A Novel Tunable Dual-band Microwave Metamaterial Absorber Based on Split Ring Resonant

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Abstract— We present the design, simulation, fabrication, and measurement of a tunable metamaterial at microwave frequencies by embedding varactor diodes as an active elements inside metamaterial units. A pair of feed lines are used to control the reverse bias voltage on the diode. The proposed absorber can perform absorption peaks at two resonant frequencies. The lower resonant frequency can be tuned in a wide range by tuning the values of the diodes while the higher resonant frequency keeps unchangeable. In addition, the absorber with the thickness of $\lambda/74$ at the lowest fundamental resonant frequency is ultra-thin. We also find that the absorber is insensitive to the polarization of incident waves for a wide range of incidence angles for both TE and TM polarizations. The experimental results show excellent absorption rates under different bias voltage on the diode, which are in good accordance to the simulated results.

1. INTRODUCTION

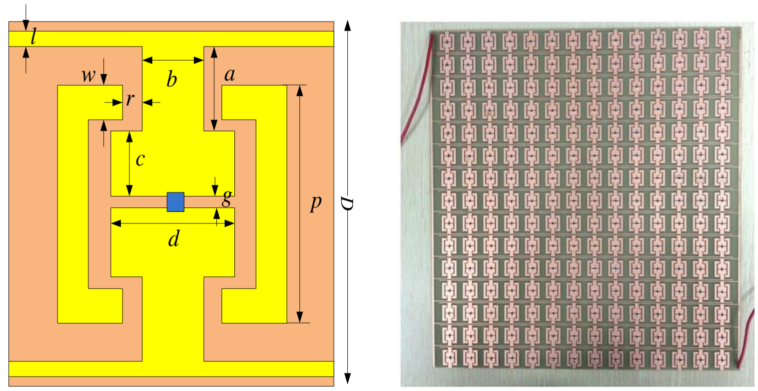
In the last decade, the research on electromagnetic (EM) metamaterial has attracted a lot of attention, due to its peculiar behaviors, such as negative refraction, miniaturization. Owing to its unusual properties, potential applications of metamaterial have been studied in many ways, like antenna structure, perfect lens, concentrator, cloaking and so on.

Recently, the metamterial absorber (MMA) has become a research focus, by designing proper resonant units, a perfect absorber has many wonderful properties like high absorptivity and ultra-thin thickness. In 2008, Landy [1] first reported the concept of perfect metamaterial absorber, which consists of artificial sub-wavelength composites and has high absorption with small-size. Recently, MMAs are available in the microwave region, terahertz region, infrared and visible regions [2–5]. Dual-band and muti-band MMAs has been successfully realized which are based on different electric resonators [6, 7]. Broadband MMAs have also been studied in various designed forms of units [8]. However, the traditional metamaterial absorbers have a common shortcoming that their absorption performance can not be changed if they have been fabricated. Therefore, the design of tunable MMAs has attracted more and more interests. Jie Zhao et al. [9] introduced a tunable metamaterial absorber using varactor diodes. Its absorption frequency can be tuned by changing the bias voltage at the both ends of the diodes. A microwave diode switchable metamaterial reflector/absorber has been investigated by Wangren Xu et al. [10].

In this paper, we propose a simple design of tunable absorber structure to achieve a tunable dual-band absorber in GHz frequency regime. The lower absorption frequency can be tuned continuously by changing the reverse bias voltage on the diode while the higher absorption frequency keeps unchangeable. The thickness of the dielectric material in our absorber in only $\lambda/76$ at the lowest fundamental resonant frequency. In addition, current and field distribution analysis are performed to better understand the resonant mechanism. The simulation and experiment results are in excellent agreement to verify the designs with high absorption rate of more than 90%.

2. DESIGN AND BASIC UNIT

The proposed MMA based on the novel resonant structure is presented in Fig. 1. Fig. 1(a) shows the perspective view of the proposed MMA, which is composed of two conductive layers with a single substrate (FR-4) between them. Fig. 1(b) shows the photograph of the fabricated MMA sample and the detailed patters of the unit cells appearing in the top layer. There are a cut wire and a SRR on the top layer, where the bottom layer has a metallic ground plate without patterning. The varactor diode illustrated as the blue cube in Fig. 1(a) is embedded in the disconnection of the



(a) (b)

Figure 1: Structure of the unit cell of the proposed MMA. (a) Perspective view. (b) The photograph of the fabricated MMA sample.

cut wires. The chosen substrate is FR-4 with a relative permittivity $\varepsilon_r = 4.4$ (loss tangent 0.025) and thickness $h = 1.5\,\text{mm}$. The feeding lines of the diode are in the same plane with resonators. The dimensions of the resonator unit are shown in Fig. 2. All units are in millimeters: $D = 20\,\text{mm}$, $a = 3\,\text{mm}$, $b = 3.6\,\text{mm}$, $c = 4.25\,\text{mm}$, $d = 8\,\text{mm}$, $g = 0.5\,\text{mm}$, $l = 0.5\,\text{mm}$, $w = 2\,\text{mm}$, $p = 14\,\text{mm}$, $r = 2.5\,\text{mm}$.

3. SIMULATION RESULTS

Based on the previous dual-band absorber designed structure without varactor diode, the varactor diode is embedded between the gap in the middle of the surface. The absorption rates of the designed unit under different value of the diode are simulated in Fig. 4. Firstly, the two absorption frequencies are more close after added the varactor diode, then the ripple beside the lower absorption frequency disappears and the absorption rate becomes nearly 99%. Through tuning the bias voltage applied on the varactor, the junction capacitance of the varactor is changed, which results the shift of the resonance frequency. We found that there is a wide tuning frequency range from 2.69 GHz to 3.37 GHz by changing the diode's reverse bias voltage from −0 V to −15 V with the absorption rates closing to 99%.

At last, we will discuss the situations with large incident angles and instable polarization states. It is clear that the tunable MMA has a stable performance under both TE and TM polarizations, as shown in Fig. 3. The absorption rates is insensible to the incident angles (θ, defined as the angle between the wave vector and the normal). Fig. 4 shows the simulation results for the oblique incidence at different incident angles for TE [Fig. 4(a)] and TM [Fig. 4(b)] under the capacitance of 1.090 pF. From the figure, it can be concluded that the MMA unit has excellent performance even when the incident angle is up to 50°.

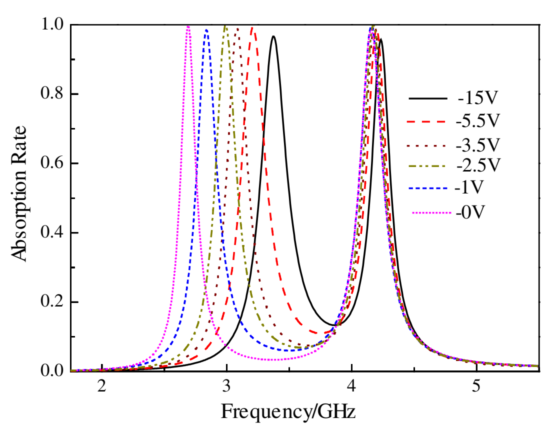
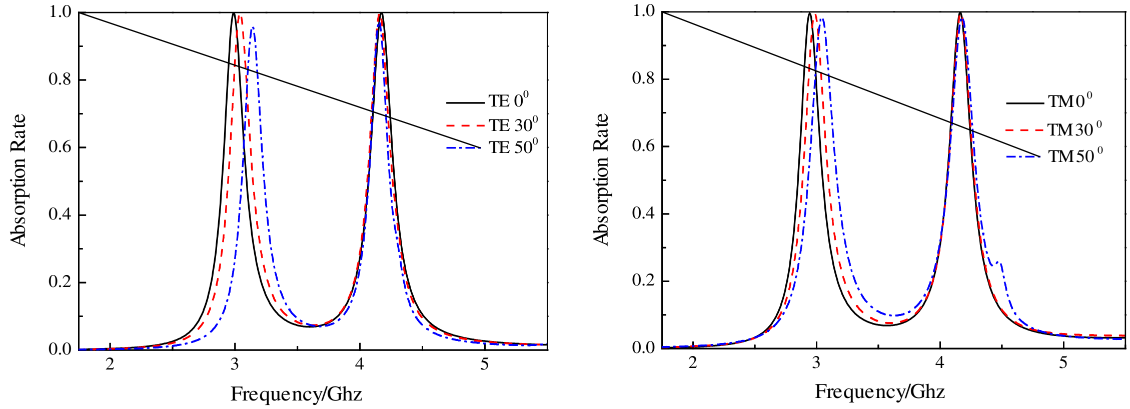


Figure 2: Simulation results of the absorption rates under different reverse bias voltages.



(a) (b)

Figure 3: Simulation results of the absorption rates for oblique incidences at various incident angles for (a) TE and (b)TM polarizations under the capacitance 1.090 pF.

4. EXPERIMENTAL RESULTS

To experimentally verify the design procedure of the proposed tunable MMA, we have fabricated a MMA sample,as shown in Fig. 10(a). The unit cells are fabricated using the print circuit board technique on the FR4 substrate, with total footprint of 280 mm × 300 mm consisting of 210 elementsand the thickness of 1.5 mm as that used in numerical simulations. The fabricated tunable MMA is then measured by the free-space method, using two horn antennas in a controlled environment of an anechoic chamber. Fig. 10 illustrates the fabricated sample and the experimental simulation setup, in which two pairs of horn antennas connecting to the vector network analyzer (Agilent N5230C) by a low-loss coaxial cable. The incident wave's polarization is chosen to be along the vertical direction. The distance between the sample and the antenna is D^2/λ_0, which is far enough to avoid the near-field effects of the antenna and the DFSS sample being tested. We also use pyramid absorbing materials to eliminate the electromagnetic (EM) scattering from the environment.

The experimental results of the reflection coefficient of the fabricated tunable MMA for TE polarizations under different reverse bias voltage are illustrated in Fig. 11. It is observed that the absorption rate is nearly 90% when the bias voltage changes from -1 V to -14 V. The slight frequency discrepancy may be due to the fabrication tolerance as well as the dielectric board material whose actual dielectric constant is slightly different from the value used in the simulations. In spite of these discrepancies, it is clearly that the experimental results agree with the simulation results that high can be obtained at the resonance frequency and validate the tunability of the tunable MMA and. In addition, the proposed MMA is relative thin, with a thickness nearly of $\lambda/74$ at the lowest fundamental resonant frequency of the working wavelength.

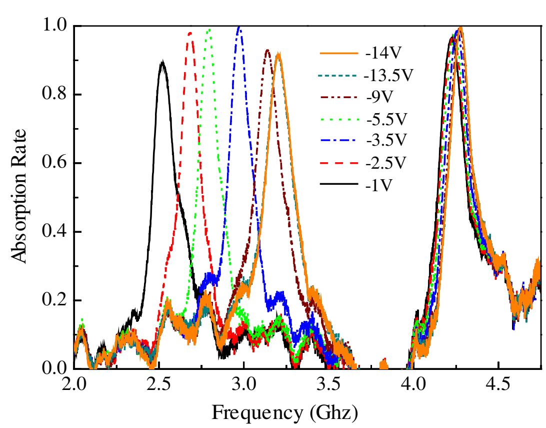


Figure 4: Experimental results of the absorption rates at different reverse bias voltage, ranging from -1 to -14 V.

5. CONCLUSIONS

In summary, we have proposed a tunable metamaterial absorber using cut wires embedded varactor diodes and SRR working in microwave region. The lower absorption frequency of the MMA can be tuned continuously by changing the bias voltage on the both ends of the varactor diode. While the higher absorption frequency keeps unchangeable. Both the absorption rates remain greater than 90% throughout the process of measurement. By placing the basic units orthogonally, we can achieve its property of polarization and large incident angles insensitivity. The detailed analysis of the surface current of the structure and E-field distributions have performed to better understand the resonant mechanism. The simulation and the experimental results are in good consistency, which verified the tunability of the dual-band MMA.

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