Ultra-wideband Optically Transparent Metmaterial Absorber

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Abstract. In this paper, an optically transparent, wide-angle, polarization-insensitive ultra-wideband metamaterial absorber is presented. The structure is a two-layer configuration. The unit cell of the first layer is composed of an indium tin oxide (ITO) film cross and a square ring, and that of the second layer is also a square ITO film ring with different size from the one on the first layer. Moreover, there is a complete ITO film on the back of the absorber which is used as the reflecting layer. Absorptivity of the structure is higher than 90\% from 5.3 to 17.45 GHz, and the fractional bandwidth of the absorber is 106.8\%. In addition, the structure is insensitive to polarization and incidence angle.

1. Introduction

Microwave absorber, a component that can absorb the incident electromagnetic wave, is highly applicable in the field of stealth technology, electromagnetic compatibility, etc. [1]. The original microwave absorber is the Salisbury screen that appeared in World War II [2]. It is consisted of a thin resistive layer, a dielectric layer with a quarter-wavelength thickness, and a metal backplane. With the extensive application of wireless communication and other electronic systems, the problems of electromagnetic interference and information leakage have become more prominent [3] and the microwave absorber takes an important role in coping with such problems. The classical microwave absorber has been unable to meet requirements of the modern environment because of its shortcomings such as narrow bandwidth and large thickness [4].

Metamaterial absorber was first proposed by Landy et al. in 2008 [5]. Metamaterial is an artificial composite structure consisting of periodic subwavelength units which are made of traditional materials, but it has unique electromagnetic properties different from traditional materials [6]. Metamaterial absorbers have advantages of small thickness, high absorptivity and simple structure. Unlike conventional absorbers whose thickness must be 1/4 of the operating wavelength, the metamaterial absorbers could greatly reduce the thickness of the absorber and increase the design flexibility. In recent years, much effort has been devoted to metamaterial absorber [7-9]. Although metamaterial absorbers have many advantages, most of them have drawbacks of narrow bandwidth and high polarization sensitivity [4]. To overcome the shortcoming of metamaterial absorbers, an enhanced bandwidth metamaterial absorber is proposed in [10] by making two overlapped resonances, and the structure shows an enhanced bandwidth from 10.15 to 10.65 GHz, but the bandwidth is still relatively narrow. In addition, most microwave absorbers are opaque and this characteristic limits their applications in some specific workplaces. However, most dielectric substrates and coating materials are opaque. Thus, it is difficult to achieve absorption property and optical transparency at the same time.

In this paper, an optically transparent, ultra-wideband metamaterial absorber is presented. Indium tin oxide (ITO) thin film, a kind of transparent resistive thin film, is used to replace the classical coating material like copper. In addition, glass is adopted as the substrate to achieve optical
transparency. It is expected that the absorber can be used as window glasses in some office locations to protect workers from large amount of radiation, or confidential workplaces to protect important information from disclosure.

2. Absorber design

2.1 Theory of the absorber

In order to achieve high absorptivity, the equivalent impedance of the metamaterial absorber should be matched to the air to minimize the reflected wave. The equivalent impedance of the metamaterial absorber $Z(\omega)$ can be defined by effective permittivity $\varepsilon_{\text{eff}}$ and effective permeability $\mu_{\text{eff}}$ of the structure:

$$Z(\omega) = \sqrt{\frac{\mu_{\text{eff}}\varepsilon_{\text{eff}}}{\varepsilon_{\text{ref}}\mu_{\text{ref}}}}$$  \hspace{1cm} (1)

The reflection coefficient $\Gamma(\omega)$ can then be expressed as:

$$\Gamma(\omega) = \frac{Z(\omega) - Z_0}{Z(\omega) + Z_0}$$ \hspace{1cm} (2)

When $Z(\omega)$ is equal to $Z_0$, there will be no reflected wave from the structure surface. The impedance of the absorber can be matched to the air by adjusting effective permittivity and permeability. The ratio of the absorbed electromagnetic energy to total incident power is the absorption rate of the absorber, it can be expressed as follows.

$$A(\omega) = 1 - R(\omega) - T(\omega)$$  \hspace{1cm} (3)

where $R(\omega) = |S_{11}(\omega)|^2$ is reflected power and $T(\omega) = |S_{21}(\omega)|^2$ represents transmitted power.

In this design, the absorber uses an ITO thin film with a sheet resistance of 10Ω/sq to act as a reflecting layer. The ITO film with a low sheet resistance can be regarded as a metal plate, so the transmitted power $T(\omega)$ is nearly zero. When transmitted power and reflected power both equal to zero, the electromagnetic power is completely dissipated by the resistive thin film of the proposed absorber.

2.2 Absorber structure design

The structure diagram of the absorber is exhibited in Fig. 1. Glass ($\varepsilon_r=4.5; \tan\delta=0.008$) is selected as dielectric substrate in order to achieve optical transparency. The unit cell of first layer (layer 1) is composed of an ITO film cross and a square ITO film ring, which is shown in Fig. 1(a). The unit cell of the second layer (layer 2) is a single square ITO film ring, which is shown in Fig. 1(b). The sheet resistance of the ITO films is 65Ω/sq. There is a complete ITO thin film with a sheet resistance of 10Ω/sq coated on the bottom surface of the glass substrate of layer 2 to act as a conduction plane, which is shown in Fig. 1(c) and Fig. 1(d). The dimensions of the absorber unit are: $p_1=10$mm, $p_2=20$mm, $t_1=3$mm, $t_2=3$mm, $w_1=0.25$mm, $w_2=0.8$mm, $w_3=5.9$mm, $l_1=5$mm, $l_2=4$mm, $l_3=17.6$mm. The absorber is modelled by commercial simulation software CST2015. All parameters and sheet resistance have been optimized to obtain high absorption rate and broad bandwidth.
3. Simulation results

The model of proposed absorber is built up in CST2015, and unit cell boundaries conditions and Floquet ports are used in simulation. The absorption rate and reflection rate of the proposed absorber are shown in Fig 2. From the simulation results, it can be clearly seen that the absorption rate under normal incidence is greater than 90% over the frequency range 5.3-17.45 GHz. The maximum absorption rate is 94.7% and the absorption peak appears at the frequency of 6.73 GHz. The bandwidth of the absorber reaches 106.8% of the center frequency. High absorption and ultra-wideband characteristic is achieved.
Fig. 3 shows the normalized impedance of the structure. It can be seen that the real part of the impedance is close to $Z_0$ and the imaginary part is close to zero over a broad frequency range. It implies that there will be less reflected wave from the absorber surface, and the incident electromagnetic power will be converted into heat energy by the resistive thin film.

In the case of normally incident plane wave, absorption rate of different polarization angles ($\varphi=0^\circ, 45^\circ$) is given in Fig. 4. It is observed that the absorption rate and bandwidth are almost unchanged for different polarized wave. That means the absorber shows polarization insensitive response because of the center-symmetric unit structure.
4. Summary

In this paper, an optically transparent ultra-wideband metamaterial absorber based on ITO film is proposed. Glasses and ITO thin films are used to construct the unit structure of the absorber. By optimizing the dimensions of the unit structure and the sheet resistance of the thin film, a broad absorption band is obtained. Absorption rate is higher than 90% from 5.3 to 17.45 GHz, and the bandwidth reaches 106.8%. Absorption rates of different polarization and incident angles have been studied. Simulation results indicate that the absorptivity is insensitive to polarization and incident angles. These characteristics make the absorber a feasible scheme in some specific application, such as radiation protection, confidential information protection and electromagnetic compatibility.
References


