A Terahertz Polarization Splitter Using a Hybrid Plasmonic Waveguide

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Abstract

We investigate a waveguide-based polarization splitter in the terahertz (THz) region, in which a hybrid plasmonic waveguide and a dielectric waveguide are placed in parallel. The eigenmode analysis of each waveguide shows that the phase matching condition is satisfied for the quasi-TE mode and not for the quasi-TM mode, leading to a TM-pass polarizer. The device length is also predicted with the analysis of the supermode of the parallel waveguide.

1. Introduction

It is known that a surface plasmon polariton (SPP) propagates along a metal/insulator interface at optical frequencies [1]. Note, at terahertz (THz) frequencies, that a metal/insulator interface cannot support the SPP, due to negligible penetration of the electromagnetic waves into metal. In contrast, a semiconductor material, such as indium antimonide (InSb), has a negative permittivity at THz frequencies, leading to supporting SPP waves. We have proposed a surface plasmon resonance (SPR) waveguide sensor, in which a thin InSb layer is adopted for the sensing section [2]. This THz SPR waveguide sensor utilizes only a TM wave as an input source. In this article, we investigate a waveguide-based polarization splitter in the THz region to extract the TM wave.

2. Discussion

The splitter is composed of a parallel waveguide, in which a hybrid plasmonic waveguide (HPW) with an InSb layer and a dielectric waveguide (DW) are placed in parallel. The HPW and DW are respectively shown in Fig. 1(a) and (b). The core width is denoted by w_1 and w_2, the heights of Si and SiO_2 are respectively chosen to be $h_{Si} = 50\ \mu$m and $h_{SiO_2} = 10\ \mu$m. For the HPW, an InSb layer is added on the top of the waveguide ($h_{InSb} = 20\ \mu$m). The permittivities of Si and SiO_2 are $\varepsilon_{Si} = 3.4^2$ and $\varepsilon_{SiO_2} = 1.94^2$ and the permittivity of InSb [3] is $\varepsilon_{InSb} = -36.54 - j13.05$ at 1 THz and 293 K.

The eigenmode analysis is performed to know the mode characteristics of the two waveguides. The Yee-mesh-based imaginary-distance beam-propagation method [4] is used to calculate the effective indices of the waveguides. Figure 2 shows the real part of the effective indices of the HPW and DW, as a function of w_1 and w_2. It is shown that the difference of the effective indices of the quasi-TE modes is small between the HPW and DW. In contrast, the difference of the quasi-TM mode is found to be large, when compared to the TE case. This is because for the HPW the SPP is excited and localized in the SiO_2 layer under the InSb one, leading to the increase of the effective index.

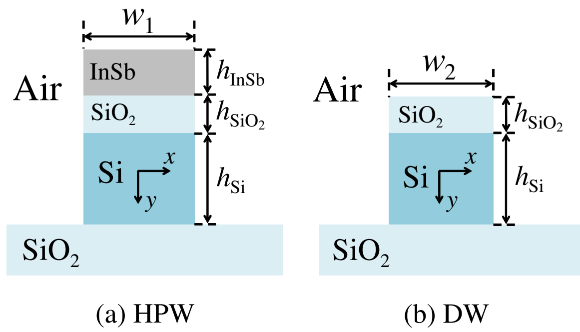

Figure 1: Waveguide structures. (a) HPW and (b) DW.

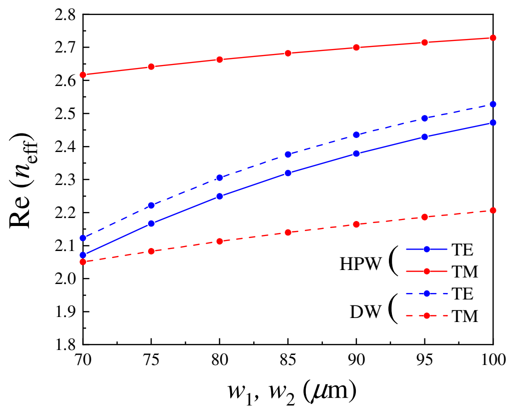

Figure 2: Effective indices.

It should be noted that the phase matching condition is satisfied only for the quasi-TE mode with slightly different core widths in Fig. 2. For example, the effective indices for the TE mode is $n_{eff} = 2.37$, when the widths of the HPW and DW are respectively chosen to be $w_1 = 90$ and $w_2 = 85\ \mu$m. On the other hand, for the quasi-TM mode, the phase matching condition is not satisfied. As a result, a polarization splitter can be realized with these waveguides being placed in parallel, in which the TE wave is coupled to the other waveguide and the TM one is obtained from the original input waveguide.

Finally, we perform the eigenmode analysis of the splitter, in which the HPW and DW are placed in parallel with a gap of 40 μm. The even and odd modes of the quasi-TE mode are calculated for the splitter. The coupling length is obtained using the real parts of their propagation constants as $L = \pi/(\beta_{\mathrm{even}} - \beta_{\mathrm{odd}})$. For the above case, i.e., $w_1 = 90$ μm for the HPW and $w_2 = 85$ μm for the DW, the device length is calculated to be $\simeq 8600$ μm, while it is reduced to be $\simeq 2700$ μm for $w_1 = 73$ and $w_2 = 70$ μm.

3. Conclusion

We have investigated a THz polarization splitter with a hybrid plasmonic waveguide and a dielectric waveguide being placed in parallel. It is shown that the phase matching condition is satisfied for the quasi-TE mode, while it is not satisfied for the quasi-TM mode. As a result, the polarization splitter can be realized, in which the TE wave is coupled to the other waveguide and the TM one is obtained from the original input waveguide. The propagating beam analysis using the simple frequency-dependent FDTD method [5] will be shown at the presentation.

Acknowledgement

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