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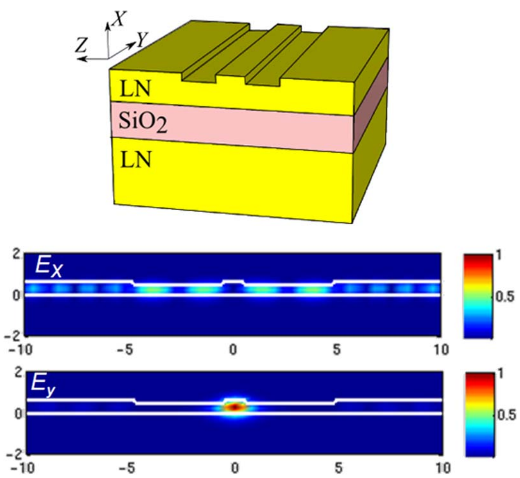

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TE/TM-Pass Polarizer Based on Lithium Niobate on Insulator Ridge Waveguide

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Abstract: We propose a TE/TM-pass polarizer based on a shallow X-cut lithium niobate-on-insulator (LNOI) ridge waveguide. In shallow X-cut LNOI ridge waveguides, the leaky mode is interchanged between TE and TM polarization waves depending on the ridge waveguide height. The phenomenon does not occur in silicon-on-insulator ridge waveguides. We use this special loss mechanism for TE/TM-pass polarizers. We evaluate structural and wavelength dependencies of polarizers by a vectorial finite-element method. The extinction ratios of 108 dB/mm and 27 dB/mm are obtained for TE-pass and TM-pass polarizers.

Index Terms: Theory and design, waveguides, waveguide devices.

1. Introduction

Optical devices to handle polarization are essential for photonic circuits. Polarizer is one of the most important and simplest devices of them. For progress of photonic integrated circuits, compact waveguide polarizers are required. To satisfy the demand, silicon-on-insulator (SOI)-based compact TE-pass and TM-pass polarizers have been reported [1], [2]. SOI can minimize device size because of its high refractive index contrast. Therefore, various SOI-based compact optical devices have been demonstrated, and polarizer is one of them. TE-pass polarizer based on SOI ridge waveguides uses large leakage loss of TM polarization [1]. On the other hand, TM-pass polarizer based on silicon photonic wires uses cutoff of TE polarization [2]. They are very compact, but they use different loss mechanisms of different waveguide structures. TE/TM-pass polarizers using the same loss mechanism have not been reported in SOI.

SOI is suitable for integrated photonic devices, but it is not always ideal for various optical devices because of its weak electrooptic effect [3]. Electrooptic devices are usually fabricated by materials that have large electrooptic property, such as $LiNbO_3$ (LN). LN offers not only large electrooptic property but also great acoustooptic and nonlinear optical properties [4]. Hence, LN is suitable for broad optical devices. However, it is difficult to minimize device size for LN. Many fabrication methods are studied to realize small LN waveguides. The most popular methods are metal diffusion or proton exchange [5]. These methods induce very small index change. The light is confined in index-changed regions. LN waveguide polarizers depending on the fabrication processes were also reported. For example, Zn-diffused LN waveguide was reported as TE-pass polarizer with extinction ratio of 32 dB/cm [6]. However, they cannot be used for photonic integrated devices owing to their low index contrast.

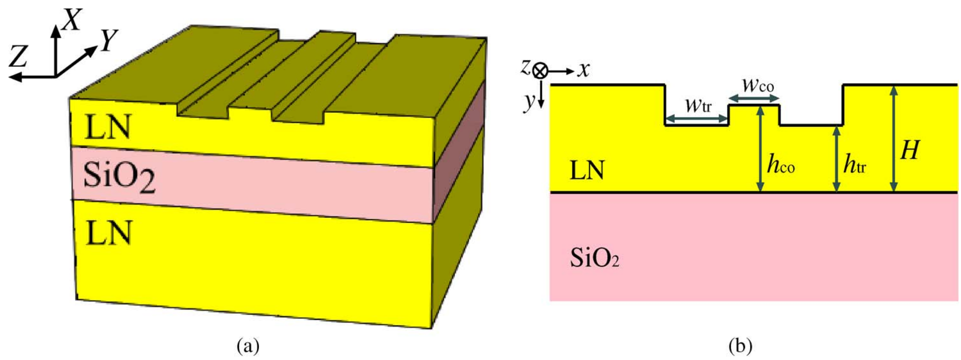

Fig. 1. (a) LN on insulator ridge waveguide polarizer and (b) its cross section.

Recently, high-quality LN thin films have been reported [7]. The thin films with bulklike quality can be obtained and adhere to low index materials such as silica by crystal ion slicing and wafer bonding [7]. It realizes high index contrast, and the fabrication method is very similar to SOI fabrication. The fabricated wafer (LN film on the insulator material) is named "LN on insulator (LNOI)" [8], [9]. LNOI achieves ridge waveguides [10] and photonic wires [8]. These waveguides are also applied in modulators [10] and microring resonators [11]. LNOI has excellent and special properties that are not in SOI, and thus, LNOI becomes a key element for the future integrated optics.

LNOI differs from SOI in anisotropy. For example, in SOI shallow ridge waveguides, only TM polarization is inherently leaky [12]. On the other hand, in shallow X-cut LNOI ridge waveguides, the leaky polarization is changed depending on the ridge waveguide height [13]. The phenomenon is caused by anisotropy of LNOI, and we have proposed that this special loss mechanism can be used for design of TE/TM-pass polarizers [14].

Generally, polarizers are obtained by making one polarization lossier than another one. Various polarizers have been reported, but TE/TM-pass polarizers based on the same loss mechanism are not reported in SOI. In this paper, we show that compact polarizer for TE/TM polarization can be achieved by using the single loss mechanism in shallowly etched X-cut LNOI ridge waveguides. We show the TE/TM-pass polarizer can be designed with enough extinction ratios. We use ridge waveguide height for switching transmitted polarization of polarizer, and we find that both TE/TM-pass polarizers can be designed in the same LNOI wafer.

This paper is structured as follows. In Section 2, we explain the loss mechanism of X-cut LNOI ridge waveguides and how to switch TE/TM-pass of polarizer. In Section 3, we evaluate structural and wavelength dependencies of TE/TM-pass polarizers. We use a vector finite-element method (VFEM) [15] for analysis of leakage losses in ridge waveguides. We also discuss the results and explain the cause of quasi-periodic leakage loss behavior in Section 3. The conclusions are written down in Section 4.

2. Loss Mechanism of LNOI Ridge Waveguide

We use LNOI ridge waveguides formed by two trenches as TE/TM-pass polarizers. We consider that such a ridge waveguide is etched on the LNOI wafer as shown in Fig. 1(a). LNOI wafer is often composed of three layers as follows: LN thin film, silica cladding layer, and LN substrate. Cladding layer is often replaced by other materials such as benzocyclobutene, but we assume silica as a cladding layer in this paper. We assume X-cut Y-propagation LN for the LNOI wafer. Capital X, Y, and Z in Fig. 1(a) indicate LN crystalline orientation. Fig. 1(b) shows the cross section of LNOI ridge waveguide. Lowercase x, y, and z in Fig. 1(b) are used for the coordinate system of VFEM solver. Light is guided in the central ridge region with the slab thickness of h_{co}. The slab thickness of the trench region is h_{tr}, and the total slab thickness of the LN layer is H. The ridge width is w_{co}, and the trench width is w_{tr}. We note that h_{co} is necessarily less than or equal to H.

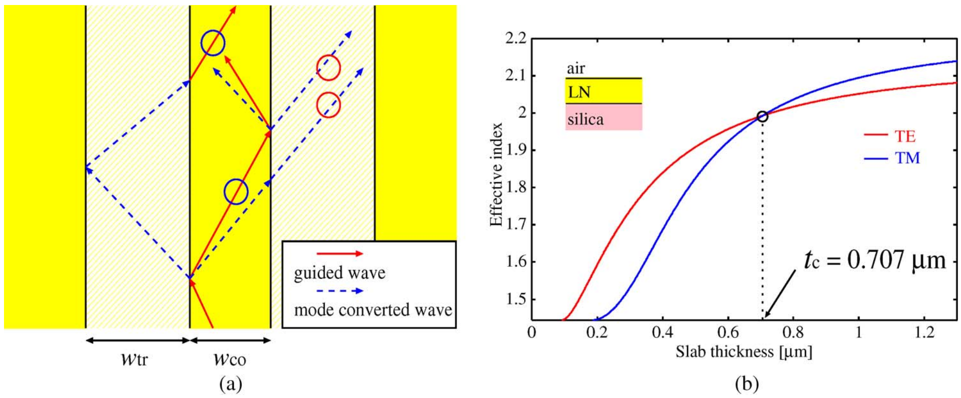

Fig. 2. (a) Top view of LNOI ridge waveguides. (b) Effective index of X-cut LNOI slab waveguide as a function of slab thickness.

Inherently, shallow ridge waveguides have leakage loss [12]. The loss is not caused by any scattering loss due to roughness of the side wall. In addition, shallow ridge waveguides achieve low scattering loss due to their low ridge height. Generally, leakage loss occurs only for TM polarization, in isotropic waveguides such as SOI. But in LNOI ridge waveguides, the leakage loss behavior changes [13]. The reason of this is explained as follows.

Leakage loss is caused by mode conversion. We explain light propagation and mode conversion using an equivalent five-layer slab waveguide as shown in Fig. 2(a). The central yellow layer is the ridge region, and its lateral two strip layers are the trench regions. The red solid arrows represent guided waves, and the blue dashed arrows represent mode-converted waves. We assume that the waves of TM (TE) polarization are guided at the central ridge layer. When guided waves reach the ridge layer boundary, TE/TM mode conversion occurs due to discontinuity between the ridge and trench layers. Most of the waves are reflected and continue to propagate in the ridge layer. However, some of the waves are mode converted to TE (TM) polarization and leak to the lateral trench layers. This is the cause of leakage loss. The converted waves radiate to two directions; some of the converted waves radiate directly to the lateral trench layer, but the other waves are reflected at the ridge boundary and propagate across the ridge layer and radiate to the another side trench layer. And some of converted and radiated waves in the trench regions are reflected at the trench boundary and enter the ridge layer again. When phases of different radiated waves marked with red circles in Fig. 2(a) are equal, leakage loss becomes larger. When the phases of guided waves in the ridge layer and re-entered waves marked by blue circles are equal, leakage loss becomes smaller. These phases can be adjusted by the values of w_{co} and w_{tr}.

As mentioned, mode conversion is the cause of leakage loss. Mode conversion at the ridge boundary always happens from polarization of low effective index to that of high effective index. In SOI ridge waveguides, only TM-like mode has leakage loss because the effective index of TE-like mode is always higher than that of TM-like mode [12]. However, in LNOI ridge waveguides, the relationship of effective index between TE- and TM-like modes is different due to anisotropy. The effective index of the ridge waveguide is predicted by that of the slab waveguide. Fig. 2(b) shows the effective index of X-cut Y-propagation LNOI slab waveguide [inset in Fig. 2(b)] at wavelength of $\lambda = 1.55$ μm. We can see that the effective indices of TE and TM modes are crossing at t_c. We note that the slab thickness of crossing point $t_c = 0.707$ μm, there is a little difference from t_c in our previous work [13], [14] because material index in this paper is given by Sellmeier equation [16] while we did not use the equation in refs. [13] and [14]. When h_{co} and h_{tr} are thinner/thicker than t_c, TM-like/TE-like mode becomes leaky. Therefore, we can switch transmitted waves of polarizer by changing waveguide heights h_{co} and h_{tr} of X-cut LNOI ridge waveguides.

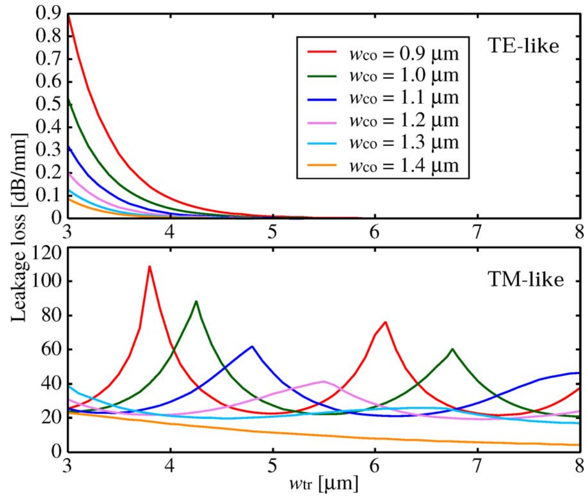

Fig. 3. Leakage losses of X-cut LNOI ridge waveguide with $H = h_{co} = 0.6$ μm and $h_{tr} = 0.48$ μm for TE-like mode and TM-like mode, as a function of trench width.

3. Numerical Analysis and Discussion

3.1. Calculation Method

We numerically investigate leakage losses of X-cut Y-propagation LNOI ridge waveguides by using VFEM [15]. We calculate leakage losses by the following processes. The waveguide cross section is divided by curvilinear hybrid edge/nodal elements. We calculate matrix eigenvalue equation with anisotropic-type perfectly matched layer [15]. By solving the eigenvalue equation, we obtain the complex propagation constant β. The leakage loss can be calculated by

$$\textit{Leakage loss} = 8.686\ \mathrm{Im}\{\beta\}\ [\mathrm{dB/m}] \tag{1}$$

where Im stands for the imaginary part. The indices of LN and silica are calculated by Sellmeier equation [16]. At wavelength of $\lambda = 1.55$ μm, ordinary and extraordinary indices of LN and the index of silica are approximately 2.211, 2.138, and 1.444, respectively. We assume that over cladding is air. We set the device length as 1 mm to realize compact polarizer.

3.2. Structural Dependency

In this section, we investigate leakage losses of X-cut LNOI ridge waveguides at $\lambda = 1.55$ μm to show that the ridge waveguide can be used for TE/TM-pass polarizer. First, we assume h_{co} and H to be identical, which condition was used in SOI TE-pass ridge waveguide polarizer [1]. In this case, fabrication process is simple because only two trenches are needed. We assume two kinds of structures with waveguide heights of $(h_{co}, h_{tr}) < t_c$ and $(h_{co}, h_{tr}) > t_c$. The former/latter structure predicted that TM-like/TE-like mode is leaky. We set the former and latter structures as $(h_{co}, h_{tr}) = (0.6\ \mu\mathrm{m}, 0.48\ \mu\mathrm{m})$ and (1.0 μm, 0.8 μm). Here, we choose temporarily $h_{tr} = 0.8h_{co}$ in order to achieve shallow ridge waveguides. Figs. 3 and 4 show leakage losses in the former and latter structures as a function of trench width with several values of w_{co}. Leakage losses of TE-like mode in Fig. 3 and TM-like mode in Fig. 4 are very small at most under 1 dB/mm, while TM-like mode in Fig. 3 and TE-like mode in Fig. 4 have large leakage losses. The losses of TE-like mode in Fig. 3 and TM-like mode in Fig. 4 become smaller when w_{co} and w_{tr} become larger. On the other hand, leakage losses of TM-like mode in Fig. 3 and TE-like mode in Fig. 4 are still large when w_{co} and w_{tr} increase. These modes are leaky modes, and the losses are caused by mode conversion as explained in Section 2. We can see quasi-periodic leakage loss behavior in those modes. When $w_{co} = 0.9$ μm in Fig. 3, leakage loss of TM-like mode is 108 dB/mm at $w_{tr} = 3.8$ μm, while that of

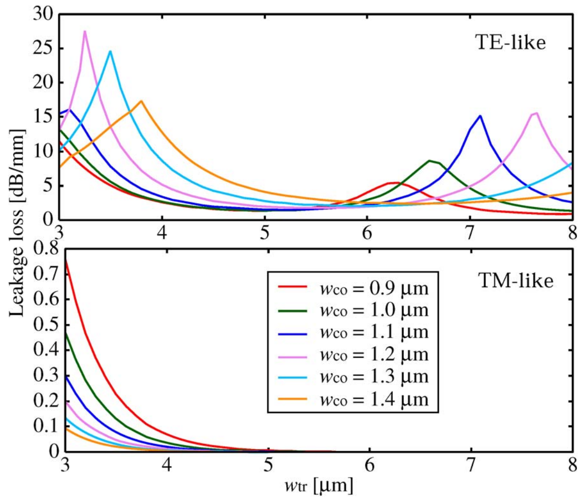

Fig. 4. Leakage losses of X-cut LNOI ridge waveguide with $H = h_{co} = 1.0$ μm and $h_{tr} = 0.8$ μm for TE-like mode and TM-like mode, as a function of trench width.

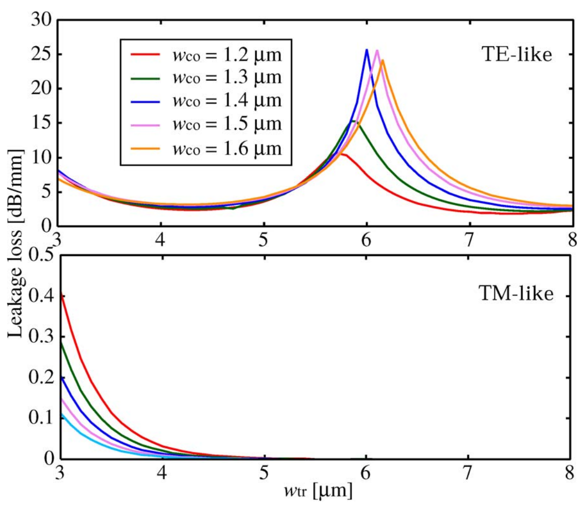

Fig. 5. Leakage losses of X-cut LNOI ridge waveguide with $H = h_{co} = 1.0$ μm and $h_{tr} = 0.82$ μm for TE-like mode and TM-like mode, as a function of trench width.

TE-like mode is 0.14 dB/mm. When $w_{co} = 1.2$ μm in Fig. 4, leakage loss of TE-like mode is 27 dB/mm at $w_{tr} = 3.25$ μm, while that of TM-like mode is 0.1 dB/mm. Extinction ratio of polarizer can be estimated by the difference of loss between TE-like mode and TM-like mode. Therefore, the former structure of $(h_{co}, h_{tr}) < t_c$ operates as TE-pass polarizer, and the latter structure of $(h_{co}, h_{tr}) > t_c$ operates as TM-pass polarizer. Both polarizers have enough extinction ratios.

In contrast to TE-pass polarizer, the extinction ratio of TM-pass polarizer is low. We investigate another TM-pass polarizer with the same height but etching depth is shallower. Fig. 5 shows leakage losses of TM-pass polarizer with $H = h_{co} = 1.0$ μm and $h_{tr} = 0.82$ μm, with several values of w_{co}. In this case, leakage loss of 25.7 dB/mm for TE-like mode is obtained with $w_{co} = 1.4$ μm and 1.5 μm for $w_{tr} = 6$ μm and 6.1 μm. At these w_{tr}, leakage losses of TM-like mode are almost zero. This ridge waveguide also operates as TM-pass polarizer. Compared with Fig. 4, the peak of leakage loss in TE-like mode is shifted to larger w_{tr}. As a result, we can obtain high extinction ratio without leakage loss of TM-like mode. The extinction ratio of TM-pass polarizer is still smaller than

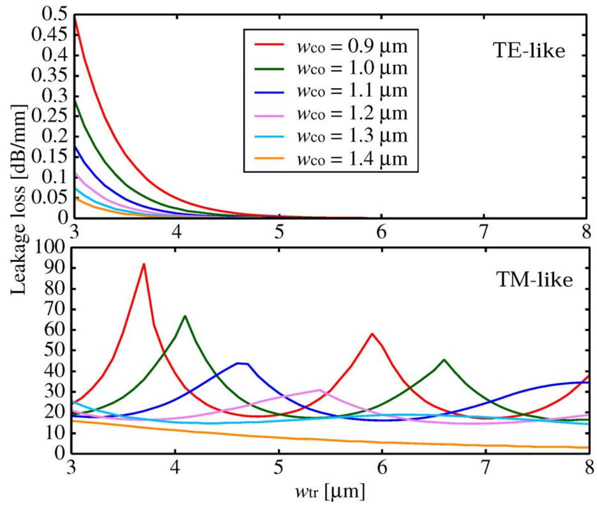

Fig. 6. Leakage losses of X-cut LNOI ridge waveguide with $H = 1.0$ μm, $h_{co} = 0.6$ μm, and $h_{tr} = 0.48$ μm for TE-like mode and TM-like mode, as a function of trench width.

that of TE-pass polarizer, but leakage loss of transmitted waves is negligibly small if w_{tr} is large enough. Thus, higher extinction ratio is easily obtained by extending the length of polarizer.

Up to here, we have shown that TE/TM-pass polarizers can be designed in LNOI ridge waveguides by changing h_{co} and h_{tr}, but with $h_{co} = H$. When $h_{co} = H$, we have to change the height of the LNOI wafer for TE/TM-pass polarizers. It means that we must prepare two LNOI wafers that have different H. Then we suppose that we design both polarizers on the same wafer. Here, we set $H = 1.0$ μm for both polarizers. For TM-pass polarizer, $H = h_{co}$ can be achieved, and the leakage loss behavior is the same as shown in Figs. 4 and 5. But, for TE-pass polarizer, h_{co} cannot become equal to H because h_{co} is required to become smaller than t_c. We show leakage losses of TE-pass ridge waveguide polarizer as a function of trench width with $h_{tr} = 0.48$ μm, $h_{co} = 0.6$ μm, and $H = 1.0$ μm in Fig. 6. The leakage loss behavior is almost the same as the case of $H = h_{co} = 0.6$ μm in Fig. 3. However, the losses in Fig. 6 are smaller than those in Fig. 3 for both TE- and TM-like modes. And the peaks of leakage losses of TM-like mode shift slightly to smaller w_{tr}. Though these differences appear, the leakage losses of TM-like mode are still much larger than those of TE-like mode. Therefore, both TE/TM-pass polarizers can be obtained with the same H and designed on the same LNOI wafer.

3.3. Discussion of Quasi-Periodic Leakage Loss Behavior

We explained that the cause of leakage loss is mode conversion in Section 2. But we can also explain the quasi-periodic behavior of leakage loss by mode coupling [1]. At the peak of leakage loss, mode coupling happens between leaky mode and higher order mode. We show mode coupling in TE-pass polarizer with $H = h_{co} = 0.6$ μm, $h_{tr} = 0.48$ μm, and $w_{co} = 1.0$ μm in Fig. 7. Fig. 7(a) and (b) shows the leakage losses and the effective indices of TE-like, TM-like, and higher order TE modes. We can see that mode coupling happens between TM-like and higher order TE modes at $w_{tr} = 4.3$ μm and 6.8 μm. We also show electric fields of x- and y-components for two coupled modes at $w_{tr} = 4.3$ μm in Fig. 8(a)–(b) and 6.8 μm in Fig. 9(a)–(b). The fields are normalized by the maximum value of each mode. The mode profiles of TM-like and higher order TE modes as shown in Fig. 8(a) and (b) are very similar owing to mode coupling. The mode profiles in Fig. 9(a) and (b) are also very similar. The x-component of the electric field around ridge and trenches is much smaller than the y-component in Figs. 8(a) and 9(a). Thus, Figs. 8(a) and 9(a) show TM-like mode, and Figs. 8(b) and 9(b) show higher order TE modes. At $w_{tr} = 4.3$ μm, TM-like mode couples with the third-order TE mode. At $w_{tr} = 6.8$ μm, TM-like mode couples with the fifth-order TE mode. When w_{tr} increases, the order of TE mode that couples with TM-like mode becomes

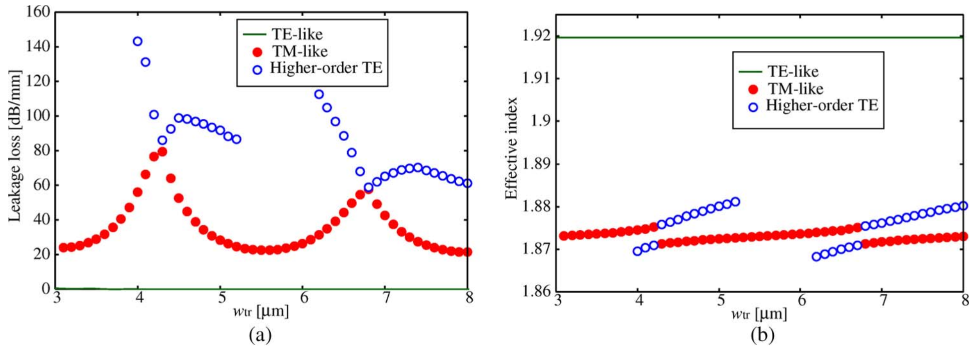

Fig. 7. (a) Leakage losses and (b) effective indices of TE-pass polarizer with $H = h_{co} = 0.6$ μm, $h_{tr} = 0.48$ μm, and $w_{co} = 1.0$ μm, as a function of trench width, for TE-like, TM-like, and higher order TE modes.

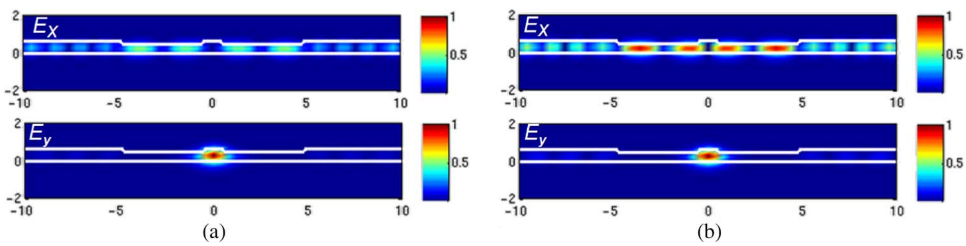

Fig. 8. Mode profiles of (a) TM-like mode and (b) higher order TE mode at $w_{tr} = 4.3$ μm.

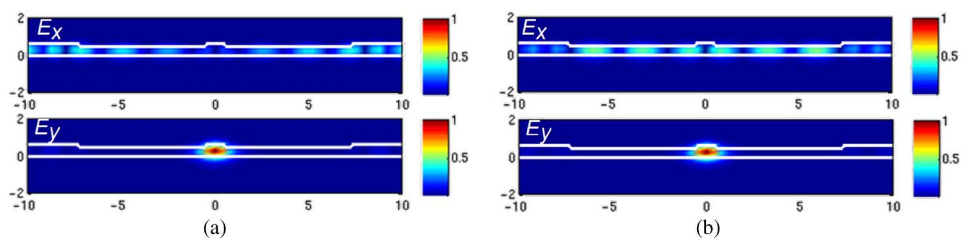

Fig. 9. Mode profiles of (a) TM-like mode and (b) higher order TE mode at $w_{tr} = 6.8$ μm.

higher. The higher order modes are almost confined in the trench regions. Thus, the higher order modes are very leaky and there is no effect to TE-like mode, which is almost confined in the central ridge waveguide region. This phenomenon is also seen in TM-pass polarizer, but mode coupling happens between TE-like mode and higher order TM modes.

The period Δw_{tr} of quasi-periodic leakage loss behavior can be approximately estimated by a simple equation [1]. We transcribe the equation of Δw_{tr} for both TE- and TM-like leaky modes in X-cut LNOI ridge waveguides as follows:

$$\Delta w_{tr} = \frac{\lambda}{2\sqrt{n_{trench}^2 - N_{eff}^2}}. \tag{2}$$

When TM-like mode is leaky, $n_{trench} = n_{trench\_TE}$ and $N_{eff} = N_{eff\_TM}$. When TE-like mode is leaky, $n_{trench} = n_{trench\_TM}$ and $N_{eff} = N_{eff\_TE}$. n_{trench_TE} and n_{trench_TM} are the effective indices of slab waveguides at slab thickness of the trench region, for TE and TM modes, respectively. N_{eff_TE} and N_{eff_TM} are the effective indices of ridge waveguides, for TE-like and TM-like modes, respectively. Commonly, TM-like mode is leaky when $n_{trench\_TE} > N_{eff\_TM}$, and TE-like mode is leaky when $n_{trench\_TM} > N_{eff\_TE}$. If both n_{trench_TE} and n_{trench_TM} are smaller than N_{eff_TE} and N_{eff_TM}, there is no

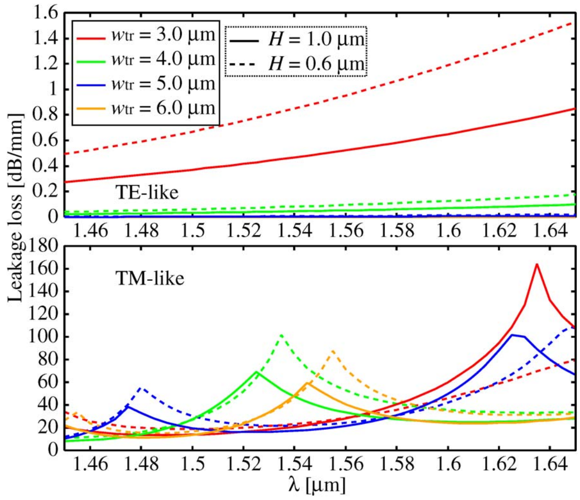

Fig. 10. Leakage losses of TE-pass polarizers with $h_{co} = 0.6$ μm, $h_{tr} = 0.48$ μm, and $w_{co} = 0.9$ μm for TE- and TM-like modes, as a function of wavelength. Solid lines represent $H = 1.0$ μm, and dashed lines represent $H = 0.6$ μm.

leakage loss in each polarization of LNOI ridge waveguide. When the etching depth of ridge waveguide is deep (the difference of h_{co} and h_{tr} is large) or ridge waveguide width w_{co} and trench width w_{tr} are enough large, leakage loss becomes small and disappears (e.g., leakage loss of TM-like mode at $w_{co} = 1.4$ μm in Figs. 3 and 6). This is because n_{trench_TE} and n_{trench_TM} become smaller than N_{eff_TE} and N_{eff_TM}. Here, we estimate Δw_{tr} of TE/TM-pass polarizers from calculated leakage losses and (2). First, we evaluate Δw_{tr} of TE-pass polarizer with $H = h_{co} = 0.6$ μm, $h_{tr} = 0.48$ μm, and $w_{co} = 1.0$ μm. Calculated Δw_{tr} from leakage losses in Fig. 3 is 2.5 μm. The effective index of leaky mode is oscillatory as shown in Fig. 7(b). $N_{eff\_TM} = 1.871$ when $w_{tr} = 4.3$ μm, but $N_{eff\_TM} = 1.875$ when $w_{tr} = 6.7$ μm. We chose $N_{eff\_TM} = 1.873$ as the average, and $n_{trench\_TE} = 1.8969$, so calculated Δw_{tr} from (2) is 2.58 μm. These two results are approximately equal. The case of $H \neq h_{co}$ and $H = 1.0$ μm is almost the same result. Next, we investigate Δw_{tr} of TM-pass polarizer. The calculated Δw_{tr} from Fig. 4 is 4.4 μm. The effective index of TE-like mode oscillates from 2.0285 to 2.0291, and we use 2.0288 for N_{eff_TE} as the average of those. $n_{trench\_TM} = 2.0366$, so calculated Δw_{tr} from (2) is 4.35 μm. Thus, (2) can approximate Δw_{tr} practically.

3.4. Wavelength Dependency

We investigate wavelength dependency of TE/TM-pass polarizers. For TE-pass polarizers, we assume two cases: $H = h_{co}$ and $H \neq h_{co}$. Fig. 10 shows leakage losses of TE-pass polarizer with $w_{co} = 0.9$ μm, $h_{tr} = 0.48$ μm, and $h_{co} = 0.6$ μm. The solid lines represent $H = 1.0$ μm, and the dashed lines represent $H = 0.6$ μm. Fig. 11 shows leakage losses of TM-pass polarizer with $w_{co} = 1.2$ μm, $h_{tr} = 0.8$ μm, and $h_{co} = H = 1.0$ μm. The leaky modes in each polarizer have the peaks of leakage losses at particular wavelengths. Leakage losses of solid lines are smaller than those of dashed lines in Fig. 10. This is the same tendency of relationship between Figs. 3 and 6 as shown in Section 3.2. Leakage losses of TE-like mode in TE-pass polarizer and those of TM-like mode in TM-pass polarizer increase monotonically when wavelength increases. This is because light confinement becomes weak by wavelength increment. On the other hand, leakage losses of TM-like/TE-like modes in TE/TM-pass polarizer show a different tendency. The leakage loss of TE-like/TM-like mode in TE/TM-pass polarizer oscillates with wavelength. We can expect that the mode coupling occurs at the peak of leakage loss. Figs. 12(a)–(b) and 13(a)–(b) show leakage losses and the effective indices of TE/TM-pass polarizers with $w_{tr} = 4.0$ μm. In Fig. 12, TM-like mode couples with the third-order TE mode at $\lambda = 1.525$ μm. In Fig. 13, TE-like mode couples with the first-order TM mode at $\lambda = 1.57$ μm. Here, we can see that the leakage loss of TE-like mode tends to be

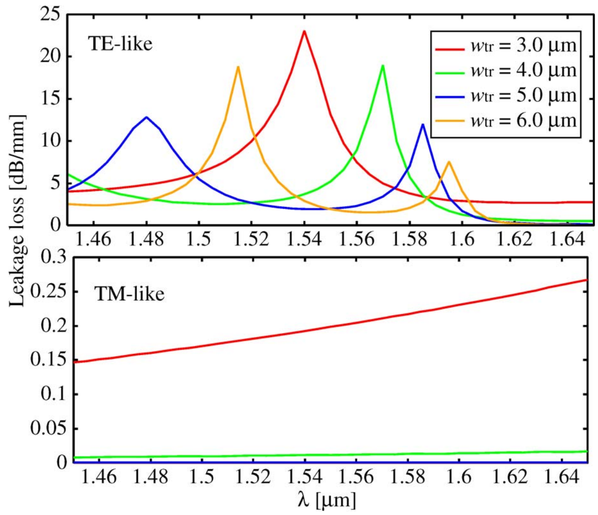

Fig. 11. Leakage losses of TM-pass polarizer with $H = h_{co} = 1.0$ μm, $h_{tr} = 0.8$ μm, and $w_{co} = 1.2$ μm for TE- and TM-like modes, as a function of wavelength.

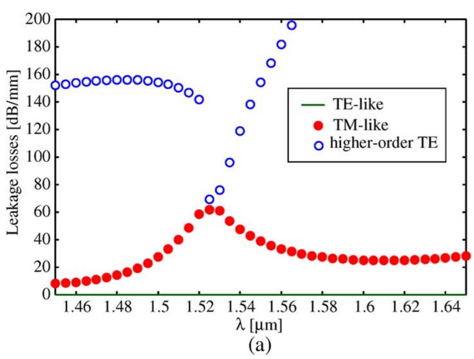

Fig. 12. (a) Leakage losses and (b) effective indices of TE-pass polarizer with $H = 1.0$ μm, $h_{co} = 0.6$ μm, $h_{tr} = 0.48$ μm, $w_{co} = 0.9$ μm, and $w_{tr} = 4.0$ μm for TE- and TM-like modes, as a function of wavelength.

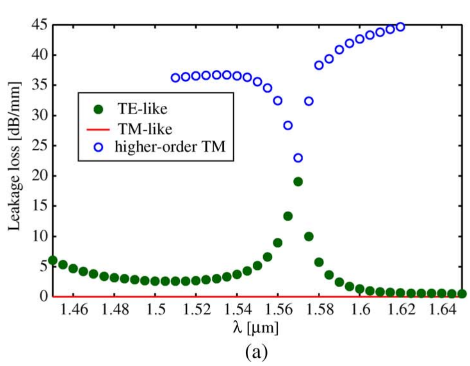

Fig. 13. (a) Leakage losses and (b) effective indices of TM-pass polarizer with $H = h_{co} = 1.0$ μm, $h_{tr} = 0.8$ μm, $w_{co} = 1.2$ μm, and $w_{tr} = 4.0$ μm for TE- and TM-like modes, as a function of wavelength.

small in Fig. 13(a) except at the mode coupling wavelength when wavelength increases, while that of TM-like mode tends to be large in Fig. 12(b) except at the mode coupling wavelength. Relationship of effective index contributes to this phenomenon. When wavelength increases, the difference of effective index between TE- and TM-like modes becomes small in Fig. 13(b), while the difference becomes large in Fig. 12(b). Leakage loss does not occur when the difference of effective index between two polarization modes is very small. Thus leakage loss of TE-like mode tends to be small when wavelength increases in Fig. 13(a).

4. Conclusion

We have proposed a TE/TM-pass polarizer based on special loss mechanism of X-cut LNOI ridge waveguides. TE/TM-pass polarizer based on single loss mechanism cannot be realized in SOI. The leaky mechanism of shallow X-cut LNOI ridge waveguides and how to design TE/TM-pass polarizers have been explained. We can switch transmitted polarization of polarizer by changing ridge waveguide height. By making slab thickness of waveguide height thinner/thicker than specific slab thickness (t_c in this paper), TE-pass/TM-pass polarizer can be achieved. We have shown and discussed the structural and wavelength dependencies of leakage loss for each polarizer. The extinction ratio of TM-pass polarizer is much lower than that of TE-pass polarizer, but that is above 25 dB with 1-mm-long device. Structure and wavelength with high extinction ratio can be changed by varying waveguide parameters. We have proved that both TE-pass and TM-pass polarizers can be designed on the same LNOI wafer. LNOI technology is still developing, and this paper is a theoretical one. But we are certain that the polarizer in this paper can be fabricated for real because only two trenches are required for fabrication and various waveguides and devices are already fabricated practically [9]. LNOI technology will become a key element in the future integrated photonics, and this report will be useful for the design of LNOI devices and circuits.

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