Journal of Physics: Conference Series

Design and measurement of a single-band metasurface sample in the terahertz band

To cite this article: Hengbo Xu 2022 *J. Phys.: Conf. Ser.* **2310** 012064

Design and measurement of a single-band metasurface sample in the terahertz band

Hengbo Xu[1]

[1]College of Electrical and Elctronic Engineering, The University of Manchester, Oxford Rd, Manchester, M13 9PL, UK

E-mail address: txznlj@163.com

Abstract—A single-band metasurface sample in the terahertz band is designed, simulated, and measured. This terahertz metasurface sample reveals a transmission peak. And the resonance frequency of this peak is 2.06THz (amplitude is 0.74, half-bandwidth is 0.7THz). In experiments, the diameter is reduced, which leads to the amplitude is enahcned and this peak move to low frequencies. The parameter T3 is reduced, which results in the amplitude of the transmission peak strengthened, while the resonance frequency stable. When the incident angle of the electromagnetic wave is increased, this transmission peak is reduced and the resonance frequency moved to the low frequencies. The polarization angle is increased, the metasurface sample exhibits similar resonance behaviors.

1. Introduction

Electromagnetic metamaterials/metasurfaces have rich resonance properties, such as negative refraction, perfect transmission, perfect absorption [1]. Properties and resonance behaviors of metasurfaces are mainly determined by the design strategy and material composition. Functional devices developed based on metasurfaces can be applied in many fields [2]. Metasurface devices are appplied in the field of communication [3-5]. Therefore, a single-band metasurface sample is designed and validated in the terahertz band in this paper. The metasurface can obtain obvious single transmission band resonance performance in the dark frequency band, which can be used in the fields of communication and sensing. The measurement results show that the transmission properties of the metasurface samples can be enhanced by optimizing the structural parameters.

2. Construction and Geometrical Dimensions of Specimens

The structure of this metasurface sample can be found in Fig1. Structural unit contains of metal layers, SU-8 layers, and one Si layer. An array of circular holes is defined on the metal layers. The lattice constant is defined as $P = 20\mu m$. Other parameters are $D = 14\mu m$, $T1 = 0.5\mu m$, $T2 = 2.5\mu m$, $T3 = 10\mu m$. All of simulations are revealed by the HFSS. The boundaries of structural elements are defined as ideal electromagnetic boundaries. The scan step size was set to 0.01 THz, and the excitation end of the electromagnetic wave was located 20 μm above the structural unit. The sample preparation steps are as follows: 1. Select a piece of glass as a temporary substrate (washed and dried). 2. Use a glue spinner to cover the SU-8 layer over the substrate, and use a hot plate to dry and cure. 3. Use a coater to deposit a layer of metal over the SU-8 layer. 4. Use acetone solution to remove the SU-8 layer to obtain an independent metal layer. 5. Use a glue spinner to cover a layer of SU-8 on top of the metal layer, and use a hot plate to cure the SU-8 layer. 6. Use a coater to deposit a silicon layer over the SU-8 layer. 7.

Use a glue spinner to cover the second SU-8 layer over the silicon layer and cure it with a hot plate. 8. Use a coater to deposit a second metal layer over the second layer of SU-8. 9. Use the etching machine to define the circular hole array, which can be found in Fig 1(c)

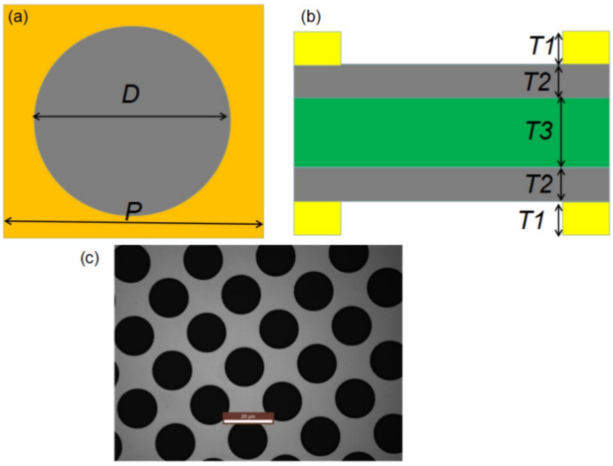

Fig 1. Structural design and samples. (a) the top of the proposed unit. (b) The cross-sectional of the proposed structural unit. (c) Optical photograph of this metasurface sample

3. Test results and discussions

The transmittance measurement and simulation results of this metasurface sample are ahceived, which are found in Fig. 2. A transmission peak is excited at 2.06THz, (amplitude is 0.74, half-bandwidth is 0.7THz). At the same time, a simulated transmission peak was also obtained (amplitude 0.88, half-bandwidth 0.83 THz). The simulation results are agree with the measurement results, which indicates that the configuration of this structural unit is effective. The physical principle of this peak come from the LSP modes coupling effect, which is excited at the circular hole array. This is because the electromagnetic waves couples with the metasurface samples, localized regions are excited with distinct electronic oscillations and induced electric fields on the circular hole array. These induced electric fields interfere with electromagnetic waves to excite strong transmitted electric fields. The transmission impedance of the metasurface structural unit is improved and the transmission performance is enhanced.

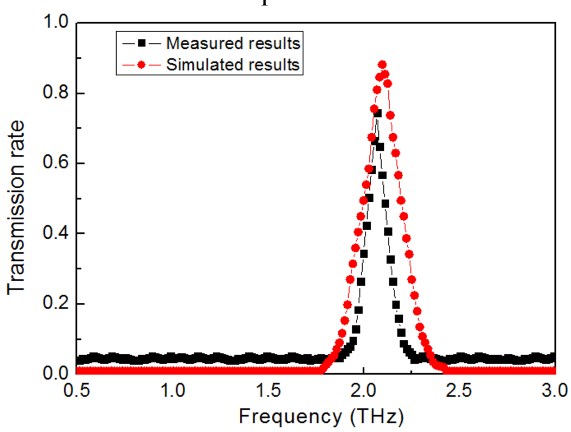

Fig 2. Transmittance measurements and simulation results of this metasurface sample.

Structural parameters are important factors in determining the transmission properties of the metasurface samples. The parameter D is set to D=14, D=15, and D=16, respectively, which can be found in Fig 3. These results reveal that the diameter of the circular hole array has an important influence on the transmission peak. When the diameter is D=15, the transmission peak is strengthened, the

2310 (2022) 012064 doi:10.1088/1742-6596/2310/1/012064

amplitude is increased to 0.81, and the resonance frequency is shifted to 1.74THz. When the diameter is D=16, the transmission peak is further strengthened, the amplitude is increased to 0.93, and this peak is shifted to 1.53 THz. This is because the excitation of the transmission peak is related to the geometrical parameters of the circular hole array. As the parameter D is increased, the transmitted electric field is strengthened. At the same time, the reflection loss of the electromagnetic wave is simultaneously weakened. These factors cause the transmission peak to be enhanced.

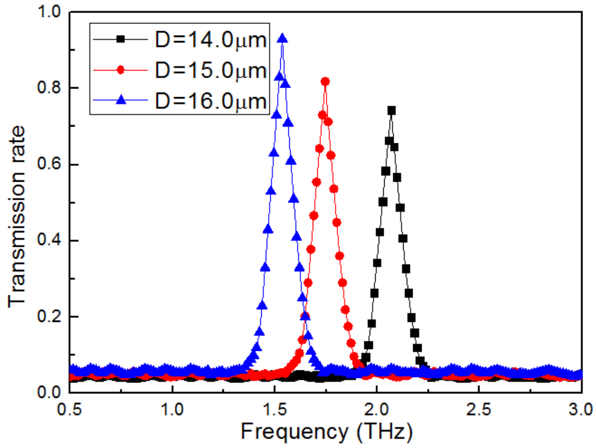

Fig 3. Transmittance measurements at different hole array diameters D.

In the second set of experiments, the thickness of the dielectric layer Si was gradually reduced, as shown in FIG. 4. The measurement results show that the influence of the thickness of the dielectric layer on the transmission peak is not obvious. When the parameter T3 is reduced to T3=8.0 μm, the amplitude of the transmission peak is increased to 0.81. And when the parameter T3 is reduced to T3=6.0 μm, the amplitude of the transmission peak is increased to 0.89. Due to the parameter T3 is reduced, dielectric loss of the electromagnetic wave is weakened, resulting in the enhancement of the transmission peak. It should be pointed out that the resonance locations are basically the same. The excitation principle of this peak is based on the transmission electric field of the circular hole array.

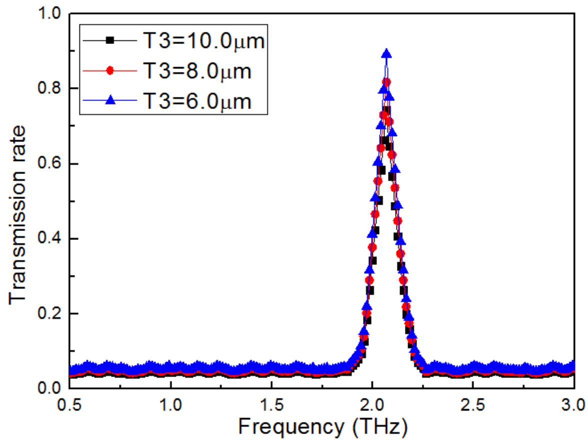

Fig 4. Transmittance measurements at different thickness T3.

The incident angle is gradually increased, the measured results can be found in Fig. 5. When the incident angle is 30^0, the amplitude of the transmission peak is 0.66, and the resonance frequency is 1.95 THz. When the incident angle is 45^0, the amplitude of the transmission peak is 0.63, and the resonance frequency is 1.83 THz. When the incident angle is 60^0, the amplitude of the transmission peak is 0.41, and the resonance frequency is 1.40 THz. These measurements show that the incident angle of electromagnetic waves has an impact on the metasurface samples. This is because the angle of incidence is related to the excitation strength of the transmitted electric field. When the incident angle is reduced, the excitation intensity of the transmitted electric field is weakened. It should be pointed out that when the incident angle is 60^0, the transmission peak is abnormally reduced. Moreover, when the incident angle of electromagnetic waves is 60°, the coupling effect is disabled.

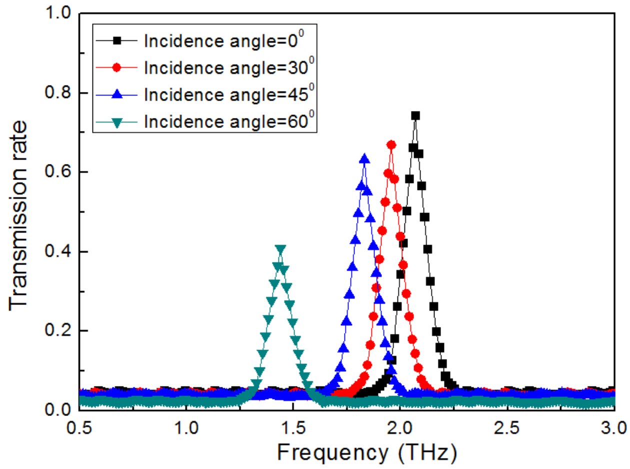

Fig 5. Transmittance measurements at different incidence angles.

The polarization angle is gradually increased, measured results can be found in Fig 6. When the polarization angle is 30^0, the amplitude of the transmission peak is 0.71, and the resonance frequency is 2.02 THz. When the polarization angle is 45^0, the amplitude of the transmission peak is 0.66, and the resonance frequency is 1.97 THz. When the polarization angle is 60^0, the amplitude of the transmission peak is 0.61, and the resonance frequency is 1.89 THz. The polarization angle of the incident electromagnetic wave has an important influence on the samples. The polarization angle is related to the coupling effect. The increase of the polarization angle will directly lead to a weaken coupling.

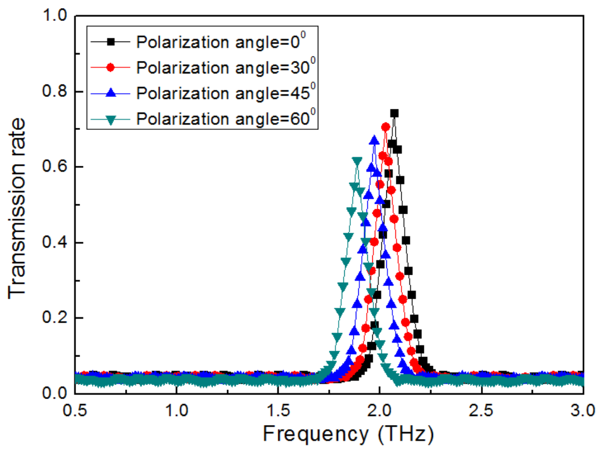

Fig 6. Transmittance measurements at different polarization angles.

4. Conclusion

In this paper, a terahertz metasurface sample is designed and measured. The metasurface sample can excite an obvious peak at 2.06THz (amplitude is 0.74, half-bandwidth is 0.7THz). The influence of structural parameters is revealed.

(1) When parameter D is reduced, the peak is strengthened and moved to low frequencies.

(2) When parameter T3 is reduced, the transmission peak is also strengthened but the resonance frequency is basically stable.

(3) When the incident angle of the electromagnetic wave is increased, this peak is also reduced and shifted to the low frequencies.

(4) When the polarization angle is also increased, the metasurface sample exhibits similar resonance behavior.

References

[1] Per Lunnemann, A. Femius Koenderink, The local density of optical states of a metasurface, Scientific Reports,6:20655-20661(2015).

[2] !SamanKarami, !M.Nikoufard, !Seyed Mohammad Shariatmadar, !SaeidJavadi,Plasmonic hyperbolic metamaterial and nanosphere composite for light trapping as a solar cell: Numerical study, GotoOpticalMaterialsonScienceDirectOptical Materials,122, 2021, 111740

[3] Mehmood M Q, Mei S T, Hussain S, Huang K, Siew S Y et al. Visible-frequency metasurface for structuring and spatially multiplexing optical vortices. Adv Mater 28, 2533–2539 (2016)

[4] Hengbo Xu, Design, Simulation and measurement of a Single-band High-Transmittance All-Dielectric Metamaterial Filter, Optical Materials, 125, 2022, 112145

[5] Hengbo Xu, Design, simulation, and measurement of a multiband tunable metamaterial filter, Optical Materials, 127, 2022, 112253