A Tunable Absorber with Switched Absorption/Transmission Property

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***Abstract*—In this paper, a tunable absorber with switched absorption/transmission property is presented, which is composed of a dielectric substrate and metamaterials. The microfluidic channel is etched inside the dielectric substrate, and wideband absorption can be achieved when adding liquid water and the absorption peak can reach 99%. While, without adding water, electromagnetic waves can propagate through the periodic planar structure and three transparency bands can be realized. Overall, the state of absorption and transmission can be tuned by changing the structure state. Therefore, it has potential application prospects and great potential applications in the fields of electromagnetic stealth.**

Keywords—tunable; metamaterial absorber; transmission

I. INTRODUCTION

Metamaterials [1] are either periodic or non-periodical arrays of macroscopic basic units with specific geometries, so that they have an artificial composite structure or an artificial composite material with extraordinary electromagnetic properties not possessed by natural materials. About the application of metamaterial, there has already a wide range of components based on metamaterial, such as antenna [2] based on metamaterial, metamaterial absorbers [3]-[13], perfect lenses [14] and so on.

With regard to the metamaterial absorber, there have been many researches. The metamaterial absorber with nearly 100% of the absorption rate was first proposed by Landy in 2008 [3]. In recent years, many papers have been reported to this area, aiming to design an absorber exhibiting excellent performances, such as multiband [4], [5], wideband [6-11], tunable absorber [9], [12], [13], etc. In order to realize wideband absorber, the scholars have proposed many methods. Such as multi-layer metal pattern layer and dielectric layer alternately superimposed to achieve broadband absorption [6], broadband absorption with different size metal patterns in plane [7], designing the intermediate dielectric layer as a magnetic medium [9], and so on. The introduction of microfluidic channels in the dielectric layer also provides novel ideas for broadband absorption. This broadband absorption is achieved by injecting liquid metal [10] or water [11]. The above metamaterial absorber adopts a metal back plate structure to achieve a transmittance close to zero, it is also commonly known as metal-dielectric-metal system to achieve perfect absorption. However, it cannot be changed once they are determined, so, it has no flexibility.

In this work, the metamaterial absorbers can not only achieve the broadband absorption, but also can be controlled by adjusting the media properties of the microfluidic channels to obtain passbands. Specially, the dielectric substrate layer introduces microfluidic channels and the metal ground uses the slot-type frequency selective surface. Absorption is obtained through adding water, and transmission is obtained by not adding water.

II. DESIGN AND ANALYSIS

To minimize the dielectric loss and introduce microfluidic channels, the material used as the substrate is UV-light photosensitive resin (UV-PR) [11], and the dielectric constant of UV-PR is 3.5 and the loss tangent is 0.001. The copper sheet with the conductivity of 5.8×10^7 S/m as the bottom layer. Fig.1.shows the rear and lateral views of this metamaterial cell. The periodic dimension of the unit cell is p=15mm. Fig. 1(a) is the typical frequency selective surface [15] as the bottom layer. The length of the slot is l=11mm, and the width is w=1.2mm. Fig. 1(b) shows the separation of the overall structure. From right to left, the first to the third layer of the unit cell are dielectric substrate using UV-PR, the thicknesses are $t1$=2mm, $t2$=1.8mm, $t3$=0.5mm, respectively. The width of the microfluidic channel is b=3mm in the second layer. The thickness of the metal back plate with cross slit is t=0.018mm.

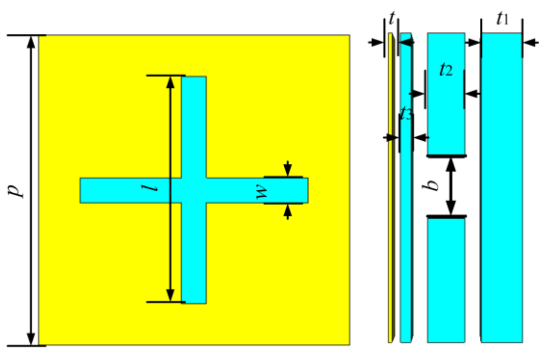

Fig.1.The unit cell (a) Rear view and (b) Lateral view

To see the microfluidic channel clearly, the substrate of the top layer is removed, as shown in Fig. 2. The width of the connection between the units is *b*=3mm. The side length of the square area in the middle is *a*=10mm. Fig. 2 (a) is the top view of the microfluidic channel, and Fig. 2 (b) is the 2*2 cells connection each other.

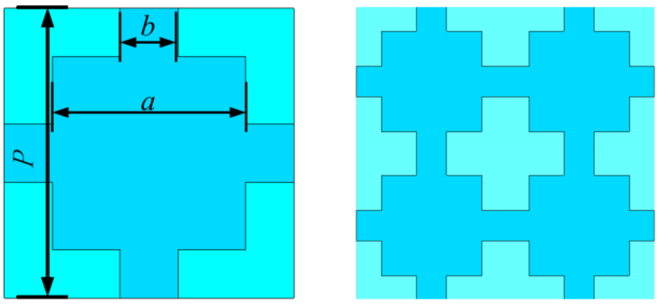

Fig.2. (a) The top view of the microfluidic channel (b) Channel connection

III. RESULTS OF SIMULATION

A. *State of Absorption*

For the normal absorbers, calculate the absorption rate using the formula

$$A=1-\left|S_{11}\right|^2-\left|S_{21}\right|^2 \qquad (1)$$

Due to the use of the full metal ground, the transmittance $T=\left|S_{21}\right|^2 \approx 0$. In the formula, S_{11} is the reflection coefficient of the structure, and S_{21} is the transmission coefficient of the structure.

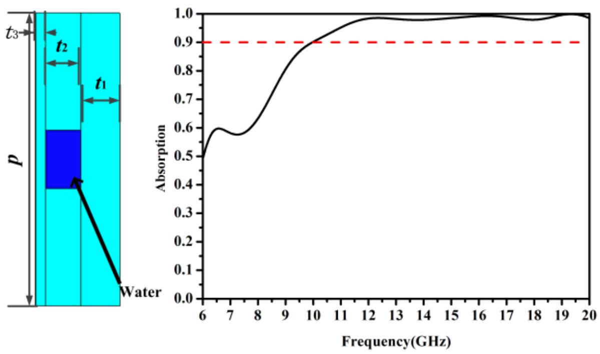

Fig.3. (a) Structure with water (b) Absorption rate

Fig. 3. shows the absorption results by the simulation. The simulation is operated by the commercial software CST MICROWAVE STUDIO. Based on the frequency domain solver, the open(add space) boundary condition is used for the *z* direction and unit cell boundary conditions with Floquet port are applied on the four boundaries in the *x* and *y* directions. The Debye formula can well describe the dispersion relation of the water. In the case where water is added to the microfluidic channel, the overall structure absorbs incident electromagnetic waves, as shown in Fig. 3 (a). It is worth mentioning that the use of water is relatively low cost, unlike the use of liquid metal [10]. Combining formula (1) can calculate the absorption rate (see Fig. 3(b)). The red dotted line indicates that the absorption rate can reach 90%, and above 90% from 10.0 GHz to 20.0 GHz and the maximum absorption rate is 99% at 16.5GHz.

B. *State of Transmission*

The microfluidic channel is filled with air when it is not in the state of passing water. Under the condition that the structural parameters remain unchanged, it can be optimized to obtain the transmission characteristic curve, as shown in Fig. 4, Fig. 4(a) is the state of the structure, and Fig. 4(b) is the transmission coefficient after calculation by formula (1), corresponding to the TE polarized wave.

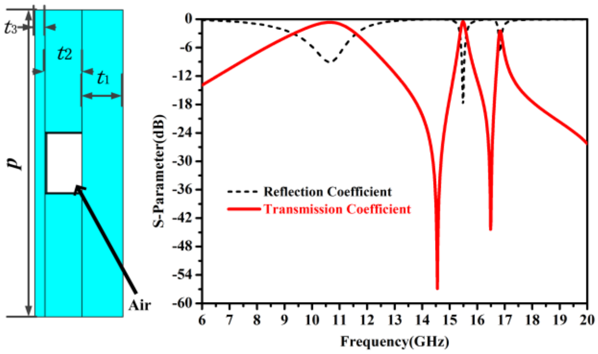

Fig.4. (a) Structure without water (b) S parameter

There are three transmission windows, at 10.6GHz with the insertion loss of -0.67dB, at 15.5GHz with -0.52 dB, at 16.8GHz with -2.5 dB, respectively. Additionally, in order to understand the physical resonant mechanism of the cell structure in depth, the surface current distributions are observed. Fig.5. is the surface current distributions at 15.5GHz. In the cross slot, the current density is relatively large, the current converges between the upper and lower slits and generates the resonance.

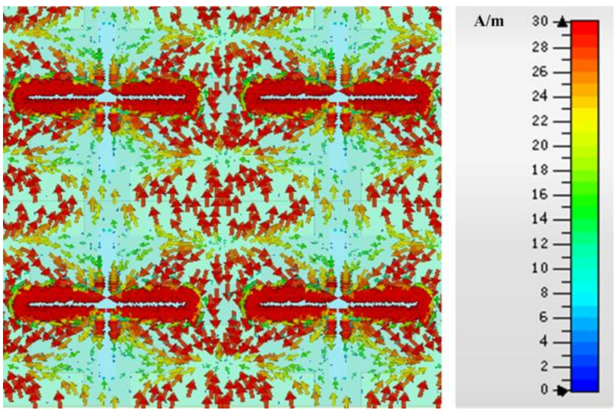

Fig.5.The surface current distributions at 15.5GHz (2*2 cells).

IV. CONCLUSION

In the above analysis, an absorber with wide absorption and transmission passbands in the desired waveband is discussion. In the case of absorption, the absorption rate of 90% can be obtained from 10.0 GHz to 20.0 GHz. After removing the water, three transparency passbands appear. In general, absorption and transmission can be switched.

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REFERENCES

[1] D. R. Smith, J. B. Pendry, and M. C. K. Wiltshire, "Metamaterials and Negative Refractive Index." Science, 305.5685, pp.788-92,2004.

[2] M.T. Islam, M.M. Islam, M. Samsuzzaman, MRI Faruque, N. Misran, "A Negative Index Metamaterial-Inspired UWB Antenna with an Integration of Complementary SRR and CLS Unit Cells for Microwave Imaging Sensor Applications," Sensors, vol. 15(5): pp.11601-11627, May 2015.

[3] N.I. Landy, S. Sajuyigbe, J.J. Mock, D.R. Smith, W.J. Padilla, "Perfect Metamaterial Absorber". Phys Rev Lett. pp. 207402-207402-4, 2008.

[4] X. Shen, T.J. Cui, J. Zhao, H.F. Ma, W. X. Jiang, & H.Li, "Polarization-independent wide-angle triple-band metamaterial absorber," Opt. Express, vol. 19(10), pp. 9401-9407, 2011.

[5] Y. Zhang, J. Duan, B. Zhang, W. Zhang, & W. Wang, "A flexible metamaterial absorber with four bands and two resonators," J. Alloy. Compd., vol. 705, pp. 262-268, 2017.

[6] Ding, F., Cui, Y., Ge, X., Jin, Y., & He, S. "Ultra-broadband microwave metamaterial absorber," Appl. Phys. Lett., vol. 100(10), pp. 103506-103506-4, 2011.

[7] Y.Cheng,Y.Nie,R. Gong,"A polarization-insensitive and omnidirectional broadband terahertz metamaterial absorber based on coplanar multi-squares films," Opt. Laser. Technol., vol. 48(6), pp. 415-421,2013.

[8] S. Ghosh, S. Bhattacharyya, D. Chaurasiya and K. V. Srivastava, "An Ultrawideband Ultrathin Metamaterial Absorber Based on Circular Split Rings," IEEE Antenn. Wirel. PR., vol. 14, pp. 1172-1175, 2015.

[9] Y. Cheng, Y. Nie, X. Wang, R. Gong, "Adjustable low frequency and broadband metamaterial absorber based on magnetic rubber plate and cross resonator," J. Appl. Phys., vol.115(6), pp. 207402, 2014.

[10] H. K. Kim, D. Lee, S. Lim, "Wideband-switchable metamaterial absorber using injected liquid metal," Sci. Rep., 6, 31823,2016.

[11] X. Huang, H. L. Yang, Z. Shen, J. Chen, H. Lin, Z. Yu,. "Water-injected all-dielectric ultra-wideband and prominent oblique incidence metamaterial absorber in microwave regime," J. Phys. D: Appl. Phys. vol. 50(38), 2017.

[12] J. Zhao, J. Chen, M. Q. Qi, W. X. Jiang, Q. Cheng, T. J. Cui, "A tunable metamaterial absorber using varactor diodes," New. J. Phys., vol. 15(4), pp. 043049, 2013.

[13] Y. Huang, G. Wen, W. Zhu, J. Li, L. M. Si, Premaratne, M. " Experimental demonstration of a magnetically tunable ferrite based metamaterial absorber,"Opt. Express,vol. 22(13), pp. 16408-16417,2014.

[14] N. Fang, H. Lee, C. Sun, X. Zhang, "Sub-diffraction-limited optical imaging with a silver superlens," Science, vol.308(5721), pp.534-537,2005.

[15] S. Zheng, Y. Yin, J. Fan, X. Yang, B. Li and W. Liu, "Analysis of Miniature Frequency Selective Surfaces Based on Fractal Antenna–Filter–Antenna Arrays," IEEE Antenn. Wirel. PR., vol. 11, pp. 240-243, 2012.