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Ultracompact, low-loss waveguide polarizer based on plasmonics

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Abstract

An ultracompact waveguide type TM-pass polarizer is proposed based on hybrid plasmonic waveguide with a device length of only 5 μm. The extinction ratio is higher than 18 dB while the insertion loss is as low as 0.6 dB. Furthermore, the structure is of high fabrication tolerance and could be CMOS-compatible.

1. Introduction

Integration of photonic devices and microelectronic devices into a single chip provides one of the most promising approaches for high speed, high capacity data processing in the "post-Moore" age. For photonic integrated circuits (PICs), polarization handling is essential since many integrated photonic devices are polarization sensitive [1]. Polarizer is an important and effective device to realize uni-polarization system by filtering a specific polarization. Waveguide type polarizers have been proposed based on dielectric structures, but the device sizes are usually too large (e.g. 1mm). Plasmonics is a great candidate to realize compact polarization handling devices [2,3] due to its strong confinement and natural polarization sensitivity. However, metal structures usually suffer from high insertion loss or difficult fabrication. Here we propose an ultracompact TM-pass polarizer based on hybrid plasmonic waveguide (HPW). Specifically, the metal cap is wider than Si wire, enabling free alignment and easy metal lift-off. The total device length is only 5 μm while the insertion loss is as low as 0.6 dB, competitive to dielectric devices.

2. Principle

Figure 1 illustrates the proposed structure, which is built on an SOI substrate with the top Si layer thickness of 340 nm. The coupling in and coupling out sections are standard single mode Si wire waveguides with a width of 400 nm, connected seamlessly with a HPW section by tapers, whose lengths L_t are 0.5 μm .The HPW section composes of a Si wire, a thin SiO_2 spacing layer and a metal cap. The metal cap has a width of W_m and a length of L_m, covering both taper sections and the narrow Si wire section. Different from normal HPW structures that metal cap is as wide as the Si wire, here metal width W_m is much wider than the Si width W of the HPW section. For example, W_m could be 1 μm, thus avoiding the critical requirement of precise alignment between Si layer and metal layer in fabrication, also overcoming the challenge of narrow metal strip lift-off.

In order to realize TM-pass polarizer, TM mode should propagate well while TE mode is lossy. Similar to Si wire waveguides, HPW could also support both TE and TM modes. Therefore, waveguide parameters need to be carefully designed to enhance the birefringence. Mode effective index for TM mode and TE mode at various Si widths are calculated by finite element method, and the results are shown in Fig. 2. Here metal is set as Ag for an example. Other metals such as Cu and Al can also be used to make the device fully CMOS-compatible. It can be seen from Fig. 2 that TE mode experiences cut-off at a width of around

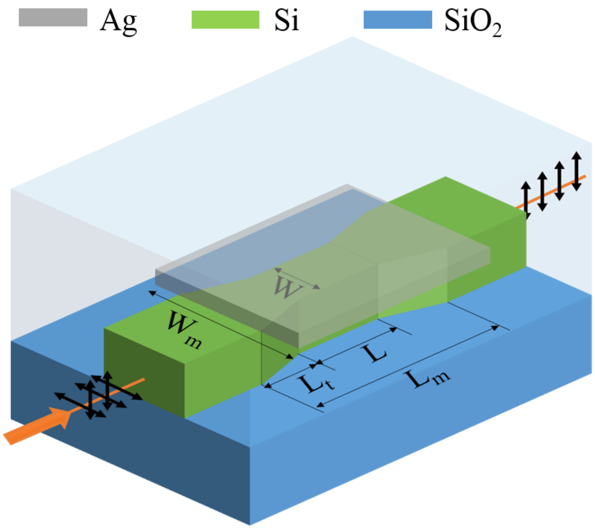

Fig. 1 3D schematic of the proposed polarizer.

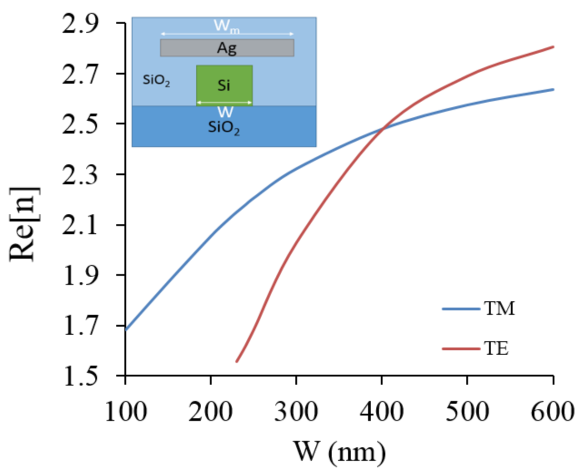

Fig. 2 The real part of mode refractive index of TM and TE modes as a function of Si width W.

230 nm, while TM mode still propagates well even at a very small width of 100 nm. This phenomenon is quite different from Si wire waveguides in which TE and TM modes have similar cut-off widths. This is because in HPW, TM mode is hybrid plasmonic mode that metal contributes much in strong confinement, while TE mode is photonic-like mode. Therefore, we can make W smaller than 230 nm to approach TE mode cut-off and TM mode passing through.

3. Discussions

3D FDTD simulation is carried out to confirm the mechanism. W is set to be 150 nm as an example, and the SiO_2 spacing layer thickness and metal width W_m are 70 nm, and 1 μm, respectively. In simulation, TM mode and TE mode are injected separately from the input Si wire waveguide. Checking the power distribution along the propagation direction from a top view, the results are shown in Fig. 3. We can see that TM mode passes through while TE mode starts to exhaust when going through the taper and finally disappears at the output end. Two key figures of merits of a polarizer are extinction ratio (ER) and insertion loss (IL), defined as

$$\mathrm{ER} = 10\lg(P_{\mathrm{TM}} / P_{\mathrm{TE}}),$$

$$\mathrm{IL} = -10\lg(P_{\mathrm{TM}} / P_{\mathrm{Input}}),$$

where P_{input} P_{TM}, and P_{TE} are the input power, and output power for TM mode and TE mode. In the above case, ER is 18 dB and IL is only 0.6 dB.

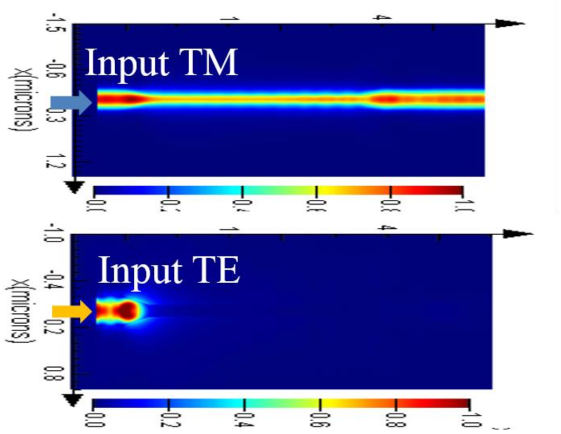

Fig. 3 Power distribution along the propagation direction from top view when input TM mode and TE mode respectively. Here W= 150 nm and L= 4 μm.

Furthermore, the influence of W to ER and IL are studied. In Fig. 4(a), ER increases markedly as W decreases below 230 nm, and reaches 23 dB at the point of W equaling to 100 nm. Meanwhile, IL also goes up as W decreases, because of HPW's initial property that narrower waveguides have larger propagation loss. The good point is that IL always keeps at a low value below 0.7 dB when W is as small as 125 nm. For a typical W of 150 nm, ER and IL as a function of narrow Si wire length L is shown in Fig. 5. ER experiences a gradual increase when the HPW section become longer, and saturates around 7 μm. IL always keeps in a low level around 0.7 dB even metal length increases.

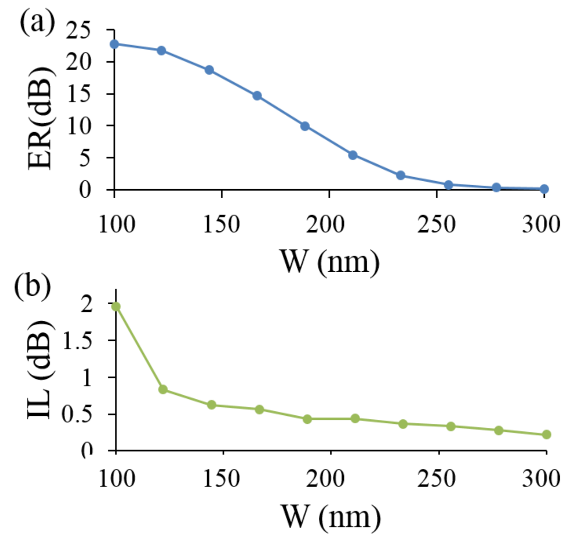

Fig. 4 ER and IL as a function of narrow Si wire width W. Here L= 4 μm.

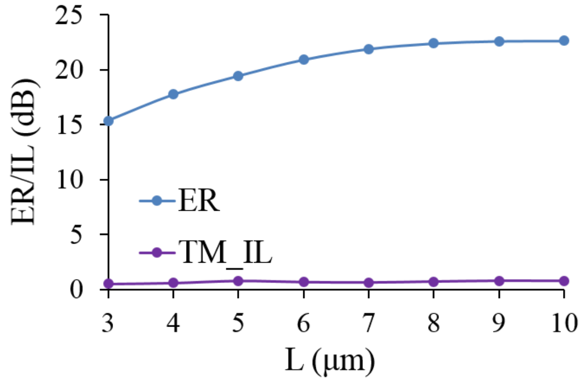

Fig. 5 ER and IL as a function of narrow Si wire length L. Here W= 150 nm.

4. Conclusions

In summary, a compact, low loss and fabrication-tolerant TM-pass polarizer is proposed based on HPW. The metal strip here is wider than Si layer and alignment-free, avoiding the biggest challenge in traditional HPW that precise alignment between metal and Si needed. For a 5 μm-long device, ER is 18 dB and TM insertion loss is only 0.6 dB. This device paves the way to realize high density integration of various applications that need polarization control, such as optical communication, quantum information and sensing.

Acknowledgements

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References

[1] Barwicz, H.I. Smith, et al, Nat. Photonics, **1**, 57, (2007).
[2] L. Gao, Z. Zhou, et al, Appl. Phys. B, **113**, 199, (2013).
[3] L. Gao, Y. Huo, J. S. Harris and Z. Zhou, IEEE Photonic. Tech. Lett., **25**, 2081, (2013).