Proposal of total-internal-reflection optical switch with slowing light in Bragg reflector waveguide

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Abstract: We propose a total-internal-reflection optical switch with a Bragg reflector waveguide. Slowing light in a Bragg reflector waveguide gives us an extremely large change in the equivalent refractive index of the waveguide, which is increased by a factor of more than 10 near a cut-off wavelength. Slowing light is caused by the giant waveguide dispersion of a Bragg reflector waveguide. The proposed structure enables a large bending angle of over 40 degrees even for reasonable refractive index changes of waveguide materials. The calculated result shows a possibility of large-scale and compact cross-bar waveguide optical switches.

Keywords: optical switch, Bragg reflector waveguide, slow light, total internal reflection

Classification: Photonics devices, circuits, and systems

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1 Introduction

A large scale and high-speed optical switch is necessary to realize future photonic networks with cross-connect functions [1]. Various types of optical switches have been studied [2, 3, 4, 5, 6]. However, there have been difficulties in making compact optical switches, since available refractive index changes of materials for optical switching is typically limited to be below 1%. It is interesting to use slow light for miniaturization of optical devices [7, 8]. We recently proposed and demonstrated a slow light modulator [9, 10] based on Bragg reflector waveguides [11]. The proposed structure gives us dramatic size reduction using a slow light effect.

In this paper, we propose a novel total-internal-reflection optical switch with slowing light in a Bragg reflector waveguide, which enables an extremely large bending angle of over 40 degrees.

2 Device Structure

The schematic structure of our proposed slow light optical switch with a Bragg reflector waveguide is shown in Fig. 1 (a). The cross-sectional view of the Bragg reflector waveguide is also shown in Fig. 1 (b). The waveguide consists of 7-pair Si/SiO₂ top DBR, 40-pair InP/AlGaInAs bottom DBR and $\lambda/2$ -InGaAsP core. The structure is similar to that of VCSELs with a half-wavelength-cavity. The top view of switch is shown in Fig. 1 (c). When the refractive index of the core in the right-hand-side is changed with carrier injection, incident light is reflected at the boundary for functioning as a total-internal reflection switch. Our modeling shows that the group velocity of light decreases with increasing the waveguide dispersion when the wavelength approaches to the cut-off wavelength. Fig. 2 shows the calculated waveguide dispersion and slow-down factor f , which is defined as the ratio of the group velocity of slow light versus that in conventional semiconductor waveguides.

The cut-off wavelength for the fundamental mode is assumed as 1560 nm.

The slow-down factor is over 10 in the wavelength range of 1550–1560 nm. An important issue is how to couple with slow light in a Bragg waveguide. We demonstrated a simple and practical method of a tilt-coupling scheme [10], showing a low coupling loss of below 2 dB.

Figure 3 shows the calculated change in the equivalent refractive index of the Bragg reflector waveguide when the refractive index of a core is decreased by 0.1–1.0%. The definition of the equivalent refractive index is the propagation constant divided by a free-space propagation constant. It is noted that the equivalent refractive index change is increased by a factor of more than 10 near the cut-off condition. We found that the relative change in equivalent

Fig. 1. (a) Schematic structure of slow light optical switch (b) Cross-sectional view of a Bragg reflector waveguide (c) Top view of optical switch.

Fig. 2. Calculated slow-down-factor and waveguide dispersion of Bragg reflector waveguide.

Fig. 3. Calculated change in equivalent refractive index of Bragg reflector waveguide for different changes of core refractive index.

refractive index $\Delta n_{eq}/n_{eq}$ is expressed by the following equation.

$$\frac{\Delta n_{eq}}{n_{eq}} \cong f \cdot \frac{\Delta n}{n} \quad (1)$$

where f is the slow down factor and $\Delta n/n$ is the material refractive index change. Thus, slowing light enables us to increase the critical angle for total internal reflection, resulting in a large bending angle of input light. Plasma effect would reduce the refractive index of a core, realizing nanosecond-order switching speed.

3 Result

We carried a Gaussian beam propagation analysis for total internal reflections based on an equivalent refractive index method that means the critical angle is determined by the change of equivalent refractive index. No lateral optical confinement is considered. The incident angle of a Gaussian beam with a spot size of $10\ \mu\text{m}$ is assumed to be 20 degrees for the boundary with a reduce refractive index region. We used the numerical simulator based on a film-mode-matching method (FIMMWAVE, Photon Design Co.). Figure 4(a) and (b) show the top view of the calculated intensity distribution for the reflection state ($\Delta n/n = 1.0\%$) and the through state ($\Delta n/n = 0\%$). The wavelength is 1550 nm, which is 10 nm shorter than the cut-off wavelength of 1560 nm. Slowing light gives us an extremely large change in equivalent refractive index and thus a large bending angle of 40 degrees can be obtained even for a reasonable change (1.0%) of refractive index of the core. Figure 5 shows the intensity profile of the input light and the reflected light. Reflection loss is 0.02 dB. While the peak intensity decreases with optical diffraction, noticeable reflection losses cannot be seen. This can be avoided with a three dimensional slow light waveguide.

Fig. 4. Top view of calculated intensity distributions of total-internal reflection switch for (a) reflection state ($\Delta n/n = 1.0\%$) and (b) through state ($\Delta n/n = 0\%$), and (c) calculated intensity distributions of input light and reflected light.

4 Conclusion

We proposed a novel total-internal-reflection optical switch with slowing light in a Bragg reflector waveguide. The proposed structure gives us a giant change of the equivalent refractive index, which enables a large bending angle of over 40 degrees even for reasonable refractive index changes of waveguide materials below 1%. The proposed concept may open up a new scheme of photonic switching waveguide devices.

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