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A Suspended Array of Square Patch Metamaterial Absorbers for Terahertz Applications

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Abstract

A suspended array of square metallic patches on a thin dielectric layer is introduced as a terahertz absorber. The absorber is fabricated on a metalized substrate and the device exhibits metamaterial behavior at specific frequencies determined by the size of the patches. It is feasible to place patches with different sizes in an array formation for a broadband absorber. Design of the absorber is described using electromagnetic simulations. The absorber structure was fabricated on a silicon wafer and its characteristics were measured using a terahertz time domain spectroscope. The measured data match well the simulations indicating strong absorption peaks in a band of 0.5-2 THz.

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Keywords: Metamaterials; Absorber; Terahertz

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1. Introduction

Metamaterials are patterned sub-wavelength sized structures that are usually made of dielectrics and metals. They exhibit strong resonant behavior when they are excited with electromagnetic waves and the resonant frequencies are determined by the geometries of the patterned structures. Metamaterials with different geometries and sizes have been introduced for a wide range of bands in electromagnetic spectrum spanning from microwave to terahertz and visible frequencies. The wavelength of the radiation at 1 THz corresponds to 300 µm, so it is feasible to fabricate metamaterial structures for terahertz applications using standard UV photolithography. In addition, most of the materials used for the realization of metamaterials are compatible with micro fabrication technology. Consequently, a wide variety of metamaterial microstructures have been presented for terahertz applications. Variety of imaging and spectroscopy applications in terahertz band has been increasing rapidly including detection of explosives, surveillance and medical screening. High performance terahertz absorbers enable developing new devices for these applications.

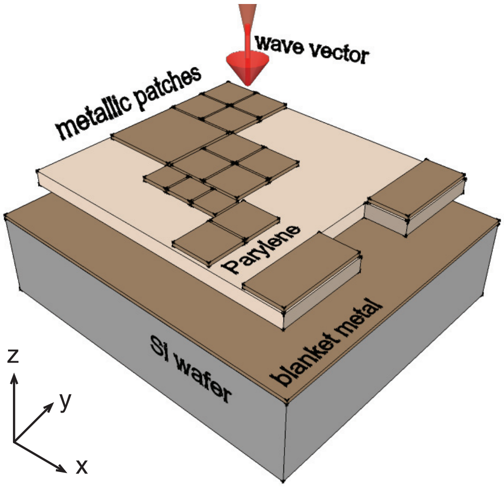


Fig. 1. Three-dimensional drawing of the metamaterial-based terahertz absorber structure.

Metamaterial-based terahertz absorbers have been employed that exhibit a magnetic or electric resonance at desired frequencies. Different geometries have been demonstrated including split-ring resonators [1,2], Swiss crosses [3-5], concentric rings [6], square patches [7-11], and circular disks [12]. At resonance, these structures can absorb radiation with high efficiency. Unity absorption is observed with metamaterial absorbers at terahertz frequencies [13]. However, the absorption band is usually very narrow. As an example, the full width at half maximum (FWHM) of the absorption peak is 0.1 THz for an absorber at 1 THz [13]. Structures with different sizes are combined together to increase the number of absorption bands for broadband absorbers. Similarly sized square patches are located in a planar array [7] or are stacked on top of each other with dielectric spacers in between [8,11] to increase the number of absorption bands. Similarly, concentric rings are used for the same purpose [6].

In this paper, we present a metamaterial-based terahertz absorber employing metallic square patches with different sizes. Fig. 1 shows a three-dimensional drawing of the absorber structure on a silicon wafer. The metallic patches are fabricated on top of a patterned Parylene layer that is suspended over a metallized substrate. The intended configuration for the absorber is when the wave vector is perpendicular to the device as shown in Fig. 1. Patches with different sizes are arranged on a single Parylene film and the film is anchored to the substrate. This configuration is desirable for terahertz detectors that requires detector structures isolated from their substrate. The metamaterial behavior is observed for unit cells including the metallic patches on top, blanket metal on the substrate and the Parylene and air spacing in between. Transmission is guaranteed to be zero with the presence of the blanket metal, whereas reflection diminishes at certain frequencies set by the geometry of the square patches. So, absorption increases at those frequencies.

Square patches made of titanium with side lengths of 86 µm, 43 µm, 30 µm and rectangular patches with side lengths of 100 µm and 43 µm are designed with a thickness of 200 nm. The thickness of the blanket metal is also 200 nm. The Parylene layer is patterned in patches of 270 µm x 270 µm with a thickness of 2 µm. The thickness of the air gap between the Parylene layer and the blanket metal is 5 µm.

2. Simulation and modeling

Fig. 2 shows the reflection, transmission and absorption spectra of the absorber obtained using commercially available electromagnetic simulation software (CST Studio Suite, Darmstadt, Germany). The computational domain includes all the structures shown in Fig. 1. Electric field is along *y*-axis for the simulations. Absorption spectrum exhibits sharp resonant peaks at 0.63 THz, 1.12 THz, 1.47 THz and 1.87 THz.

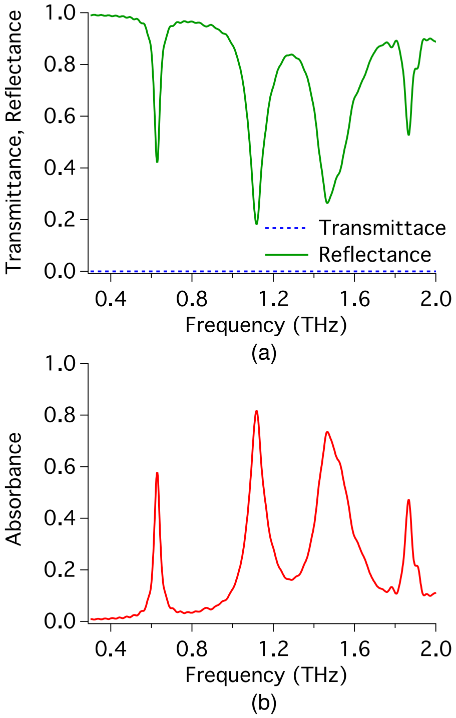
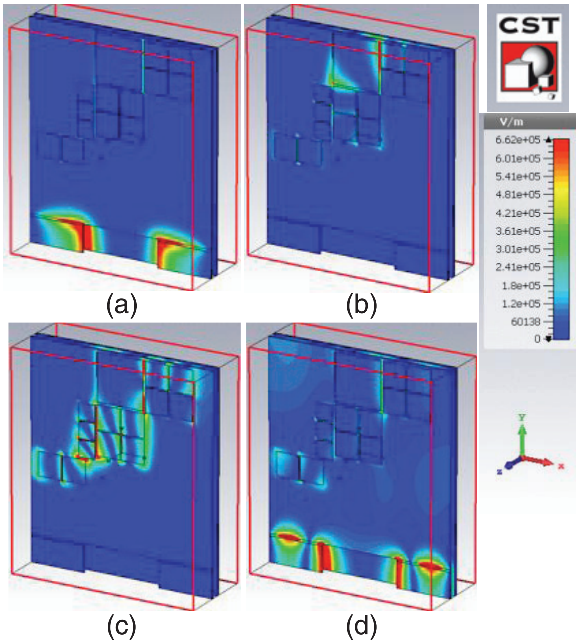


Fig. 2. Simulated transmission, reflection (a) and absorption spectra (b) of the absorber

The square patch structures induce electric dipole resonances at specific frequencies. Electric field distributions corresponding to the resonant frequencies are shown in Fig. 3. Larger patches are associated with smaller frequencies. Specifically patches with 100 µm side lengths excites resonance at 0.63 THz, 86 µm patch excites resonance at 1.12 THz, 43 µm patches and their interactions with 30 µm patches excite resonance at 1.47 THz. The rectangular patches also excite another resonance at 1.87 THz.



(a) (b) (c) (d)

Fig. 3. Distribution of electric field at a) 0.63 THz, b) 1.12 THz, c) 1.47 THz and d)1.87 THz.

The resonant frequency is proportional to the reciprocal of the side length of a patch [7]. At resonance, the metamaterial can be modeled using a parallel combination of an equivalent capacitance and inductance given in equation 1.

$$C_{eq} = \frac{\alpha \varepsilon_{\text{eff}} L^2}{t_{\text{eff}}} \quad , \quad L_{eq} = \beta \mu_{\text{eff}} t_{\text{eff}} \tag{1}$$

where L is the side length of a square patch, t_{eff} is the effective thickness of the structure between top and bottom metal films, α and β are geometrical correction parameters, ε_{eff} and μ_{eff} are the effective permittivity and permeability of the structure, respectively. So, the resonant frequency of the absorber is inversely proportional to L and is independent of t_{eff}. Thus the thickness of the Parylene layer and the air gap underneath do not alter the resonant frequency. This is advantageous for structures where the air gap changes during operation.

3. Fabrication and experimental characterization

The designed absorbers are implemented using standard micro fabrication methods. Electron microscope photo of a fabricated structure is shown in Fig. 4. The Parylene layer is anchored to the substrate near to the rectangular patches. Electromagnetic characteristics of the absorber are characterized using a terahertz time-domain spectroscope (TERA K15, Menlo Systems GmbH, Martinsried, Germany).

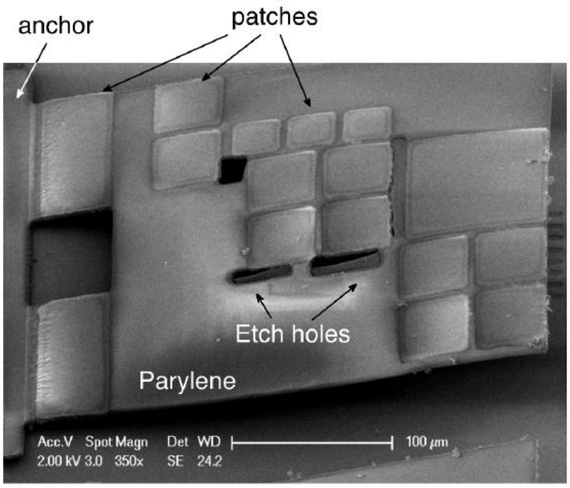


Fig. 4. SEM image of a fabricated absorber

The measured absorption peaks match well with the simulated peaks. The measured resonant frequencies exhibit red-shift with respect to the simulation results. The largest deviation is observed with the first resonant frequency where the measured frequency is 20% smaller than the simulation results. The smallest deviation is with the third resonant frequency by 9%.

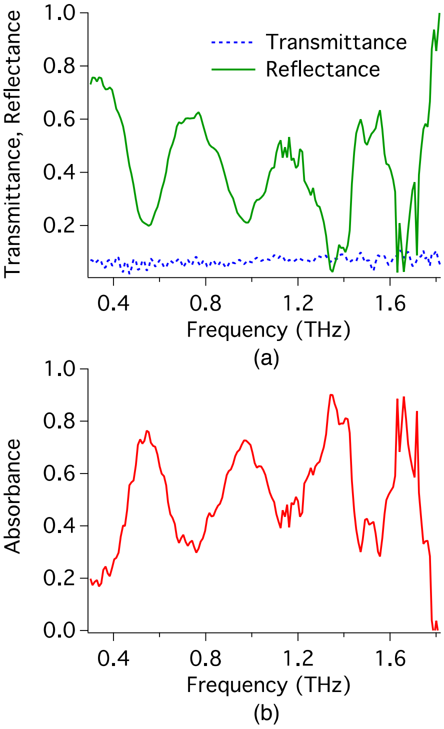


Fig. 5. Measured transmission, reflection (a) and absorption spectra (b) of the absorber

4. Conclusion

An array of square patch metamaterial absorbers that can be used as a terahertz absorber is presented. Square patches with different geometries are designed on a thin layer of Parylene that is suspended over a substrate for a frequency range of 0.5-2 THz. Absorber devices are fabricated on a Silicon wafer and their characteristics are extracted at terahertz frequencies. The fabricated absorber exhibits strong absorption peaks with absorbance of 0.8 at desired frequencies and the absorbance of the device is larger than 0.4 in a band of 0.5-1.8 THz.

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References

[1] Hu Tao, C M Bingham, D Pilon, Kebin Fan, A C Strikwerda, D Shrekenhamer, W J Padilla, Xin Zhang and R D Averitt, Journal of Physics D: Applied Physics **43**, 225102 (2010).
[2] Qi-Ye Wen, Huai-Wu Zhang, Yun-Song Xie, Qing-Hui Yang and Ying-Li Liu, Applied Physics Letters **95**, 241111 (2009).
[3] Yu Qian Ye, Yi Jin and Sailing He, JOSA B **27**, 498-504 (2010).
[4] Jiahui Fu, Wan Chen, Bo Lv, Lei Zhu and Qun Wu, Solid State Communications **204**, 5-8 (2015).
[5] James Grant, Yong Ma, Shimul Saha, Ata Khalid and David R S Cumming, Opt Lett **36**, 3476-8 (2011).
[6] Yong Ma, Qin Chen, James Grant, Shimul C Saha, A Khalid and David R S Cumming, Opt Lett **36**, 945-7 (2011).
[7] Yongzhi Cheng, Yan Nie and Rongzhou Gong, Optics & Laser Technology **48**, 415-421 (2013).
[8] Ben-Xin Wang, Ling-Ling Wang, Gui-Zhen Wang, Wei-Qing Huang, Xiao-Fei Li and Xiang Zhai, Applied Physics A **115**, 1187-1192 (2014).
[9] Alexandre Sellier, Tatiana V Teperik and André de Lustrac, Opt Express **21 Suppl 6**, A997-1006 (2013).
[10] Fabio Alves, Brian Kearney, Dragoslav Grbovic, Nickolay V Lavrik and Gamani Karunasiri, Applied Physics Letters **100**, 111104 (2012).
[11] Ben-Xin Wang, Ling-Ling Wang, Gui-Zhen Wang, Wei-Qing Huang, Xiao-Fei Li and Xiang Zhai, Photonics Technology Letters, IEEE **26**, 111-114 (2014).
[12] Govind Dayal and S Anantha Ramakrishna, Journal of Optics **15**, 055106 (2013).
[13] D Yu Shchegolkov, A K Azad, J F OHara and E I Simakov, Physical Review B **82**, 205117 (2010).