Quarter Waveplate at Upper Terahertz Range based on Form Birefringence

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***Abstract*—Quarter waveplates (QWPs) at upper terahertz range are demonstrated based on form birefringence of silicon grating. With depth of 15.5 and 8.4 μm, the gratings act as QWPs at 4.9 and 9.5 THz, respectively. The QWP is also successfully used to measure the state of polarization in a polarimetric system.**

I. INTRODUCTION

Waveplates are key components to introduce phase retardation in a number of optical systems, as well as the terahertz wave system[1]. The waveplates are traditionally made of natural birefringence materials, such as quartz crystal, calcite and mica. Besides, artificial structure, sub-wavelength period gratings (SPGs), which means the wavelength of grating should be small enough to avoid high order diffraction, also shows the so called form birefringence feature[2-5]. The form birefringence is usually much larger than natural birefringence. Thus waveplates based on form birefringence have relatively small size and low loss than those using natural materials.

From visible light range to wavelength of 2 μm, waveplates are usually made of quartz crystal; from wavelength of 2 μm to 8 μm, waveplates are usually made of cadmium thiogallate ($CdGa_2S_4$). However, in terahertz range, the waveplates go to several millimeters-thick by natural material, which definitely will also cause large loss. Silicon based SPG is a good solution in this range[3, 6]. Its birefringence is 20 times more, and the absorption rate is much lower than quartz crystal. Here we demonstrate some quarter waveplates based on silicon grating at 4.9 THz, and 9.5 THz respectively. Being different with the severe absorption in quartz crystal, silicon with high resistivity has a quite lower absorption in the upper terahertz range.

II. PRINCIPLE AND RESULTS

Form birefringence can be generated by SPG structure according to the effective medium theory,

$$\begin{cases} n_x^2 = n_{x0}^2 + \frac{1}{3}\left(\frac{L}{\lambda}\pi f_1 f_2 (n_1^2 - n_2^2)\right) \\ n_y^2 = n_{y0}^2 + \frac{1}{3}\left(\frac{L}{\lambda}\pi f_1 f_2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) n_{x0} n_{y0}^3\right) \end{cases} \quad (1)$$

where f1 and f2 are volumetric fractions of the individual components, and n1, n2 are refractive index of alternative layers in Fig.1. L is the period of the grating. n_{x0} and n_{y0} are the quasi-static refractive index given by,

$$\begin{cases} n_{x0}^2 = f_1 n_1^2 + f_2 n_2^2 \\ n_{y0}^2 = \left(\frac{f_1}{n_1^2} + \frac{f_2}{n_2^2}\right)^{-1} \end{cases} \quad (2)$$

which are only effect when $L \ll \lambda$.

1mm-thick silicon wafers, with its resistivity larger than

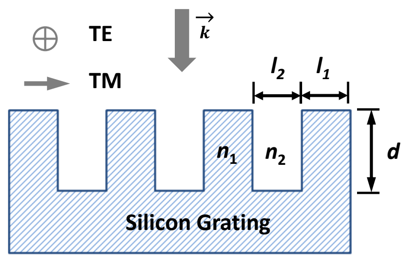


Fig.1 the structure of the sub-wavelength period grating

2000 ohm*cm are used to fabricate the SPGs. The period of grating is 6 μm, and the fill factor (f1=1-f2) is 0.5. Deep reactive ion etching (DRIE) processes are used to make the gratings with depth of 15.5 and 8.4 μm for QWPS at 4.9 and 9.5 THz respectively, according to equation (1).

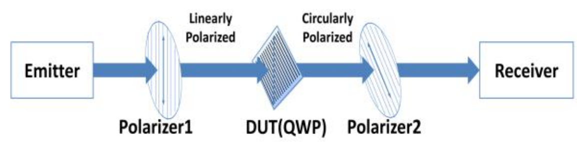
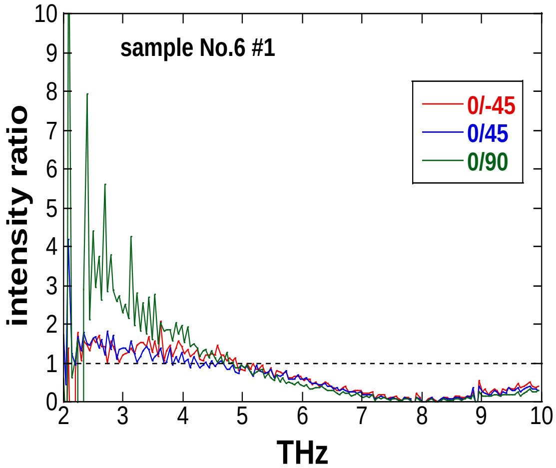


Fig.2 Setup of the measurement system

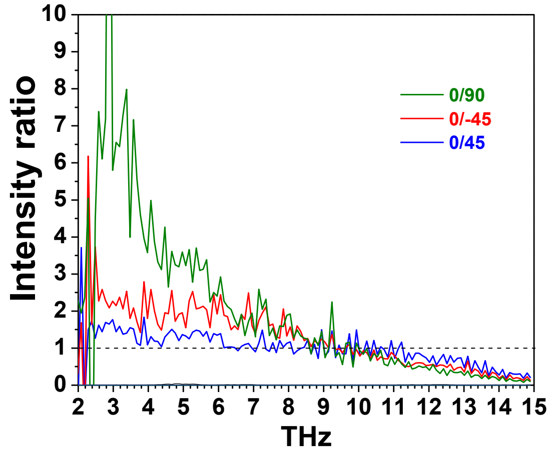
The gratings are measured in a frequency domain terahertz spectroscopy system as Fig. 2. Polarizer 1 is set to generate vertical linear polarized beam with SOP of (1, 0, 0). Hereinafter, all alignment angles of gratings are expressed as angles between the grating lines and the orientation of (1, 0, 0); all angles of polarizer are expressed as angles between its principle axis and the orientation of (1, 0, 0).

The linear polarized beam travels through the grating aligned at 45 degree. Then, at the frequency where the grating to be a QWP, the outgoing beam will be converted to a circularly polarized beam. The received intensities are measured when polarizer 2 located at 0, 45, -45 and 90 respectively, with respect to the principle axis of polarizer 1. Thus the ratios between these intensities will be 1 for a circular polarized beam. Fig. 3 shows the ratios between the intensities. The curves merge at the point of (4.9, 1) in Fig. 3 (a) and (9.5, 1) in Fig. 3 (b), which means the gratings act as QWPs at 4.9 and 9.5 THz respectively.

In a polarimetric THz-FDS system, a quarter-wave plate can be used to measure the state of polarization (SOP) of THz radiation together with a THz polarizer. To further investigate the performance of the QWP, we also use QWP at 4.9 THz to measure the SOP of the system. In this case, polarizaer1 in Fig. 2 is used to generate SOP of (1, 0, 0) and (0, 1, 0) at 0 and 45 degree respectively; and polarizer 2 is parallel with the orientation of (1, 0, 0). The SOP is measured by rotating the QWP with angles of 0, -45, 30 and 60 degree respectively. Fig.

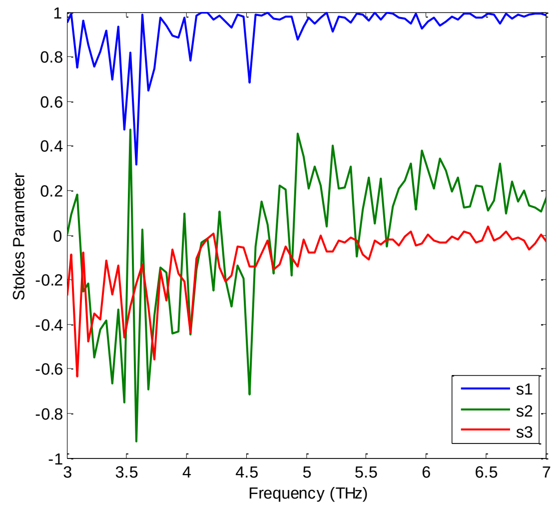


(a)

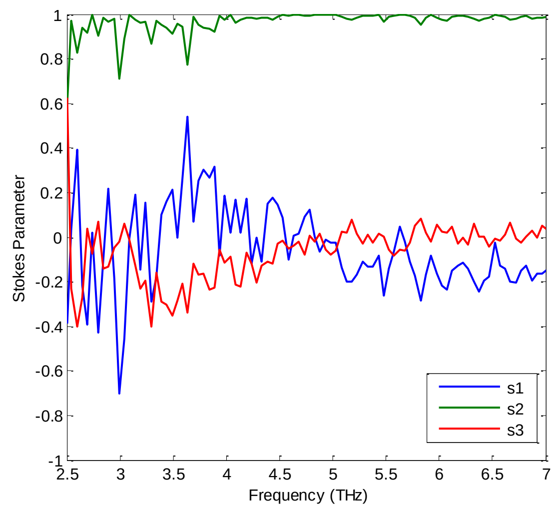


(b)

Fig.3 Intensity ratios of QWPs at (a) 5 and (b) 9.5 THz



(a)



(b)

Fig. 4 calculated SOP of the system (a) (1, 0, 0); (b) (0, 1, 0).

4 shows the calculated SOP by QWP at 4.9 THz. Obviously, the calculated Stokes parameter at 4.9 THz is close to (1, 0, 0) and (0, 1, 0) in Fig. 4(a) and Fig. 4(b), respectively. The calculated results have a good agreement with the input SOP.

III. Conclusion

SPG-based QWPs at upper terahertz range are demonstrated 4.9 and 9.5 THz, respectively. The QWP is also successfully used to measure the state of polarization in a polarimetric system.

Acknowledgements

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