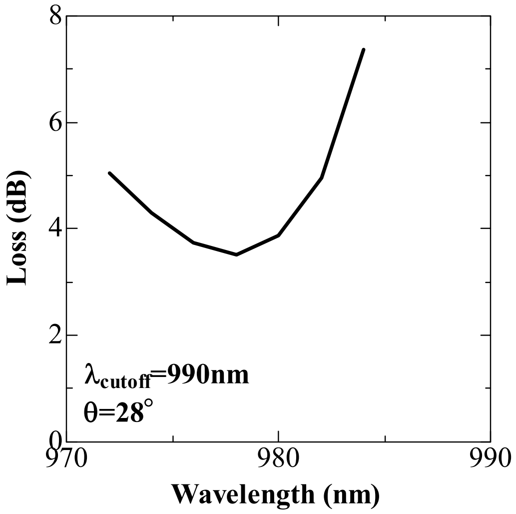

Fig.6 Calculated insertion loss versus wavelength