Waveguide Polarizer Based On Resonant Tunneling
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Abstract—We propose a novel and highly efficient waveguide polarizer based on the phenomenon of resonant tunneling. Based on this principle it is possible to fabricate both TE and TM pass polarizers. We show that by proper choice of materials it is possible to obtain TM mode loss greater than 80 dB/mm with a TE mode loss of only 0.5 dB/mm for the TE pass polarizer and TE mode loss up to 24 dB/mm with a TM mode loss less than 0.8 dB/mm for the TM pass polarizer.

I. INTRODUCTION

RECENTLY there has been considerable interest in waveguide polarizers since they form vital components in coherent optical communication systems and fiber-optic sensors. Various mechanisms [1]-[7] have been used for the design of such polarizers. We present here a novel and highly efficient polarizer structure based on resonant tunneling effects.

II. PRINCIPLE OF OPERATION

It is well known that in an optical waveguide, the difference in propagation constants of TE and TM polarizations can be increased by having a large refractive-index difference between the guiding region and the surrounding. This large difference can be made use of in the construction of polarization selective devices based on resonant coupling phenomena. Fig. 1 shows the proposed polarizer structure with the corresponding refractive-index variation. It essentially consists of a nonidentical waveguide directional coupler formed between the given waveguide (#1) and another waveguide (#2) formed by a thin high index layer (such as silicon) of refractive index \( n_h \); waveguide 2 is then covered by a high index overlay (the uppermost layer in Fig. 1). The waveguide formed by the thin high index layer is so chosen that its TM mode is resonant with the TM mode of waveguide #1. If the value of \( n_h \) is chosen to be sufficiently large then the TE mode of waveguide 2 will be completely nonresonant with the TE mode of waveguide #1. Thus light launched in waveguide #1 in the TM polarization can resonantly leak out of the waveguide to the overlay medium through waveguide #2 (much like in quantum mechanical tunneling) while for light in the TE polarization, the leakage losses will be extremely small. Thus the device will behave like a TE pass polarizer.

The operation of the polarizer structure can also be analyzed in terms of the supermodes of the directional coupler. Since the two waveguides are resonant for the TM polarization, the fundamental and the first excited TM modes (i.e., the supermodes which we label the " + " and " - " super modes) of the coupled structure will have large amplitudes in both waveguides (see Fig. 2). Hence, their leakage losses due to the presence of the high index layer would be large. On the other hand, since the propagation constants of the TE modes of the waveguides are widely spaced, the " + " and " - " supermodes would respectively have most energy confined to the high index layer and the waveguide #1 as shown in Fig. 3 (since \( n_h \gg n_i \)). Thus the leakage loss of the first excited TE supermode (which is peaked in the lower index waveguide) will be much smaller. Hence, the TM polarized light launched into waveguide #1 would excite both the supermodes corresponding to the TM polarization and would suffer large leakage losses. On the other hand, TE polarized light launched into waveguide #1 would mainly excite only the supermode that has a peak in waveguide #1, which has very low leakage losses.

Based on the same principle, it is also possible to obtain a TM pass polarizer. In this case, the thickness of waveguide 2...
the guiding layer of the high-index waveguide. However, it is possible to obtain extremely efficient polarizers with silicon as the thickness of the silicon layer. It can be seen that there is a discontinuity in the loss curve for the TM mode around a S-antisymmetric TM modes and the antisymmetric TE mode with Fig. 4 shows the variation of the loss for the symmetric and small leakage losses.

These values correspond to waveguides fabricated in glass [9]. As high index materials we have chosen silicon and TiO$_2$ with corresponding refractive index values at $X = 1.3 \mu$m as

$$n(Si) = 3.5, \quad n(TiO_2) = 2.3$$

Fig. 4 shows the variation of the loss for the symmetric and antisymmetric TM modes and the antisymmetric TE mode with thickness of the silicon layer. It can be seen that there is a discontinuity in the loss curve for the TM mode around a S-layer thickness of 30-34 nm. This is the true resonance region where the losses are extremely large and we have therefore not been able to show this on the same scale in the figure. The TE supermode has an effective index higher than the refractive index of the guiding layer of waveguide 1 and that of the high index overlay and is therefore lossless. It can be seen that it is possible to obtain extremely efficient polarizers with silicon as the guiding layer of the high-index waveguide. However, it is also possible to have polarization action with materials of smaller refractive index such as TiO$_2$. The variation of TE and TM mode loss with the thickness of the TiO$_2$ layer is shown in Fig. 5. It can be seen that for the same value of the TE mode loss (as in the case of silicon) the TM mode loss that can be obtained is much smaller in the case of TiO$_2$ as compared to silicon. This can be explained by the fact that since the refractive index of TiO$_2$ is smaller than that of silicon, the separation in the effective indexes of the TE and TM modes is much smaller for the TiO$_2$ waveguide. Therefore, the TE mode, though nonresonant, would still have a considerable coupling into the high-index overlay. In order to reduce this, the separation between the two waveguides and the distance between the high-index overlay and waveguide 2 has been increased to 1.6 $\mu$m.

(a) The thickness of the high-index layer is so chosen that the TM$_0$ mode of waveguide 2 is in resonance with the TM$_0$ mode of waveguide 1.

(b) The separation between the two waveguides is increased till the TE mode loss comes down to less than 1 dB/mm.
c) The distance between the high-index overlay and waveguide 2 is adjusted such that the TM mode loss is maximised.

(d) The thickness of the TiO$_2$ layer is then varied around the resonance thickness to obtain a suitable operating point.

As explained earlier, we can also construct a TM pass polarizer based on the principle of resonant tunneling. In this case, the TE, mode of waveguide 2 is made to be in resonance with the TE mode of waveguide 1. Fig. 6 shows the variation of TE and TM mode losses with the thickness of the silicon layer. With such a structure it is possible to obtain TE mode loss up to 24 dB/mm with a TM mode loss less than 0.8 dB/mm.

If the high-index overlay is replaced by a waveguide identical to waveguide 1 we would have polarization splitting structure. The results for such a structure will be published elsewhere.

IV. CONCLUSION

We have proposed a novel and highly efficient waveguide polarizer which is based on the phenomenon of resonant tunneling. We have suggested designs for both TE and TM pass polarizers based on this principle. We have shown that with such a device it is possible to achieve TM mode loss greater than 80 dB/mm and TE mode loss less than 0.5 dB/mm for the TE pass polarizer and TE and TM mode loss of 24 dB/mm with a TM mode loss less than 0.8 dB/mm for the TM pass polarizer. Such a design can be used for the construction of integrated optic polarizers as well as in line fiber-optic polarization components such as polarizers, polarization splitters, etc.

REFERENCES