A Silicon-Waveguide Polarization Converter with a Metal Strip on an SiO_2 Substrate

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***Abstract*—A polarization converter consisting of a silicon waveguide is analyzed by the imaginary-distance beam propagation method based on Yee's mesh and the finite-difference time-domain method. It is revealed at a wavelength of 1.55 μm that the polarization conversion length is 15.1 μm with an insertion loss of 0.47 dB. An extinction ratio of more than 20 dB is obtained over a wavelength range of 1.53 to 1.57 μm.**

I. Introduction

Polarization converter is a key component for optical devices such as isolators, switches, and polarization transparent circuits [1]. Several converters consisting of asymmetric waveguides have been proposed and investigated [2]-[6]. These converters produce an asymmetry by eliminating a part of the waveguide core. Recently, converters using a metal strip also received attention [7]-[10], with the aid of the surface plasmon polariton (SPP). It should be noted, however, that these converters suffers from the loss caused by the SPP. For example, the SPP-based converter reported most recently still has an insertion loss of 0.86 dB [10].

In this paper, we propose a silicon-waveguide polarization converter with a metal strip on an SiO_2 substrate. The polarization conversion behavior is evaluated by the beam-propagation method based on Yee's mesh (YM-BPM) [11] and the finite-difference time-domain (FDTD) method based on the trapezoidal recursive convolution technique [12]. It is found that a converter length of 15.1 μm is obtained with an insertion loss of 0.47 dB at a wavelength of 1.55 μm. An extinction ratio of more than 20 dB is achieved over a wavelength range of 1.53 to 1.57 μm.

II. Discussion

The configuration is illustrated in Fig. 1, in which the refractive indices of the core, substrate and metal strip are, respectively, chosen to be $n_{\rm co}$ = 3.476 (Si), $n_{\rm sub}$ = 1.444 (SiO_2) and $n_{\rm m} = 0.14-j11.36$ (Ag) at a wavelength of λ = 1.55 μm. The Si core has a square shape with a width of $w_{\rm co}$ = 0.3 μm and a height of $h_{\rm co}$ = 0.3 μm. The same Si-waveguide without the metal strip is used as the input and output waveguides. For the conversion section, the metal strip is loaded on the substrate with a spacing s_x between the core and the edge of the metal. Configuration asymmetry is produced without eliminating a part of the core, rather by the existence of the metal strip. The metal width and thickness are denoted as $w_{\rm m}$ and $t_{\rm m}$, respectively.

We first optimize the configuration of the conversion waveguide, with the metal width being temporally fixed to be $w_{\rm m} = 0.4$ μm. Fig. 2 shows the contour plot of the polarization rotation angle ($\theta + \theta'$) [6] and length ($L_{\rm c}$) as a function of s_x and $t_{\rm m}$. It can be seen that $\theta + \theta'$ is sensitive to s_x. For example, when s_x = 0.06 μm and $t_{\rm m}$ = 0.06 μm are chosen, the polarization conversion can be achieved with $L_{\rm c}$ = 15.1 μm. These geometrical parameters are used in the following study.

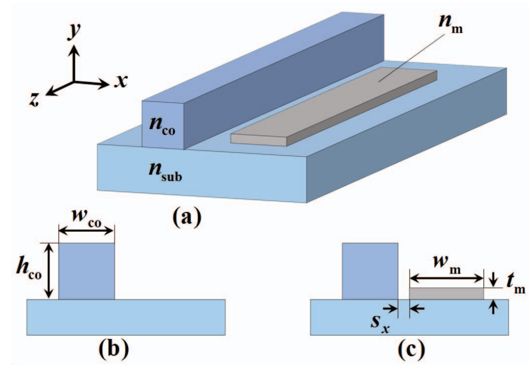

Fig. 1. Configuration. (a) Perspective view. (b) Cross-section of input and output waveguides. (c) Cross-section of conversion waveguide.

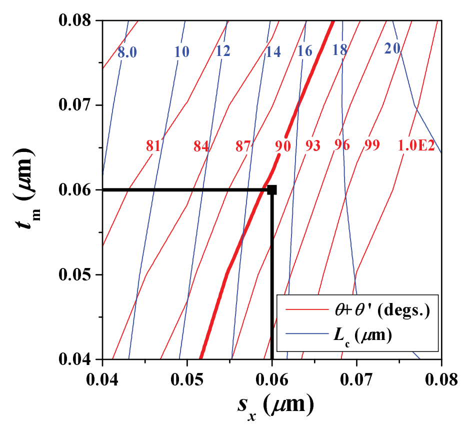

Fig. 2. Contour plot of $\theta + \theta'$ and $L_{\rm c}$ as a function of s_x and $t_{\rm m}$.

Owing to the existence of the metal film adjacent to the core, there exist two hybrid modes in the converter waveguide. The hybrid eigenmodes are calculated by the YM-BPM. Fig. 3 shows the attenuation of the first and second modes as a function of $w_{\rm m}$. It is seen that the attenuation decreases as $w_{\rm m}$ is increased and converges to a relatively small value. For example, with $w_{\rm m}$ = 0.4 μm, the attenuation of each mode

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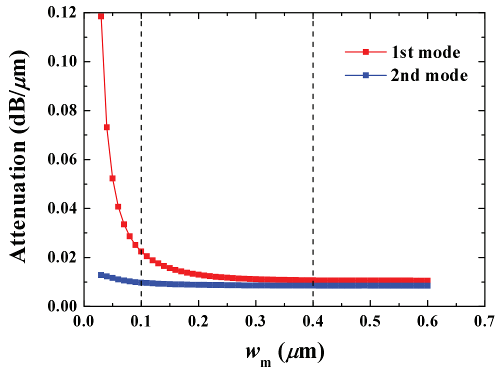


Fig. 3. Attenuation of the hybrid modes as a function of w_{m}.

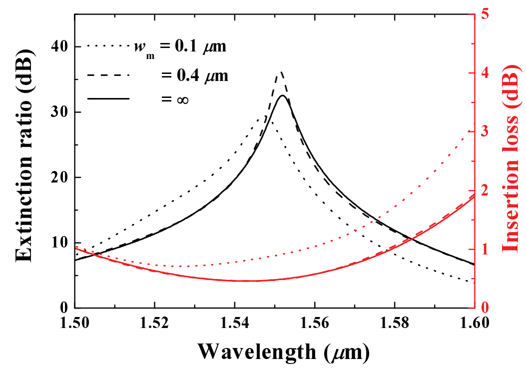
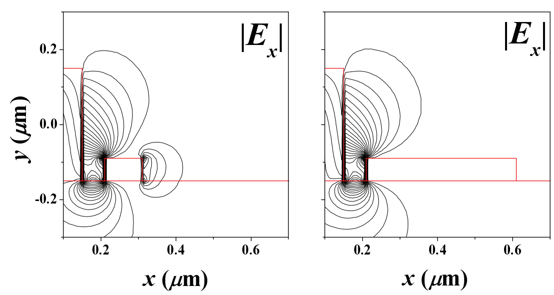


Fig. 5. Extinction ratio and insertion loss as a function of wavelength.



(a) (b)

Fig. 4. First-mode E_x field distributions of the conversion waveguide. (a) $w_{\mathrm{m}} = 0.1$ μm. (b) $w_{\mathrm{m}} = 0.4$ μm.

converges to approximately 0.01 dB/μm. We now explain this behavior in terms of the eigenmode field distribution.

Figs. 4(a) and (b) show the enlarged views of the first-mode E_x components for $w_{\mathrm{m}} = 0.1$ and 0.4 μm, respectively. It can be confirmed for $w_{\mathrm{m}} = 0.1$ μm that the E_x component is localized in not only the gap between the core and metal edge but also in the right side of the metal strip. On the other hand, almost no field exists in the right side for $w_{\mathrm{m}} = 0.4$ μm, leading to low loss behavior.

We now study the wavelength characteristic using the FDTD method. The extinction ratio and insertion loss are presented in Fig. 5, in which the results for $w_{\mathrm{m}} = 0.4$ μm are shown by broken lines. The results for $w_{\mathrm{m}} = \infty$ and 0.1 μm are also shown for comparison. As mentioned above, extension of the metal width contributes to reduction in the insertion loss. Fig. 5 also indicates that the behavior for $w_{\mathrm{m}} = 0.4$ μm is nearly the same as that observed for $w_{\mathrm{m}} = \infty$. In other words, the metal width is insensitive to the conversion behavior as long as the strip has a sufficient width. Calculation shows that an extinction ratio of more than 20 dB is obtained over a wavelength range of 1.53 to 1.57 μm.

III. Conclusion

A silicon-waveguide polarization converter with a metal strip on an SiO_2 substrate has been proposed and analyzed. Consideration is given to the relation between attenuation and metal width w_{m}. The attenuation converges to a minimum value, provided w_{m} is larger than 0.4 μm, resulting in low loss operation. An insertion loss of 0.47 dB is achieved with a conversion length of 15.1 μm at an operating wavelength of 1.55 μm. As a result, an extinction ratio of more than 20 dB is obtained over a wavelength range of 1.53 to 1.57 μm.

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