Highly Sensitive detection of Optical tunable terahertz multi-band absorber based on all-dielectric grating

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***Abstract*—An optical tunable multi-band all-dielectric metamaterials absorber has been proposed in this paper. The absorber was made of one-dimensional all-dielectric gratings. The proposed absorber can achieve four-band and tri-band absorption with different grating depth. All the peak absorbance is higher than 90% at the resonance frequencies with the higher quality factor (Q) can reach to 12.6. Otherwise, the absorber selective absorption can be achieved by adjusting the incident pump beam. The demonstrated tunability may find potential applications in dynamic functional THz devices. Finally, the proposed absorber has a great application in spectroscopic sensing.**

I. INTRODUCTION

Thz-metamaterial perfect absorbers have attracted significant interest due to Many applications require processing or designing materials that can absorb light, especially some incident light and spectral ranges selected by the user in recent years. Nevertheless, absorbers with just single narrowband are still faced with certain limitation in applications such as spectroscopy and imaging. The multi-band absorber can excite resonance at many different frequencies, which makes considerable application potential in the fields of absorption filtering and spectroscopic sensing. Therefore, multi-band absorbers with high performance are more desirable. Most absorbers are composed of metallic layers and dielectric layers, limited in applicability because of their low melting point, and high thermal conductivity of the metamaterials. Furthermore, it is difficult to change the absorption performance of a traditional perfect absorber once its geometrical and material parameters have been fixed.

In this paper, we propose a tunable all-dielectric metamaterials absorber to achieve multi-band absorption by employing the silicon gratings. Simulation results demonstrate that this absorber has four or three distinctive narrowband absorption peaks with high efficiency. In addition, the absorption of the absorber can be actively adjusted with different incident pump beam. Thus, our design has some potential applications in communication, sensing, and imaging in THz region.

II. RESULTS

The structure of the proposed perfect absorber based on one-dimensional all-dielectric gratings, which can be prepared with dielectric materials such as N-type doped silicon. Fig. 1(a) is a schematic image showing the general structure of our multi-narrowband absorber designed in this work. The four-band and tri-band absorbers are composed of the same structure, but the gratings depth is slightly different. In our simulations, we set the grating period: p=320 μm, the width of the grooves: w=40 μm, the structure thickness: t_1=300 μm, and the grating height:

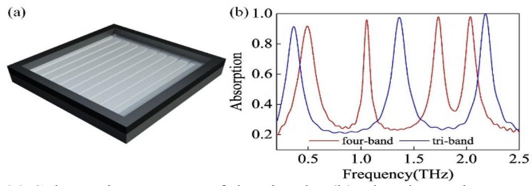

Fig.1 (a) Schematic structure of the simple, (b) The absorption spectra of four-band and tri-band absorber

t_2=108 (/160) μm. To design and optimize the grating structures, we used a commercial electromagnetic solver, in which the permittivity of the highly doped Si was treated using the Drude dispersion model.

$$\varepsilon = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\gamma\omega} \quad (1)$$

where $\varepsilon_\infty = 11.7$ is the intrinsic silicon dielectric constant, $\gamma = 1.72 \times 10^{13}\ \mathrm{s}^{-1}$ is the Drude collision frequency, $\omega_p = \sqrt{ne^2/m_0\varepsilon_0}$ is the plasma frequency, n is the doped carrier density of silicon, and $m_0 = 0.26m_e$ is the effective mass of the carriers, which includes the contributions from the N-doped electrons. The unit cell was subject to periodic boundary conditions in the x and y planes and was open in the z direction in the free space environment.

To design and optimize the structure of the absorber, we obtain the reflectance (R) and transmittance (T) of the absorber with different geometric parameters using finite-difference time-domain (FDTD) simulations and calculate the absorption by $A = 1 - S_{11}^2 - S_{21}^2$, where S_{11} denotes the reflection amplitude and S_{21} denotes the transmittance. The simulated absorption spectra for the four-band (red line) and tri-band (blue line) absorbers under normal incidence are shown in Fig.1(b). As the Fig.1(b) shown, the maximum absorption of the four-band absorber is up to 98.03%, the minimum absorption is higher than 91.79%. At the same time, the maximum absorption of the tri-band absorber is up to 99.99%, the minimum absorption is higher than 91.50%. All the peak absorbance is higher than 90% at the resonance frequencies, the quality factor(Q) can reach to 12.64 and 12.46, respectively.

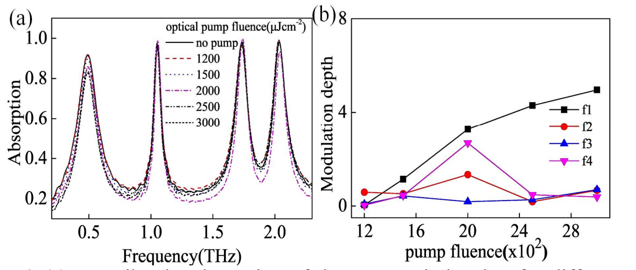

Fig. 2 (a) Describe the absorption of the proposed absorber for different pump. (b) All the modulation depth of four absorption peaks under different pump beam.

Most absorbers need to achieve adjustable of resonant frequency for application requirements. Next, we will study the tunability of the resonant frequency of the proposed structure.

To facilitate understanding of the phototunable capabilities of the proposed absorbers, we performed full-wave electromagnetic simulations. To study the tunability of the absorption performance of the proposed absorber under different incident pump beam, we simulation the absorption spectra for four-band absorber as an illustration. As shown in Fig.2(a), as the pump beam energy increase, the absorption changed. The first absorption peak decreases by 9.1% as the pump beam energy increase to 3000 μJ/cm^2. The modulation depth can reach to 4.97%, while the modulation depth of other peaks is less than 3%. All the modulation depth of four absorption peaks under different pump beam are shown in the Fig.2(b). As the result shown, we can realize photo-excitation with the proposed absorber. However, the modulation effect is not optimal.

In order to achieve a greater modulation depth, there can be greater effect in practical applications. We propose to coating a layer of phosphorus-doped silicon with thickness t_3=10 μm on the gratings. The carrier concentration of silicon layer is less than that of the gratings. The absorption spectra are shown in Fig.3(a), the absorber obtained three resonance frequency different from the absorber what was proposed at first. As mentioned before, we also simulate the structure absorption under the pump beam. It is clearly shown that the absorption performance changes under the pump beam. The first absorption peak decreases by 9.1% as the pump beam energy increase to 1800 μJ/cm^2. The modulation depth can reach to 11.08%. The second absorption peak are blue-shifted as the pump beam energy increased. The modulation depth can reach to 48.17%. The third absorption peak also has a big change. The absorption peak decreases by 47.55%, and the modulation depth is 38.28%. The trend of modulation depth is also shown in the Fig. (b). It is worth to noting that, we use lower pump fluence energy to achieve a higher modulation depth in this way. Cause to the phototunable capabilities of the proposed absorber, the absorber can be applied to spectral imaging systems communication and THz frequency non-destructive testing of tunable multi-band absorbers, has a greater prospect of development in these areas.

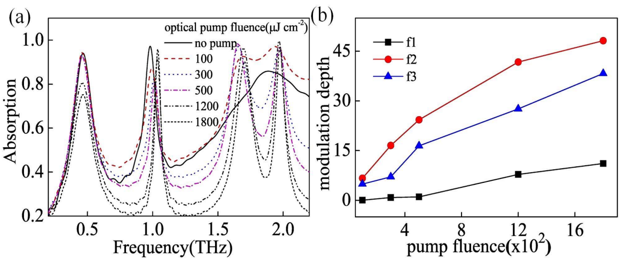

Fig. 3 (a) The absorption of the proposed absorber capped a layer with N-type silicon (different carrier concentration) for different pump fluences. (b) All the modulation depth of three absorption peaks under different pump beam.

III. SUMMARY

An all-dielectric metamaterials multi-band absorber has been proposed in this paper. The structure of the proposed perfect absorber based on one-dimensional silicon gratings. The absorption performance of the proposed absorber can be adjusted by changing the structural geometric parameters. At the same time, the absorption of the absorber is also can be adjusted by increase the incident pump beam. Cause to the excellent absorption performance of the proposed absorber, the absorber may have potential prospects in sensing, detection and imaging.

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