Silicon-Based Quarter Waveplates (QPWs) for Wide Range of THz Spectrum

Plataus THz spektrų ruožo Silicio ketvirčio bangos plokštės

Surya Revanth Ayyagari[1], Simonas Indrišiūnas[2], Daniil Pashnev[1], Vytautas Janonis[1], Andreas Kurt Klein-Schuster[3], Guillaume Ducournau[4] and Irmantas Kašalynas[1]

[1]Terahertz Photonics Laboratory, Center for Physical Sciences and Technology (FTMC), Saulėtekio 3, 10257 Vilnius, Lithuania

[2]Laser Microfabrication Laboratory, Center for Physical Sciences and Technology (FTMC), Savanoriu ave. 231, LT-02300 Vilnius, Lithuania

[3]Department of Optoelectronics, University Duisburg-Essen, Forsthausweg 2, 47057, Duisburg, Germany

[4]Institut d'Electronique de Microélectronique et de Nanotechnologie (IEMN), UMR CNRS 8520, Université de Lille 1, 59652, Villeneuve d'Ascq CEDEX, France

surya.revanth@ftmc.lt

Critical need of reduced complexity waveplates and phase retarders developed to manipulate the polarization state of light is ever-increasing process in the fields of optical imaging, spectroscopy and communication [1]. Waveplates introduce a controlled phase delay between two orthogonal polarization components, enabling modulation of EM wave properties. The main feature that exhibits a phase delay between two orthogonal polarization components in these optical devices is called birefringence. Artificial birefringence can be created either by producing electromagnetic structures or by creating subwavelength gratings which makes the material to obtain high anisotropy because of the spatial asymmetry of structures[2][3].

In this work we developed a monolayer-dielectric-based silicon grating waveplates for operation as quarter waveplate (QWP) in wide frequency range from 0.3 THz to 0.5 THz. In addition, the proposed Si waveplates exhibits anti-reflective behavior with the inclination of grating walls along the Transverse Electric (TE) mode by reducing the reflection losses caused by Silicon-air interfaces. The phase retardance of $90^{\circ} \pm 10^{\circ}$ between orthogonal Transverse Magnetic (TM) and TE polarizations within operational bandwidth of ~200 GHz was confirmed both experimentally and numerically.

Three samples were designed and fabricated of a subwavelength periodic silicon-air interfaces with a period of p = 100 µm and the ridge height g = 50, 100, and 200µm, i.e the height of grating ridge from the groove on top of a HRFZ-Si silicon wafer with a overall thickness of t = 250 µm. For data discussion, a TM (TE) polarization was oriented perpendicularly (parallel) to grating ridges as it is shown in Fig.1 inset. The Finite Difference Time Domain (FDTD) simulations and THz Time Domain spectroscopy (TDS) were used to develop and assess the performance via analysis of waveplate transmission and phase spectra under varying conditions.

Direct laser ablation (DLA) was employed to fabricated the three grating samples on Si wafer having different depth and shape of the ridges. The transmission spectra of gratings with g= 50, 100, and 200µm were measured by THz-TDs measurements. Phase spectra are shown in Fig.1. Among three samples, the sample with ridge height of 200 µm showed a clear plateau region at level of $90^{\circ} \pm 10^{\circ}$ for a bandwidth of ~200GHz centered at frequency of 0.4 THz. All experimental spectra were numerically modeled to confirm QWP performance with a good accuracy and possibility to scale grating ridges in order to change the operation frequency in THz range.

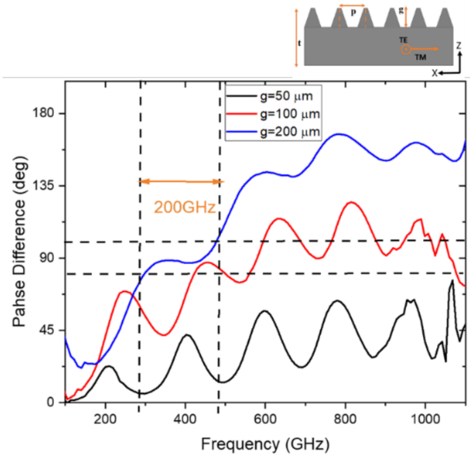

Fig.1. Phase spectra of fabricated Si waveplate samples with grating ridge height of 50, 100, and 200 µm. Inset: schematic representations of waveplate along XZ-axis with a design parameters.

ACKNOWLEDGMENT

This work received funding through the EU TERAOPTICS project (grant no. 956857, program H2020-EU.1.3.1. topic MSCA-ITN-2020) and European Regional Development Fund funded T-HP project (grant no. 01.2.2-LMT-K-718-03-0096).

References

[1] T. Kürner, D. M. Mittleman, and T. Nagatsuma, Eds., *THz Communications*, vol. 234. Cham: Springer International Publishing, 2022.

[2] M. Chen, F. Fan, S. T. Xu, and S. J. Chang, "Artificial high birefringence in all-dielectric gradient grating for broadband terahertz waves," *Sci. Rep.*, vol. 6, no. December, pp. 2–11, 2016, doi: 10.1038/srep38562.

[3] P. Birgit, N. Passilly, J. Pietarinen, P. Laakkonen, M. Kuittinen, and J. Tervo, "Low-cost fabrication of form-birefringent quarter-wave plates Abstract :," vol. 16, no. 21, pp. 2939–2943, 2008.