

A Metamaterial with Dual-Band Perfect Terahertz Transmission

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ABSTRACT. In recent years, the electromagnetic metamaterial has been development rapidly. Meanwhile, its peculiar electromagnetic properties have been widely studied in the fields of electromagnetism and optics. Compared to conventional natural materials, metamaterials show some unusual phenomena, for example, negative refractive index. Because of their exotic properties, metamaterials have been found with many applications, such as perfect lens, cloaking, solar cells and so on. In this paper, we report a metamaterial with dual-band perfect transmission in terahertz range. By tailoring the periodicity of the unit cell, significantly high transmission can be obtained with the metamaterial. The simulation results show that significant transmission peaks at 3.56THz and 7.16THz with the magnitudes of 99.8% and 99.7%, respectively.

1. Introduction

Electromagnetic metamaterials have been researched for many years due to their peculiar optical and electromagnetism properties[1, 2]. Studies of the spectral response of metamaterials included various types of resonance structures. Because of the unusual properties, metamaterials have been developed with many applications, such as perfect lenses, negative refractive index materials, invisible cloak[3-5]. Normally, metamaterials have been created with periodically unit cells consisting of metal structure and dielectric layers. The surface of metal structure resonates with the incident electromagnetic waves. Metamaterial composed of periodically splitting ring resonators (SRRs) have been widely studied^[6]. The periodic SRR array has certainly electromagnetic response by changing its configurations. Metamaterial with high transmission properties are important in some potential applications[7].

Terahertz waves are electromagnetic waves with wavelength range of from 0.1 THz to 10THz. The terahertz wavelength varies from 0.03 mm to 3 mm, which falling in the regime between the microwaves and the infrared[8]. In 1896 and 1897, Rubens and Nichols were involved in this band, and over the next 100 years, far-infrared technology has achieved many achievements and has been industrialized[9]. But there are very few studies involving terahertz, the main reason is the limitation of effective terahertz sources and sensitive detectors. As in the 1980s, the development of a series of new technology, new material, making stable broadband pulsed THz sources became a kind of conventional technology, so the THz technology development rapidly[4, 10, 11].



In this paper, we designed a metamaterial with dual band high terahertz transmission. By tailoring the split ring resonator structure, we can achieve THz wave amplitude manipulation at the resonance frequency in the transmission spectra[12, 13]. This structure can select the electromagnetic waves of the characteristic frequencies through the surface of metamaterials. Based on the metamaterial with high terahertz transmission, some potentially various sensors could be developed.

2. Structure and Design

By changing the resonant frequency features of metamaterials, we build resonance units of different structures within the same plane in order to realize the structure of metamaterial with multiple transmission peaks. According to the SRR resonance principle[14], with a particular structure formed by the SRR array, there will be an equivalent LC circuit and plasma resonance frequency corresponding to it[15-17]. Based on this feature, we designed a metamaterial that presents two peaks with high transmission at terahertz frequencies.

The unit cell of the metamaterial is shown in figure 1 a, which consist of two metallic plate and dielectric layers. The metallic layers laid on the top and bottom of the dielectric layer. The periodicity is $P=15\mu\text{m}$, the length of the arm is $L1=10\mu\text{m}$, and the wide of the arm is $L2=L3=1\mu\text{m}$. The thickness of the dielectric layers is $t=2\mu\text{m}$. The top layer and bottom layer are illustrated in figure 1 b-c. The thickness of the metal (Cu) is $0.1\mu\text{m}$. The permittivity of the dielectric is $\varepsilon = 2.1 + i0.005$. The direction of the electric field of the incident wave is along the x-axis. Perfect matched layers (PML) in the z direction and the periodic conditions in the x and y directions have been applied during the simulation.

3. Simulation and Discussion

We simulated the metal-dielectric (MD) structure and metal-dielectric-metal (MDM) structure in range of 1~10THz. The results were shown in figure 2. For MD structure, there is only one transmission peak at 4.62THz and the transmission can reach 99.7%. For MDM structure we can find there are two high-frequency transmission peaks and the high transmission band is very narrow. Two transmission peaks are at 3.56THz and 7.16THz, and the transmission rates are 99.8% and 99.7% respectively. This indicates that the metamaterials only have high transmission rates within certain frequencies. Due to increase a metal layer, the relative dielectric and permeability of this metamaterial get changed. This led to variation the resonant frequency. So the frequency of transmission peak varied.

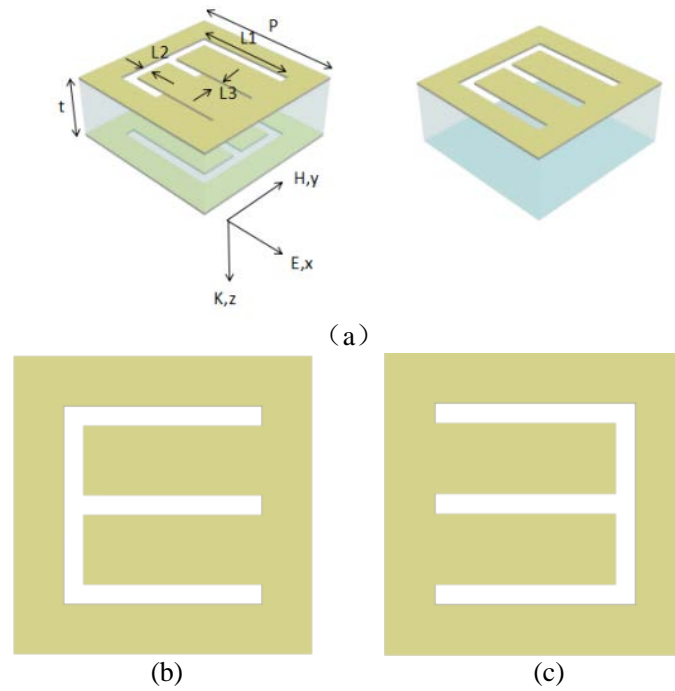


Figure 1 Schematics of the metamaterial. (a) unit cell; (b) the top layer; (c) the bottom layer.

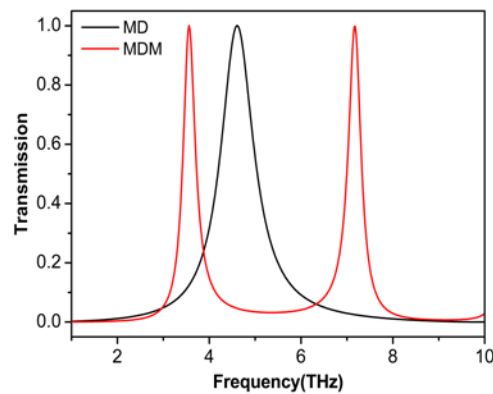


Figure 2 Simulated transmittance spectra of the MD and MDM

The response of the metamaterial transmission with obliquely incident radiation was examined. The transmissions with differently incident angles are shown in figure 3. When electromagnetic wave incident with different angles, there are still two high-transmission peaks near the frequency of 3.56 THz and 7.16 THz. Thus, the proposed metamaterial provides high transmission for wide incident angles.

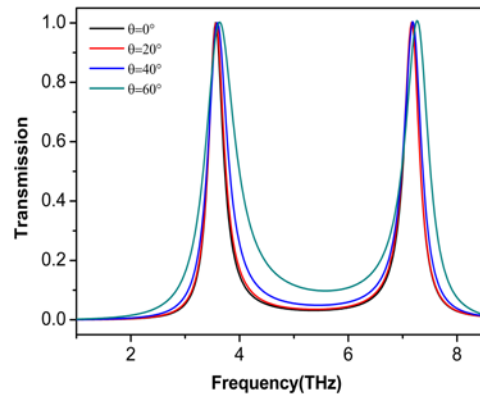


Figure 3 Transmission efficiencies as a function of incident angle

In order to further study the electromagnetic properties of the metamaterials. We change the structure of the metamaterial slightly. As shown in figure 4, by changing the distance of a and fixing other parameters, we can get the difference transmission amplitude and transmission peaks. We simulated differences distance of a , and the result is shown in figure 5. From 2 THz to 6 THz as the distance a increases, the first transmission peak moves to high frequency. According to this feature, we can change the distance of a to get the metamaterial which has specific frequency resonance.



Figure 4 The surface structure of the metamaterial.
(a) top layer.(b) bottom layer.

In order to study the influence from the thickness of the arm length, we keep other parameters constant and only change the value of L ($L=L_2=L_3$) as $L=1$ mm, 1.2 mm, 1.4 mm, 1.6 mm, 1.8 mm and 2 mm. Figure 6 plots the corresponding transmittance spectra. With the increase of the thickness L , the transmission peaks move to the high frequency.

4. Conclusion

In this paper, we proposed a metamaterial with dual band terahertz transmission that consists of two metal layers separated by a dielectric layer. We present simulation of this metamaterial, and get two maximum transmission peaks of 99.8% at 3.57 THz 99.7% at 7.16 THz, respectively. Among the narrow frequency band, the metamaterial shows high transmission at the characteristic frequency. Furthermore the structures have quite distinct advantages like multiband transmission peaks, flexibility and mechanical tunability. The transmission peaks can be adjusted by changing the structure of the metamaterial. Such kind of metamaterial could be used as candidate to achieve substantial electromagnetic response, various potential sensors and THz applications.

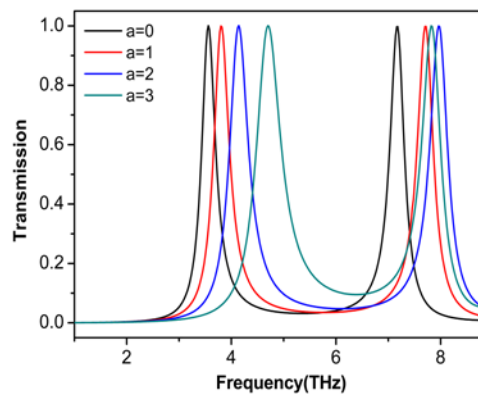


Figure 5 Simulated transmittance spectra of the metamaterial with different distance of a .

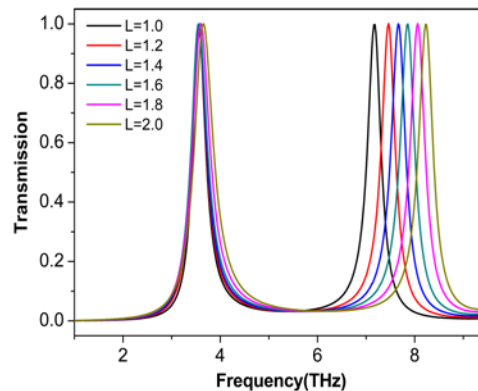


Figure 6 Simulated transmittance spectra of the metamaterial with different wall thickness of L .

5. Acknowledgements

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6. References

- [1] Liang L, Jin B, Wu J, Zhou G, Zhang Y, Tu X, Jia T, Jia X, Cao C, Kang L, et al. 2013 Terahertz narrow bandstop, broad bandpass filter using double-layer s-shaped metamaterials *Science China Information Sciences* **56** 1-7
- [2] Park S J and Ahn Y H 2015 Substrate effects on terahertz metamaterial resonances for various metal thicknesses *Journal of the Korean Physical Society* **65** 1843-7
- [3] Li X, Yang T, Zhu W and Li X 2012 Continuously tunable terahertz metamaterial employing a thermal actuator *Microsystem Technologies* **19** 1145-51
- [4] Kim J H, Hokmabadi M P, Balci S, Rivera E, Wilbert D, Kung P and Kim S M 2016 Investigation of robust flexible conformal thz perfect metamaterial absorber *Appl. Phys. A* **122**
- [5] Yao Z, Huang Y, Wang Q, Hu F, Quan B, Li J, Gu C and Xu X 2016 Tunable surface-plasmon-polariton-like modes based on graphene metamaterials in terahertz region *Computational Materials Science* **117** 544-8
- [6] Zheng W, Li W and Chang S J 2015 A thermally tunable terahertz metamaterial absorber *Optoelectronics*

Letters **11** 18-21

- [7] Wang B X, Wang L L, Wang G Z, Huang W Q, Li X F and Zhai X 2014 Frequency continuous tunable terahertz metamaterial absorber *J. Lightwave Technol.* **32** 1183-9
- [8] Bilgin H, Zahertar S, Sadeghzadeh S, Yalcinkaya A D and Torun H 2016 A mems-based terahertz detector with metamaterial-based absorber and optical interferometric readout *Sensors and Actuators A: Physical* **244** 292-8
- [9] Liu J, Zhou Q, Shi Y and Zhang C 2012 The rotation of polarization of a terahertz wave through subwavelength metallic structures *Science China Physics, Mechanics and Astronomy* **56** 514-8
- [10] Seren H R, Keiser G R, Cao L, Zhang J, Strikwerda A C, Fan K, Metcalfe G D, Wraback M, Zhang X and Averitt R D 2014 Optically modulated multiband terahertz perfect absorber *Advanced Optical Materials* **2** 1221-6
- [11] Grant J, Escorcia-Carranza I, Li C, McCrindle I J H, Gough J and Cumming D R S 2013 A monolithic resonant terahertz sensor element comprising a metamaterial absorber and micro-bolometer *Laser & Photonics Reviews* **7** 1043-8
- [12] Chen W, Zhou Q, Shi Y, Li C and Zhang C 2016 Trapped-mode resonances in asymmetric terahertz subwavelength structures *Appl. Phys. B* **122**
- [13] Kozlov D S, Odit M A, Vendik I B, Roh Y G, Cheon S and Lee C W 2011 Tunable terahertz metamaterial based on resonant dielectric inclusions with disturbed mie resonance *Appl. Phys. A* **106** 465-70
- [14] Lee D-H, Ling K, Lim S and Baek C W 2015 Fabrication of polarization-insensitive, multi-resonant metamaterial absorber using wafer bonding of glass dielectric substrate *Microelectron. Eng.* **136** 42-7
- [15] Ning R, Liu S, Zhang H, Bian B and Kong X 2015 Tunable absorption in graphene-based hyperbolic metamaterials for mid-infrared range *Physica B: Condensed Matter* **457** 144-8
- [16] Wang B X, Wang L L, Wang G Z, Huang W Q, Li X F and Zhai X 2014 A simple design of a broadband, polarization-insensitive, and low-conductivity alloy metamaterial absorber *Appl. Phys. Express* **7** 082601
- [17] Wang G D, Liu M H, Hu X W, Kong L H, Cheng L L and Chen Z Q 2013 Broadband and ultra-thin terahertz metamaterial absorber based on multi-circular patches *The European Physical Journal B* **86**