

Small-size metamaterial perfect absorber operating at low frequency

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Abstract

A small-size metamaterial perfect absorber operating at low frequency is proposed. Due to the special design, the unit-cell dimension with respect to wavelength is very small, $a/\lambda \sim 1/17$, at the absorption frequency of 377 MHz. The absorption frequency is strongly dependent on the length of zigzag wire. In addition, the absorption is more than 94% in a wide range of incident angle of electromagnetic wave up to 50°. The results show that the proposed absorber is promising to be applied into devices in radio region.

Keywords: metamaterials, perfect absorption, low frequency

Mathematics Subject Classification: 5.17

1. Introduction

Since the first realization of artificial sub-wavelength materials, the so-called metamaterials (MMs) [1], the research on MMs has been explosively developed due to the unnatural superior properties such as negative refractive index [2–4], slow light [5–7], invisibility cloaking [8, 9], and super-resolution [10, 11]. Recently, the science community has focused on another fascinating phenomenon of MMs which is the perfect absorption. The MM perfect absorber (MPA) was first demonstrated by Landy *et al* in 2008, paving the way for new applications using man-made materials, especially, in energy harvesting devices [12]. Thenceforth, MPAs have been numerously investigated and presented for different frequency regions such as GHz frequencies [13–15] and THz frequencies [16–18]. Nowadays, the application of perfect absorption in telecommunications is one of the prior concerns for practical purposes. Unfortunately, the big size of MPA is an obstacle when operating at radio frequencies. Most recent MPAs have the ratio of lattice constant over wavelength ranging from one third to a fifth, which is difficult to integrate into real radio devices [12–14, 16–18]. Therefore, miniature size is an essential requirement in the telecommunications area. In this work, we designed and investigated a small-size

MPA operating at radio frequencies. The proposed MPA has a unit-cell dimension of less than fifteenth of the wavelength of incident electromagnetic wave and maintains the absorption above 94% for the wide range of incident angle up to 50°.

2. Results and discussion

The proposed MPA includes three layers: a patterned front metallic layer is separated from continuous back metallic plane by a dielectric layer. The front pattern is the periodic arrangement of a structure composed of two halves of disk connected by a thin zigzag wire, the so-called sandglass structure. The unit cell of the designed MPA is illustrated in figure 1. The periodicities of unit cell are $a=45$ mm and $b=36$ mm corresponding to x and y directions, respectively. The geometrical parameters of zigzag wire are $g=0.5$ mm, $d=9.9$ mm, $w=0.1$ mm, and $l=3$ mm. The radii of two half disks are the same, $r=17.5$ mm. In simulation, the metal is chosen as copper with a conductivity of 5.8×10^7 S m⁻¹. The dielectric layer is FR-4 with a dielectric constant of 4.3 and a loss tangent of 0.025. The thickness of metal layers and dielectric layer are $t_m=0.036$ mm and $t=11$ mm, respectively. The simulations are performed using commercial software,

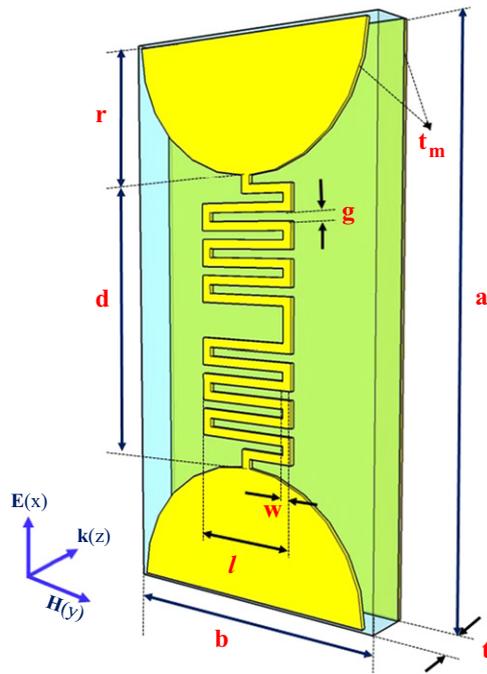


Figure 1. Illustration of the unit cell of sandglass-structure absorber and electromagnetic polarization.

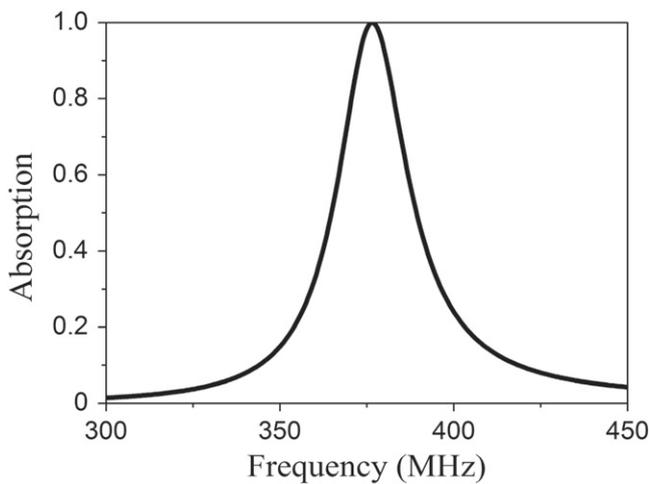


Figure 2. Absorption spectrum of the sandglass absorber.

CST Microwave Studio. The unit cell is set to the periodic boundary conditions in x and y directions and open for z direction for the propagation. The radiation source is polarized so that the electric and the magnetic fields are parallel to x and y axes, respectively. The absorption was calculated as $A(\omega) = 1 - R(\omega) - T(\omega) = 1 - |S_{11}|^2 - |S_{21}|^2$, where the reflection power $R(\omega) = |S_{11}|^2$ and the transmission power $T(\omega) = |S_{21}|^2$. It is noteworthy that the transmission power $T(\omega) = 0$ due to the back metallic plane blocking the propagation of incident wave.

Figure 2 shows the absorption spectrum of the MPA based on sandglass structure. A perfect absorption is achieved at 377 MHz, with zero transmission due to the back metallic plane and zero reflection due to the impedance matching at this frequency. The minimum unit cell dimension over

wavelength, that is, the minimum ratio of a/λ is approximately 1/17, which is much smaller than most metamaterial absorbers operating at GHz frequencies [12–14]. The result implies that our designed MPA is potentially suitable for applications in the radio region.

The absorption mechanism of proposed small-size MPA operating at MHz frequencies is further clarified in figure 3. Figure 3(a) presents the surface currents on the front and the back metallic layers at 377 MHz. The induced anti-parallel currents on two layers prove that a magnetic resonance is formed at the absorption frequency. Therefore, the absorption in the sandglass MPA originated from the magnetic resonance that is similar to the common MPAs. However, the small-size feature of the absorber comes from the special structural design. As shown in figure 3(b), the moving length of surface current is increased owing to the zigzag wire. Consequently, the resonance frequency is significantly shifted to low frequency, which leads to very small unit-cell dimension with respect to wavelength [15].

In order to emphasize importance of the designed structure as small-size MPA, the dependence of the absorption on geometrical parameter l is presented in figure 4. The absorption frequency of sandglass absorber is significantly decreased, from 452 to 323 MHz when l is increased from 1 to 5 mm. The result proves that the length of zigzag wire strongly affects the absorption frequency. Consequently, the size of sandglass absorber with respect to the operation wavelength becomes smaller when the length of zigzag wire is longer. In figure 4, for the longest zigzag wire, corresponding to $l = 5$ mm, the size of MPA is smallest, where the ratio of a/λ is approximately 1/20. It is also noteworthy that the slight reduction of absorption is due to the deviation of impedance from the perfect impedance matching condition corresponding to $l = 3$ mm. However, the absorption is still maintained well above 90% even after a large frequency shift of 129 MHz. This means that the zigzag wire mainly affects the absorption frequency without remarkable change of the absorption.

In figure 5, the dependence of absorption on the incident angle was investigated to evaluate the operation capability in reality. Interestingly, the proposed absorber maintains the absorption above 94% for a wide range of incident angle up to 50° while the absorption frequency is nearly unchanged. The result implies that the sandglass MPA is not only theoretical but a potential for reality. The small reduction of absorption according to incident angle can be explained by the coupling between the external magnetic field and the MPA. The wider the incident angle, the weaker the coupling leading to impedance mismatching, since the magnetic resonance is the origin of absorption. Hence, the absorption comes to be slightly smaller when the incident angle is increased.

3. Conclusions

We investigated a small-size MPA operating at radio frequency. The minimum unit-cell dimension over wavelength is about 1/17 at 377 MHz, which is due to the special design

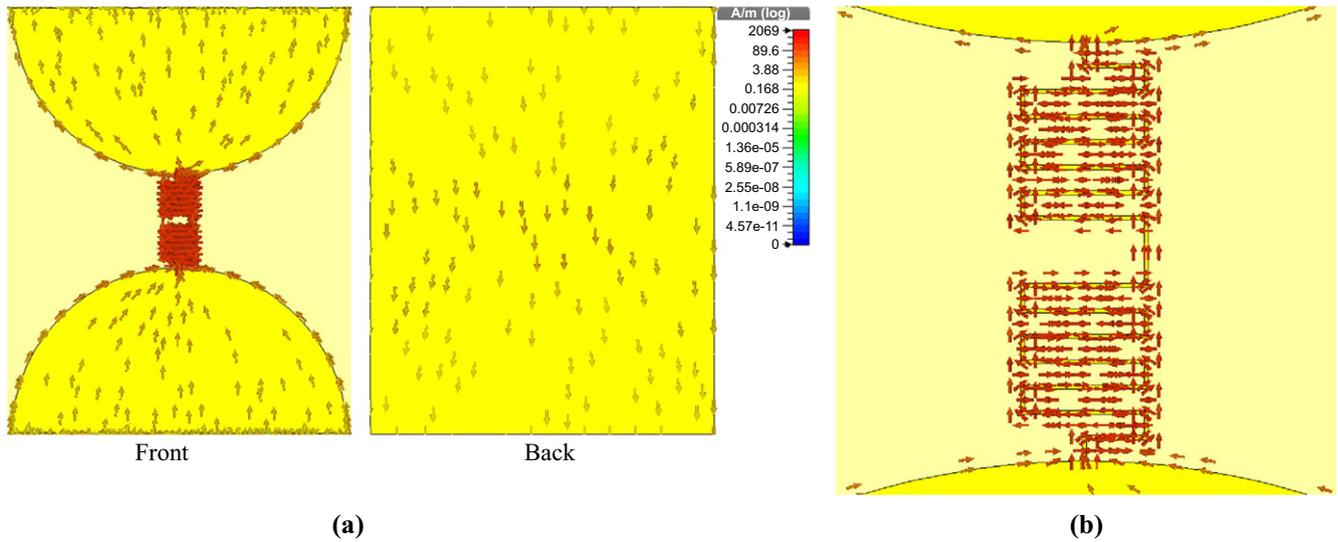


Figure 3. (a) Surface currents on the front and the back layers at absorption frequency, (b) detailed view of surface currents on the zigzag wire.

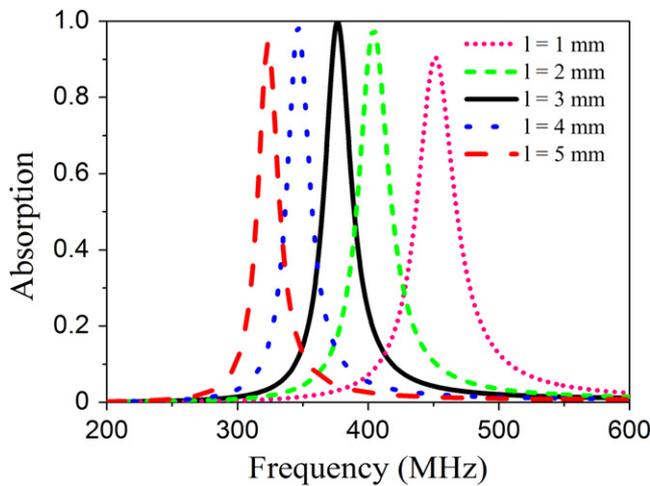


Figure 4. Absorption spectra of the sandglass absorber according to geometrical parameter l .

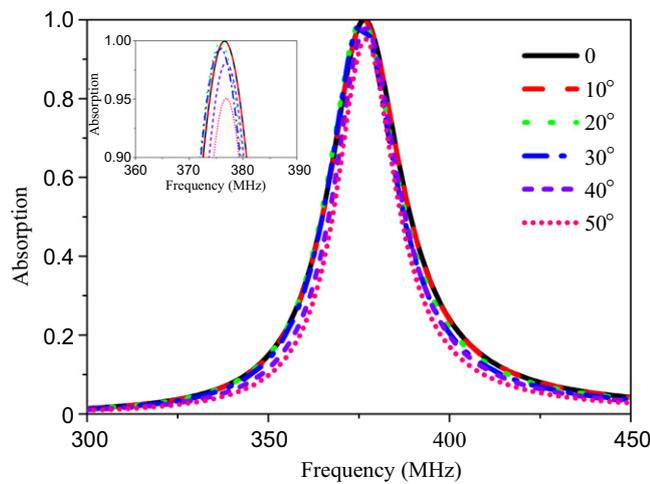


Figure 5. Dependence of the absorption on incident angle. The inset is the magnification around absorption peak.

allowing the magnetic resonance to happen at very low frequency. The length of the zigzag wire plays an important role to obtain the small-size absorber. The absorber can maintain the absorption above 94% with a wide range of incident angle of electromagnetic wave up to 50° . Our work is expected to contribute to the development of prospective equipments in radio range.

Acknowledgments

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