Phase and direction control of terahertz wave propagating in waveguide coupled with bulls-eye structure

Seigo Ohno[(1),(2)], Yu Tokizane[(2),(3)], Jun-ichi Shikata[(4)], and Hiroaki Minamide [(2)]
(1) Tohoku University, Miyagi, Japan, e-mail: seigo@tohoku.ac.jp
(2) RIKEN, Miyagi, Japan; e-mail: yu.tokizane@riken.jp, minamide@riken.jp
(3) pLED, Tokushima University, Tokushima, Japan;
(4) Nihon Univ, Fukushima, Japan; shikata.junnichi@nihon-u.ac.jp

A bulls-eye structure, in which a subwavelength aperture on a metal substrate is surrounded by a concentric circular grating structure, has been known to show the anomalous transmission effect for a normal incident electromagnetic (EM) wave when the EM wave resonates to the grating structure. Its light collecting nature into the tiny area around the aperture has been applied to high resolution imaging[1]. So far, we have proposed the light collecting nature applied to an antenna for wireless communication devices in the THz region. We will present a waveguide structure coupled with a bulls-eye which shows possibility to control the phase and the propagation direction of the THz wave in the waveguide via the polarization state of the incident beam to the bulls-eye.

Due to the bulls-eye's center symmetric character, the transmittance is independent of the polarization angle of the normal incident beam. The transmitted light passing through the subwavelength aperture has high wavenumber component. These features of the bulls-eye provide robustness for coupling to a waveguide when the waveguide is located nearby exit of the aperture. Now, we suppose that a strip-line type waveguide located nearby the aperture and the weveguide mode is coupled with the incident THz-wave through the bulls-eye and its aperture as shown in Fig. 1. The phase relation between the waves propagating along +x and -x directions depends on the polarization direction of the incident beam, as, when x-(y-) polarized case, the waves are in opposite phase (in phase). Furthermore, we introduce the symmetry breaking in y- direction by locating the waveguide not immediately above, but slightly shifting along y-direction. When immediately above case, the lowest propagation mode can not be coupled by y-polarized incident beam because of the selection rule of the coupling. However, for the asymmetric case, the lowest propagation mode can be allowed for both x and y polarized beams incidence. The waves propagating to +/-x direction excited with the beam linearly polarized to the direction tilting by θ from y axis can be formulated as,

$$\begin{pmatrix} E_{+x} \\ E_{-x} \end{pmatrix} = \begin{pmatrix} A\cos\theta\, e^{i\alpha} + B\sin\,\theta\, e^{i\beta} \\ A\cos\theta\, e^{i\alpha} - B\sin\,\theta\, e^{i\beta} \end{pmatrix} e^{-i\omega t}, \qquad (1)$$

where, A and B are coupling constant given in real numbers, α and β are phase delay through the coupling. This means that one can control the phase difference between E_{+x} and E_{-x} via the polarization angle θ. Furthermore, by modifying this formula, we found that one can switch the propagation direction if the polarization state of the incident beam is changed from linear to elliptically polarized beams. We verified such controllability with the numerical simulations (Fig.2). We believe this work will be one of base techniques for THz communication and precise measurement.

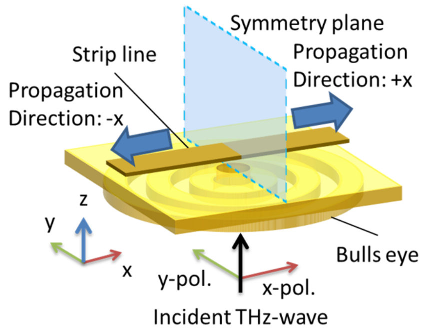

Figure 1. Configuration of the waveguide couple with a bulls eye. The location of the waveguide is slightly deviated from directly above of an aperture in the bulls eye.

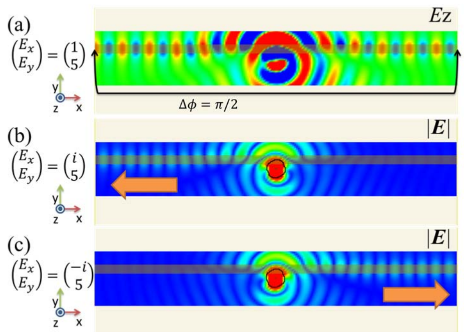

Figure 2. (a) phase difference control between the waveguide edges in $\pm$x sides and (b,c) propagation direction control by polarization state of the incident beam.

Acknowledge This work was partially supported by TOPCON CORPORATION and KAKEN (JP18K04967).

References

[1] Hua Chen,* Shihua Ma, Xiumei Wu, Wenxing Yang, and Tian Zhao, "Diagnose human colonic tissues by terahertz near-field imaging," Journal of Biomedical Optics, **20**, 3, March 2015, pp. 036017-1-4, doi: 10.1117/1.JBO.20.3.036017.