جاذب متامادهای فوق نازک حساس به قطبش در بازه‌ی تراهرتز با استفاده از دیسک بیضوی طلایی

علی سلیمانی، رویا ابراهیمی میمند، و نصرتا... گرانپایه

دانشکده مهندسی برق دانشگاه صنعتی خواجه نصیرالدین طوسی، تهران، ایران

چکیده – در این مقاله به طراحی یک جاذب متاماده‌ای فوق نازک پرداخته‌ایم که می‌تواند حدود ۱۰۰ درصد موج‌های الکترومغناطیسی تابشی در بازه‌ی تراهرتز را در فرکانس کاری خود جذب کند. نتایج به دست آمده نشان می‌دهد که جاذب به قطبش حساس بوده و می‌تواند در بازه‌ی زاویه‌ای وسیعی تابش‌های *TE* و *TM* را جذب کند. ساختار پیشنهادی برای تابش *TE* و *TM* به ترتیب جذب ۹۹/۱۴ درصدی در فرکانس ۸/۱۴ تراهرتز و ۹۶/۴۵ درصدی در فرکانس ۵/۹۵ تراهرتز را نشان می‌دهد. فرکانس جذب را می‌توان از طریق تغییر مشخصات هندسی جاذب تنظیم نمود. این ساختار متاماده‌ای می‌تواند راه را برای کاربردهای جدیدی در بازه‌ی تراهرتز مانند تشخیص‌دهنده‌های قطبش، تصویربرداری قطبش، حسگر تراهرتزی و تسهیم‌کننده قطبش هموار کند.

کلید واژه: تراهرتز، متاماده، جاذب متاماده، جاذب حساس به قطبش

Ultrathin Polarization Sensitive Terahertz Metamaterial Absorber Using Elliptical Gold Patch

Ali Soleymani, Roya Ebrahimi Meymand, and Nosrat Granpayeh

Faculty of Electrical Engineering, K. N. Toosi University of Technology, Tehran, Iran

Abstract- We have designed an ultrathin metamaterial absorber which is capable of total absorption of the incident electromagnetic waves in the terahertz regime. Results demonstrate that the absorber is sensitive to the polarization and can operate at a wide range of incident angles under both transverse electric (TE) and transverse magnetic (TM) polarizations. The absorbance for s-polarized (TE) and p-polarized (TM) waves are 99.14% at 8.14 THz and 96.45% at 5.95 THz, respectively. The absorption frequency can be dynamically tuned by the geometries of the absorber. This terahertz metamaterial structure can be used in novel THz applications such as polarization detectors, polarization imaging, THz sensing, and polarization multiplexing.

Keywords: Terahertz, Metamaterial, Metamaterial absorber, Polarization sensitive absorber.

The 24th Iranian Conference on Optics and Photonics and the 10th Iranian Conference on Photonics Engineering and Technology
Jan. 30-Feb. 1, 2018

UltrathinPolarization Sensitive Terahertz Metamaterial Absorber Using Elliptical Gold Patch

Ali Soleymani, Roya Ebrahimi Meymand

soleymani_ali@email.kntu.ac.ir,
royaebrahimi147@email.kntu.ac.ir

Nosrat Granpayeh

granpayeh@kntu.ac.ir

1 Introduction

Metamaterials are artificially constructed electromagnetic (EM) materials, whose size is much smaller than the wavelength of EM waves. The most attractive aspect of metamaterial is that its effective permittivity and permeability can be controlled, by using periodically or randomly distributed structures [1]. Other properties of metamaterials that do not exist in nature are negative refractive index [2], electric field enhancement and polarization conversion of an incident EM wave [3].

Metamaterials because of their wonderful characteristics have great potential in many applications such as superlens, cloaking, detectors, and modulators [4, 5].

Within the past few years, perfect metamaterial absorbers have rapidly improved and they have been widely researched at microwave, terahertz (THz) and optical frequencies [6-8]. Perfect EM metamaterial absorber is a device which absorbs the entire incident radiation at the operating frequency and disables all other EM wave propagation channels [9].

Recently, EM wave perfect absorbers in THz regime have attracted great attentions, which can absorb the electric and magnetic components of incident THz waves individually [9].

However, most of the EM metamerial absorbers which have been investigated are polarization-independent. For some applications such as polarization imaging, polarization multiplexing, and selective spectral detection, high absorption peaks at different operating frequencies are needed [10].

In this paper, we propose and simulate a feasible approach to design an ultrathin wide-angle terahertz absorber which its resonance mechanism depends on the polarization property of the incident waves.

The proposed compact metamaterial absorber consists of planar elliptical gold patch and a metallic ground plane separated by a single dielectric spacer. The strong coupling between the two layers and fine tuning of the geometry of structure is required to obtain perfect absorption.

Meanwhile, absorption spectra for both TE and TM configuration are displayed. Furthermore, the absorption peak can be tuned by changing the polarization angle of the incident wave.

The remaining of this paper is organized as follows: In Section 2, the design and simulation method is investigated. In Section 3, polarization-dependence of the structure is discussed. The paper is concluded in Section 4.

2 Design and Simulation

As shown in Fig. 1(a), the unit cell of the structure consists of a planar elliptical gold patch (dimensions of elliptical patch are set to $a = 5\,\mu$m and $b = 7.5\,\mu$m), the dielectric spacer and a metallic gold ground plane.

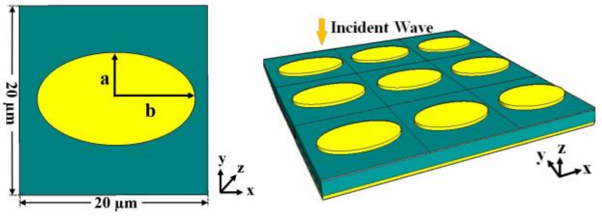
The width of the unit cell is 20 µm, and thickness of gold film and gold patch both are 0.2 µm. The ground plane and planar gold patch are made of gold with electric conductivity $\sigma = 4.09\times10^{7}$ Sm^{-1}. A 1.1 µm-thick lossy polyimide with $\varepsilon = 3.5 + 0.2i$ is modelled as the substrate.

Simulations of the proposed absorber performed using finite-difference time-domain (FDTD) method. The unit cell is periodically arranged in *x-y* plane and the incident wave is vertical to the upper surface of the structure and is along z-axis as shown in Fig. 1(b).

The absorptivity can be calculated from $A = 1 - |S_{11}|^2 - |S_{21}|^2$, where A, S_{11}, and S_{21} are absorptivity, reflection coefficient, and transmission coefficient, respectively [9].

We set the thickness of the ground plane much larger than the typical skin depth at THz frequency due to suppress transmission through the structure. Hence, the transmission is zero, and the absorptivity can be calculated using the equation $A = 1 - |S_{11}|^2$ In order to get the maximum *A*, the impedance of the absorber must be matched to free space.

Fig. 2 shows the absorbance and reflectance of the proposed MA and it can be easily found that the absorbance curve of the MA has an obvious peak at the frequency of 8.18 THz. The corresponding absorbance of 99.14% has been achieved.



(a) (b)

Fig. 1: (a) Top view of one cell of the proposed metamaterial absorber with geometric parameter and (b) The schematic view of periodic pattern.

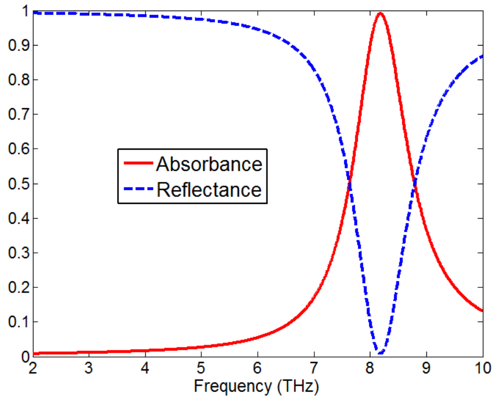
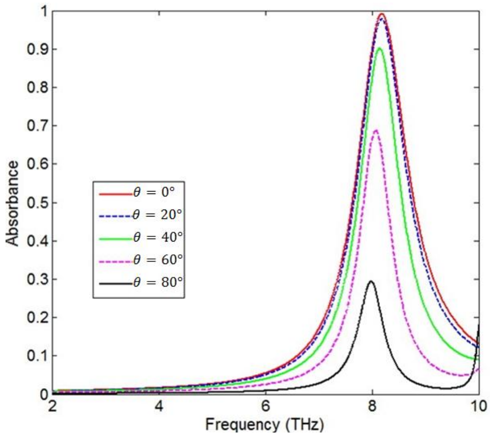


Fig. 2: The simulated reflectance and absorbance spectra of the metamaterial absorber.

3 Polarization Dependence

Figure 3(a) and (b) are shown to clarify the absorption for both s-polarized (TE) and p-polarized (TM) wave when the incident angle increases, respectively.

The incident angle θ is increased from 0° to 80° with the step of 20°. For the TE case, with increasing angle of incidence, the absorption remains strong from 0 to 50 degrees, Beyond 50°, absorption decreases. Because of that incident magnetic field component which is parallel with the surface of the MA decreases with increased θ.



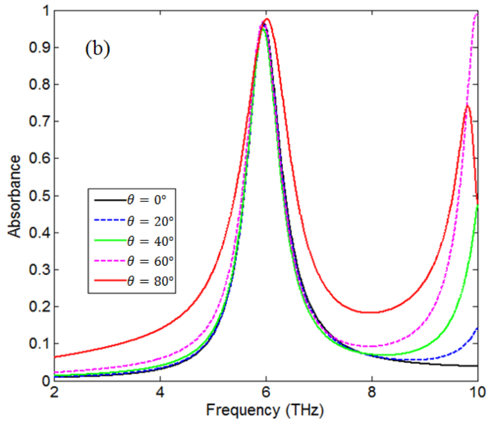


Fig. 3: The absorbance spectra of the MA at different angles of incidence for (a) TE and (b) TM waves.

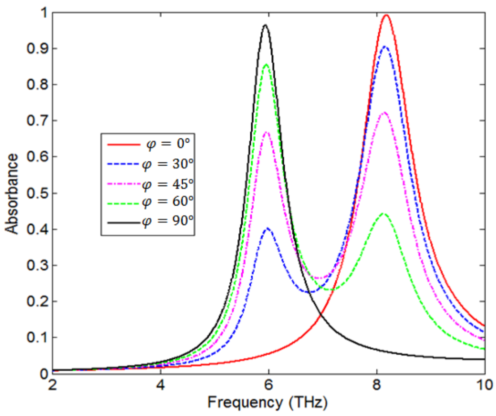


Fig. 4: The absorbance spectra of the MA for different polarization angles.

The absorption results of the proposed MA with the azimuthal angle θ (increasing from 0° to 90°) at normal incidence are shown in Fig. 4. According to the result the absorber is highly polarization dependent and the reason is asymmetry of structure.

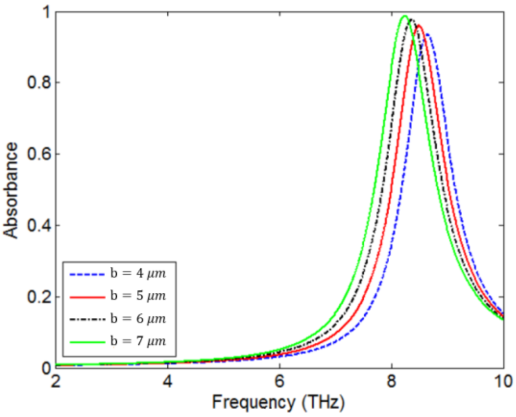


Fig. 5: The absorbance spectra of the MA for different long axis radii of the elliptical patches.

Hence, at $\varphi = 0^{\circ}$ the electric field of incident wave is along y-axis (TE) and absorption occurs at $f = 8.18$ THz, by increasing φ there is a redshift in absorption peak, at $\varphi = 90^{\circ}$ the E vector is along x-axis (TM) and absorption occurs at $f = 5.95$ THz. Therefore, the proposed MA has about 2.2 THz shift from $\varphi = 0^{\circ}$ to $\varphi = 90^{\circ}$.

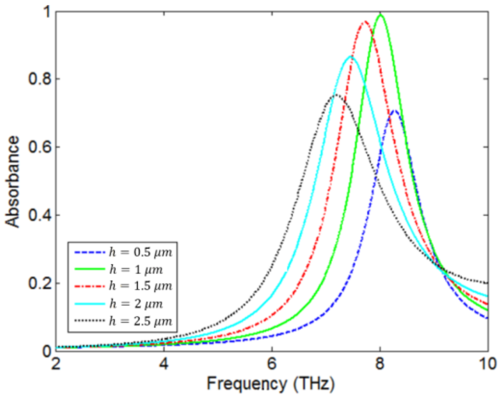


Fig. 6: The absorbance spectra of the MA for different substrate thicknesses.

The absorption frequency can be tuned by the geometries of the absorber. By increasing value of long axis radius of the elliptical patch, we see from Fig. 5, a red shift of the frequency and maximum of absorption increased and by increasing thickness of substrate (h) frequency of resonance goes to lower frequency as shown in Fig. 6.

4 Conclusion

In conclusion, we report an ultrathin metamaterial absorber that the proposed absorber is polarization-dependent under normal incidence, which can be used in polarization-dependent detection, polarizers and polarization imaging. Also, a high absorption for a wide range of TE and TM-polarized oblique incidence was achieved. As we showed the absorption peak can be tuned by simply changing the parameters of structure. The absorption band can be extended to microwave and other frequency ranges by simply scaling parameters.

References

[1] J.B. Pendry, A.J. Holden, D.J. Robbins, and W.J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Trans. Microw. Theory Tech.* Vol. 47, No. 11, pp. 2075-2084, 1999.

[2] J. Valentine, S. Zhang, T. Zentgraf, E. Ulin-Avila, D.A. Genov, G. Bartal, and X. Zhang, "Three-dimensional optical metamaterial with a negative refractive index," *Nature* Vol. 455, No. 7211, pp. 376-379, 2008.

[3] L. Cong, W. Cao, X. Zhang, Z. Tian, J. Gu, R. Sing, and W. Zhang, "A perfect metamaterial polarization rotator," *Appl. Phys. Lett.* Vol. 103, No. 17, pp. 171107 (1-6), 2013.

[4] M.G. Silveirinha, C.R. Medeiros, C.A. Fernandes, and J.R. Costa, "Experimental verification of broadband superlensing using a metamaterial with an extreme index of refraction," *Phys. Rev. B.* Vol. 81, No. 3, pp. 033101 (1-4), 2010.

[5] D.J. Cho, W. Wu, E. Ponizovskaya, P. Chaturvedi, A.M. Bratkovsky, S.Y. Wang, and Y.R. Shen, "Ultrafast modulation of optical metamaterials," *Opt. Express* Vol. 17, No. 20, pp. 17652-17657, 2009.

[6] G.D. Wang, M.H. Liu, X.W. Hu, L.H. Kong, L.L. Cheng, and Z.Q. Chen, "Broadband and ultra-thin terahertz metamaterial absorber based on multi-circular patches," *Eur. Phys. J. B.* Vol. 86 No. 7, pp. 304 (1-9), 2013.

[7] Y. Wang, T. Sun, T. Paudel, Y. Zhang, Z. Ren, and K. Kempa, "Metamaterial-plasmonic absorber structure for high efficiency amorphous silicon solar cells," *Nano Lett.* Vol. 12 No. 1, pp. 440-445, 2011.

[8] W. Xu, L. Xie, J. Zhu, X. Xu, Z. Ye, C. Wang, and Y. Ying, "Gold nanoparticle-based terahertz metamaterial sensors: mechanisms and applications," *ACS Photonics* Vol. 3 No. 12, pp. 2308-2314, 2016.

[9] T.H. Nguyen, S.T. Bui, T.T. Nguyen,Y. Lee, M.A. Nguyen, and D.L. Vu, "Metamaterial-based perfect absorber: polarization insensitivity and broadband," *Adv. Nat. Sci.: Nanosci. Nanotech.* Vol. 5, No. 2, pp. 025013 (1-7), 2014.

[10] G. Deng, P. Chen, J. Yang, Z. Yin, and L. Qiu, "Graphene-based tunable polarization sensitive terahertz metamaterial absorber," *Opt. Commun.* Vol. 380, pp. 101-107, 2016.