Analysis of polarization characteristics based on asymmetric metal-clad optical waveguides with buffer layer

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***Abstract*— We propose a plasmonics-based optical polarization rotator. The proposed device is designed using skewing phenomena of propagation waves at the slotted waveguide with metal film by 3D-FDTD method. A metal film on the waveguide acts to rapidly rotate the optical polarization, because it has characteristics of slow group velocity according to the metal-clad optical waveguide. We have overcome the high propagation loss of metal-clad structures by using a buffer layer. The length of designed polarization rotator is just 5 µm for 90 % polarization rotation ratio**

I. INTRODUCTION

Many devices in integrated optics are polarization sensitive, and their optical response changes as a function of the input polarization state. Therefore, polarization rotator is a crucial component of photonic integrated circuits (PIC) that controls and manipulates polarization of the propagating wave. In recent works, polarization rotators are researched for small size, low loss, passive operations, and SOI based devices. Polarization rotation devices in optical frequency band are mostly composed of electro-optic material, which utilize the anisotropic property of the materials [1]. On the other hand, passive or nonmagnetic polarization rotators were realized relying on the asymmetry of the structure such as slanted waveguide, periodic loaded asymmetric rectangular waveguide based polarization rotator structures and mode-evolution-based polarization rotator [2]. In many applications, a passive polarization converter is much preferred, where this could be made by using a number of uniform periodically butt-coupled waveguide sections to transfer power between two fundamental TE and TM modes. Such passive components are simpler to fabricate and thus require less processing. Shani et. al. [3] has introduced passive converters based on the use of asymmetrically periodic loaded rib waveguides, where a very good polarization conversion ratio had been suggested but at the expense of several millimeters or several hundred micrometers.

In this paper, an improved design of a polarization rotator, based on a plasmonics-based slotted optical waveguide, is presented. A metal film on the waveguide acts to rapidly rotate the optical polarization, because it has characteristics of small group velocity according to the metal-clad optical waveguide by surface plasmons. Therefore, the proposed structure is smaller than slotted or slanted waveguide-based optical polarization rotator and is more effective to control polarizations. The proposed devices would be useful for the construction of optical isolators and future Si-based optical integrated circuits

II. THE PROPOSED STRUCTURE

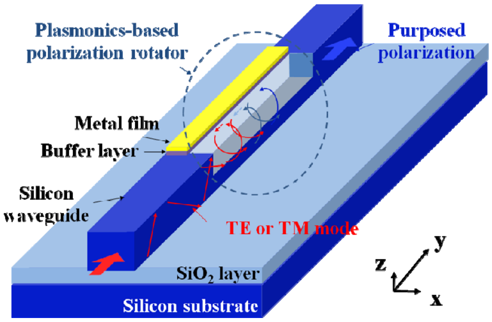
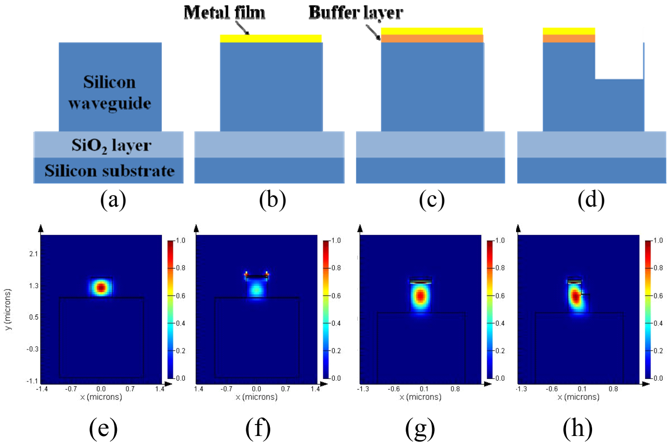


Fig. 1 Structure of plasmonics-based optical polarization rotator

The proposed polarization rotator is shown at Fig. 1. The slotted waveguides are arranged between the uniform waveguide parts such that a significant polarization rotation can take place at each junction, along with a low insertion loss. The design of the slotted optical waveguide for polarization rotation is proposed by Z. Wang, et. al., [4]. This design is based on the fact that the eigenstates of the slotted waveguide can have two orthogonal polarization states that are skewed with respect to the waveguide angle and that both of these states can be equally excited by an incoming TE or TM polarized mode. The height, the width, the refractive index of silicon waveguides, and the refractive index of SiO_2 layer for the light of 1550 nm wavelength are 500 nm, 500 nm, 3.478, and 1.458, respectively. Fig. 2(d) shows the cross section of the metal-clad based asymmetric optical waveguide used for the section of polarization rotation.

The metal-clad optical waveguides as shown at Fig. 2(b, f) have high propagation loss for TM mode because of the surface plasmon coupling phenomena. We used the buffer layer of 30 nm SiO_2 film to overcome the high loss structure as shown in Fig. 2(c, g).



(a) (b) (c) (d)

(e) (f) (g) (h)

Fig. 2 Structures of each regions in proposed structure and mode profiles about these structures

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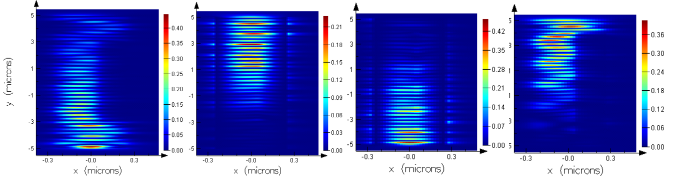
Table 1 Calculation results of the propagation loss

Structure	Mode	Effective index	Loss (dB/cm)	Loss (dB/10 μm)
Fig. 2 (a)	TE	2.898553	2.11e-5	Fig. 2(e), 0
	TM	2.907825	3.50e-6	Fig. 2(e). 0
Fig. 2 (b)	TE	2.840777	1381.8	Fig. 2(f), 1.38
	TM	2.635321	11653	Fig. 2(f), 11.65
Fig. 2 (c)	TE	2.870294	295.20	Fig. 2(g), 0.29
	TM	2.983691	607.62	Fig. 2(g), 0.61
Fig. 2 (d)	TE	2.716120	257.39	Fig. 2(h), 0.25
	TM	2.837857	650.43	Fig. 2(h), 0.65

Table 1 is shown the calculation results of the propagation loss about each structure. Fig. 2(c) structure has just 0.6 dB/ 10 μm propagation loss and has the characteristic of the weak surface plasmon. Fig. 2(d) structure that is shown the polarization rotating region has similar characteristics with Fig. 3(c).

III. ANALYSIS OF POLARIZATION CHARACTERISTICS

To overcome previous researches that have the problem of long rotation length, we use plasmonics phenomena as a thin metal film. Propagation characteristics of the metal-clad optical waveguide are shown in Fig. 3. Used metal is a gold thin film with 50 nm thickness for exciting of the surface plasmon. Generally, surface plasmon wave has a small modal volume and only TM mode operation characteristic. However, it has large out-coupling losses. Fig. 2(b, f) shows well these disadvantages. The propagating light is strongly coupled to metal/dielectric interface by surface plasmon phenomenon on the TM mode, but the propagation loss is very large as 5.8 dB for 5 μm propagation length. Therefore, we have proposed a buffer layer-coupled metal-clad optical waveguide as shown in Fig. 2(c). This structure has tunable characteristics according to the thickness of buffer layer which are weakly coupled surface plasmon wave and low loss propagation. A determined thickness of buffer layer is 30 nm, because this thickness causes the small propagation loss as 0.3 dB/ 5 μm and the excitation of the weak surface plasmon.



(a) (b) (c) (d)

Fig. 3 Simulation results of the polarization rotator
(a) E_x field in TE mode (b) E_z field in TE mode
(c) E_z field in TM mode (d) E_x field in TM mode

The structure of the simple slotted optical waveguide without metal film is previous reported [4]. It has an asymmetrical cross section of waveguide for a skewing of the propagating light. The slot width, w_{slot}, and the slot height, h_{slot}, are determined 200 nm, and 200 nm, respectively. The rotation length, L_R, is optimized to 7 μm for the maximum polarization rotation by FDTD method. We use a slotted optical waveguide with a thin metal film for minimizing of rotation length. The metal film is located on the silicon waveguide except the slot region. However, the polarization rotation is not occurred, because the thin metal film causes a strong surface plasmon wave. Therefore, we use a SiO_2 buffer layer for the weak surface plasmon wave as shown in Fig. 1. The group velocity of metal-clad optical waveguides is slower than general silicon waveguides [7]. The rotation length is shorted by which the slow group velocity leads to the large effect of the rotation mechanism. In its final analysis, the polarization rotation length, the metal thickness, and the SiO_2 buffer thickness are 5μm, 50 nm, and 30 nm, respectively.

Polarization conversion efficiencies at Fig. 3 are an eliminated ratio of the incident electric filed. For the TM mode, the eliminated ratio is similar to slotted waveguide as an approximately 90 %. However, for the TE mode, the eliminated ratio is just 70 %, because the surface plasmon phenomena only occurred on TM mode. If the rotation length become to 7 μm, the eliminated ratio is shown the same ratio with TE mode ratio. This problem can be resolved by the change of the metal position according to object of use. If the metal is located at the side of the silicon waveguide except the slot region, the TE mode is influenced as TM mode at metal surface by side located metal film. Using the overall simulation results, we have designed the polarization rotator with 5 μm slot length and 90 % polarization conversion ratio.

IV. CONCLUSION

We have designed and theoretically analyzed the optical polarization rotator based on slotted waveguide with the metal film by 3D-FDTD method. A metal film on the waveguide acts to rapidly rotate the optical polarization, because it has characteristics of slow group velocity according to the metal-clad optical waveguide. The length of designed polarization rotator is just 5 μm for 90 % polarization rotation ratio. The propagation losses for TE and TM mode are 0.12 and 0.32 dB/ 5 μm, respectively, because of used metal and slot length of 5 μm. Therefore, an ultra-small sized polarization rotator can be realized by the plasmonics-based asymmetric cross sections of waveguides.

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