Polarization-Insensitive Perfect FSS Metamaterial Absorber in THz Frequency Range

C. Sabah, F. Dincer, M. Karaaslan, E. Unal and O. Akgol

Abstract**—** We numerically presented and analyzed a new perfect frequency selective surface (FSS) metamaterial absorber (MA) based on resonator with dielectric configuration for terahertz frequency ranges. Proposed FSS MA has features of simple configuration and easy fabrication. Also, it introduces flexibility to adjust its FSS metamaterial (MTM) properties and easily re-scale the model for various other frequencies. Moreover, numerical simulations verify that the FSS MAs could achieve very high absorption at wide different all polarization angles. The proposed FSS MAs and its variations enable myriad potential application areas in defend systems, communication, stealth technologies, and so on.

Keywords**—** absorber; metamaterial; terahertz.

I. Introduction

MTMs are artificially created electromagnetic (EM) materials have gained great attention of science community. Since, MTMs show specific EM features not ordinarily encountered in nature such as negative refractive index [20, 12, 31, 5, 6]. Also, MTMs are manmade and have many potential application areas for example cloaking [3], absorber [8], super lens [10], sensing [26], antenna [22], and so on [9, 21, 25, 29, 1, 19, 14, 4].

Nowadays, the concept of MA studies has gained attention by the scientists who study on MTMs. There are many MA studies in literature. These studies are commonly realized on microwave regime. However, researchers studied on also ranges of THz and infrared frequency in last few years. Some of these are broadband terahertz absorber [13], multi-band THz MA [11], polarization-independent plasmonic absorber [7], broadband MA [24].

We considered and analyzed on the MA studies in literature. Unlike the others, we presented perfect FSS MA that operates in terahertz frequency ranges and has easy fabrication techniques. Also, we are investigated with respect to dependency on polarization angles of the suggested model. Moreover, the proposed FSS MA model has comfortable configuration and can easily be re-scaled for other frequencies. The proposed FSS MA and its variations enable numberless potential applications in medical technologies, sensors, wireless communication, and so on.

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II. Theoretical Approach

The frequency response of absorption is defined as A(ω)=1-R(ω)-T(ω), where A(ω), R(ω) and T(ω) are the absorption, reflectance and transmittance, respectively. A(ω) comes from minimizing either reflectivity $R(\omega)=|S_{11}|^2$ and transmission $T(\omega)=|S_{21}|^2$ at an specified frequency range.

Reflectivity can be reduced (near-zero) when the effective permittivity $\tilde{\varepsilon}(\omega)$ and permeability $\tilde{\mu}(\omega)$ have the same value. It is possible to absorb both the incident electric and magnetic field tremendously by accurately tuning $\tilde{\varepsilon}(\omega)$ and $\tilde{\mu}(\omega)$. They can be manipulated to create high absorption. Absorbers minimize the reflection and transmission coefficients of incident waves at a certain frequency range due to the impedance matching [8]. In the resonance condition, the effective impedance $\left(Z(\omega)=\sqrt{\tilde{\mu}(\omega)/\tilde{\varepsilon}(\omega)}=z_1+iz_2\right)$ have to match with the free space impedance $Z(\omega)=Z_0(\omega)$ and therefore, the reflection is minimized [16, 5, 23, 24, 18, 9].

III. Numerical Study, Results, and Discussion

Proposed FSS MA design is based on square and rectangular-shaped inclusions. The models consist of a resonator, metallic layer and dielectric substrate. Resonator and metallic layer are modelled as silver sheet with electrical conductivity of $6.3\text{x}10^7$ S/m and thickness of 1 um. Silver is soft, white, lustrous transition metal and also possesses the highest electrical conductivity inside of metals. Also, it has extremely low resistivity. Resonator and metallic plate are separated by the Quartz (Fused)-dielectric substrate and placed parallel to each other. The thickness, loss tangent, relative permittivity and permeability of the Quartz (Fused) are 100 um, 0.0004, 3.75 and 1, respectively. Fig. 1 shows the structure designs with their dimensions.

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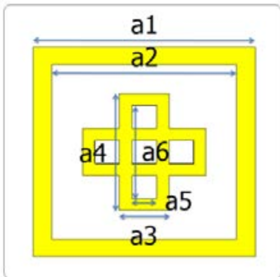

Fig. 1 Dimensions of the suggested FSS MA for terahertz frequency range-a1= 360 um, a2=300 um, a3=80 um, a4=200 um, a5=40 um, a6=160 um

We performed a commercial full-wave EM solver based on the finite integration technique for numerical studies of the periodic structure. So, we used the periodic boundary conditions with floquet port. Then, we numerically analyzed and compared results to obtain characteristics of the others FSS MA. The FSS MA shows perfect single band around 0.99 THz in the reflection spectrum thus perfect single maxima in the absorption as shown in Fig. 2(a). The resonance is about 99.98 % in the simulation. As seen, the amplitude of the reflection is 0.01 at the resonance frequency in this case.

In the next exploration, the effects of the polarization angle on the performance of the FSS MA are observed. Fig. 2(b) shows the frequency response of the absorption value for the stated process. To notice the shifts of the resonance frequency with respect to the polarization angle, wider frequency range is taken into consider as shown in Fig. 2(b). It can be seen that the proposed FSS MA provides very well absorption for 0^0, 120^0, 150^0 and 90^0 with the absorptions of 88.11 %, 98.07 %, 87.22 % and 99.98 %, respectively. The lowest absorption value is occurred around 1.05 THz as 46.95 % for 60^0 and the highest absorption is occurred around 0.99 THz as 99.98 % for 90^0. Although the suggested MA does not provide good polarization angle independency, it has good resonance with small shifts for all incident angles except for 60^0.

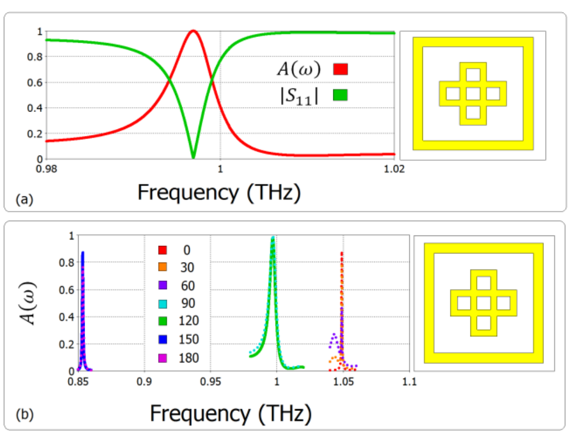

Fig. 2 Proposed THz FSS MA, a) Simulated reflection and absorption for the proposed terahertz absorber, (b) Simulated results of the absorbing performance under different polarization angles for the case of normal incidence.

IV. CONCLUSION

In conclusion, THz FSS MA is presented. This proposed model shows perfect absorption and also it can be tuned easily re-scale the structure for other frequencies. According to the results, the investigated FSS MA provides perfect absorption at resonance frequencies independent from the polarization angles. At some cases of the polarization angles, the absorption value can be enhanced. Moreover, it can be a good candidate for the applications of stealth, sensor, and so on.

REFERENCES

[1] O. Akgol, D. Erricolo, and P. L. E. Uslenghi, “Electromagnetic radiation and scattering for a gap in a corner backed by a cavity filled with DNG metamaterial”, *Radio Sci.*, vol. 46(4), 2011.

[2] A. Alù, and N. Engheta, “Anomalies of subdiffractive guided wave propagation along metamaterial nanocomponents”, *Radio Sci.*, vol. 42(6), 2007.

[3] A. Alù, and N. Engheta, “Robustness in design and background variations in metamaterial/plasmonic cloaking”, *Radio Sci.*, vol. 43(4), 2008.

[4] S. Arslanagic, R. W. Ziolkowski, and O. Breinbjerg, “Analytical and numerical investigation of the radiation from concentric metamaterial spheres excited by an electric Hertzian dipole”, *Radio Sci.*, vol. 42(6), 2007.

[5] H. Cheng, S. Chen, H. Yang, J. Li, X. An, C. Gu, and J. Tian, “A polarization insensitive and wide-angle dual-band nearly perfect absorber in the infrared regime”, *J. Opt.* vol. 14, pp. 085102, 2012..

[6] Y. Cheng, and H. Yang, “Design Simulation and Measurement of Metamaterial Absorber”, *Microw. Opt. Techn. Let.*, vol. 52, pp. 877-880, 2010.

[7] S. Dai, D. Zhao, Q. Li, and M. Qiu, “Double-sided polarization-independent plasmonic absorber at near-infrared region”, *Opt. Express*, vol. 21, pp. 13125-13133, 2013.

[8] F. Dincer, M. Karaaslan, E. Unal, and C. Sabah, “Dual-Band Polarization Independent Metamaterial Absorber Based On Omega Resoanator and Octa-Starstrip Configuration”, *Prog. Electromagn.Res.* vol. 141, pp. 219-231, 2013a.

[9] F. Dincer, C. Sabah, M. Karaaslan, E. Unal, M. Bakir and U. Erdiven, “Asymmetric Transmission of Linearly Polarized Waves and Dynamically Wave Rotation Using Chiral Metamaterials”, *Prog. Electromagn. Res.*, vol. 140, pp. 227-239, 2013b.

[10] N. Fang, H. Lee, C. Sun, and X. Zhang, “Sub-Diffraction-Limited Optical Imaging with a Silver Superlens”, *Science*, vol. 308, pp. 534-537, 2005.

[11] F. Hu, L. Wang, B. Quan, X. Xu, Z. Li, Z.Wu, and X. Pan, “Design of a polarization insensitive multiband terahertz metamaterial absorber”, *J. Phys. D: Appl. Phys.*, vol. 46, pp. 195103, 2013.

[12] R. B. Hwang, “Correlation between a negative group velocity and a slanted stop band in two-dimensionally periodic structures”, *Radio Sci.*, vol. 41(1), 2006.

[13] D. S. Kim, D. H. Kim, S. Hwang, and J. H. Jang, “Broadband terahertz absorber realized by self assembled multilayer glass spheres”, *Opt. Express*, vol. 20, pp. 13566-72, 2012.

[14] M. R. Khodja, and E. A. Marengo, “Comparative study of radiation enhancement due to metamaterials”, *Radio Sci.*, vol. 43(6), 2008.

[15] T. M. Kollatou, A. I. Dimitriadis, S. D. Assimonis, N. V. Kantartzis, and C. S. Antonopoulos, “A Family Of Ultra-Thin, Polarization-Insensitive, Multi-Band, Highly Absorbing Metamaterial Structures”, *Prog. Electromagn. Res.*, vol. 136, pp. 579-594, 2013.

[16] N. I. Landy, S. Sajuyigbe, J. J. Mock, D. R. Smith, and W. J. Padilla, “A Perfect Metamaterial Absorber”, *Phys. Rev. Lett.*, vol. 100, pp. 207402-4, 2008.

[17] L. Lu, S. Qu, H. Ma, F. Yu, S. Xia, Z. Xu, and P. Bai, “A Polarization-Independent Wide Angle Dual Directional Absorption Metamaterial Absorber”, *Prog. Electromagn.Res.*, vol. 27, pp. 191-201, 2012.

[18] J. Lee, and S. Lim, “Bandwidth-enhanced and polarisation-insensitive metamaterial absorber using double resonance”, *Electron. Lett*., vol. 47, pp.8-9, 2011.

[19] N. G. Lehtinen, “A waveguide model of the return stroke channel with a “metamaterial” corona”, *Radio Sci.*, vol. 47(1), 2012.

[20] C. Sabah, “Left-handed Chiral Metamaterials”, *Cent. Eur. J. Phys*., vol. 6, pp. 872-878, 2008.

[21] C. Sabah, “Multiband Metamaterials Based On Multiple Concentric Open-Ring Resonators Topology”, *IEEE J. Sel. Top. Quant*., vol. 19, pp. 8500808, 2013.

[22] L. M. Si, W. Zhu, and H. J. Sun, “A Compact, Planar, and CPW-Fed Metamaterial-Inspired Dual Band Antenna”, *IEEE Antenn. Wirel. Pr.*, vol. 12, pp. 305-308, 2013.

[23] J. Sun, L. Liu, G. Dong, and J. Zhou, “An extremely broad band metamaterial absorber based on destructive interference”, *Opt. Express*, vol. 19, pp. 21155-62, 2011.

[24] L. Sun, H. Cheng, Y. Zhou, and J. Wang, “Broadband metamaterial absorber based on coupling resistive frequency selective surface”, *Opt. Express*, vol. 20, pp. 4675-80, 2012.

[25] I. V. Shadrivov, A. A. Zharov, N. A. Zharova, and Y. S. Kivshar, “Nonlinear left-handed metamaterials”, *Radio Sci.*, vol. 40(3), 2005.

[26] H. Tao, E. A. Kadlec, A. C. Strikwerda, K. Fan, W. J. Padilla, R. D. Averitt, E. A. Shaner, and X. Zhang, “Microwave and Terahertz wave sensing with metamaterials”, *Opt. Express*, vol. 19, pp. 21620-6, 2011.

[27] H. Tao, N. I. Landy, C. M. Bingham, X. Zhang, R. D. Averitt, and W. J. Padilla, “A metamaterial absorber forthe terahertz regime: Design, fabrication and characterization”, *Opt. Express*, vol. 16, pp. 7181–7188, 2008.

[28] H. Tao, C. M. Bingham, D. Pilon, K. Fan, A. C. Strikwerda, D. Shrekenhamer, W. J. Padilla, X. Zhang, and R. D. Averitt, “A dual band terahertz metamaterial absorber”, *J. Phys. D: Appl. Phys*., vol. 43, pp. 225102, 2010.

[29] H. Odabasi, and F. L. Teixeira, “Analysis of canonical low-profile radiators on isoimpedance metamaterial substrates”, *Radio Sci.*, vol. 47(1), 2012.

[30] W. Qin, J. Wu, M. Yu, and S. Pan, “Dual-band terahertz metamaterial absorbersusingtwotypes of conventional frequency selective surface elements”, *Terahertz Science and Technology*, vol. 5, pp. 169-174, 2012.

[31] R. W. Ziolkowski, and C. Y. Cheng, “Lumped element models of double negative metamaterial-based transmission lines”, *Radio Sci.*, vol. 39(2), 2004.

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