A Transmission-typed Broadband Absorber

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Abstract— In this paper, we theoretically find that a wide, near complete absorption can be realized in a heterostructure composed of a dielectric layer and truncated photonic crystals with a lossy dielectric defect. A dielectric layer is put on the top of the truncated photonic crystals to gain a relative flatter broadband absorptions. The wide absorption band is located within transmission band gap of photonic crystals without lossy dielectric defect, which is different of some previous designs.

1. INTRODUCTION

The perfect absorption is greatly needed in photonic radiation detectors, efficient thermal emitters, and solar cells [1, 2]. Furthermore, electromagnetic (EM) absorbers with high absorption have been widely used in steal, EM shielding, darkroom, and so on.

To obtain high absorption, intensive EM field should be localized inside lossy materials. Photonic crystal with defect can enhance the intensity of the local EM field in the defect layer. Therefore, photonic crystals containing lossy dielectrics have attracted lots of attentions [3, 4]. A omnidirectional high absorption of photonic crystal consisting of negative-index material, positive-index material and defect layer is obtained in [5]. Lately, a efficient multiband absorber by using one-dimensional periodic mental-dielectric photonic crystal with a reflective substrate is reported by Wang et al. [6]. Moreover, by using metal and Bragg gap, a broadband omnidirectional absorption [7] is realized in photonic crystal heterstructure. It is noticed that all of broadband absorbers mentioned above is realized by using the forbidden band of photonic crystal. However, in this paper, we propose a transmission-type broadband absorber by using the transmission band of photonic crystal.

2. DESIGN

In order to let the all of electromagnetic (EM) wave enter the structures, a heterostructure $M(PN)^S D(PN)^K$ is designed. Fig. 1 shows the structure.

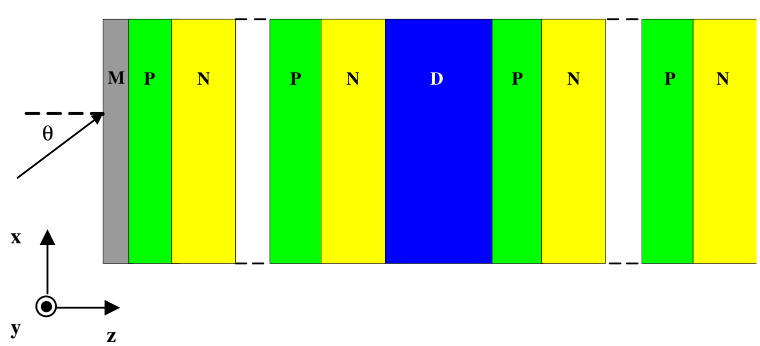


Figure 1: Schematic of the heterostructure composed of a dielectric layer (M) and a truncated photonic crystal with lossy dielectric layer (D). P and N represent positive-refractive-index and negative-refractive-index materials. S and K are the periods.

The reflectance and transmittance of the structure $(PN)^{10}$ are shown in Fig. 2. The thicknesses of P and N are denoted as d_P and d_N. The Drude model can be used to describe the property of negative-refractive-index materials, in which the relative permittivity and permeability are [8]

$$\varepsilon_N = 1.21 - \omega_{ep}^2 / \left(\omega^2 + i\gamma\omega\right) \tag{1}$$

$$\mu_N = 1 - \omega_{mp}^2 / \left(\omega^2 + i\gamma\omega\right) \tag{2}$$

where ω_{ep} and ω_{mp} are the electric plasma frequency and magnetic plasma frequency, and γ is the damping factor. The transfer-matrix method [9] is used to calculate the reflectance and transmittance. For TM wave, one of the transmittance band shown in Fig. 2 is 78.6–96.7 GHz. We can find the broadband absorption frequency locate within the pass band in Fig. 3, Fig. 4.

In order to obtain absorption effect, a lossy dielectric defect layer is introduced into the $(PN)^{10}$ structure. The defect mode can remarkably enhance the fields in the defect layer, so the EM is fully absorbed by the lossy defect. dd represents the thicknesses of D. Fig. 3(a). show the reflectance, transmittance and absorbance of the structure $(PN)^5D(PN)^5$ as a function of angular frequency for TM wave. The transmittance is near zero and the reflectance is very small with the max value 0.07. The absorption is calculated by $A = 1 - R - T$. The absorption is very high (0.92–1) within the transmittance band.

The high absorption is due to remarkably enhance the local electric fields located in the defect layer, which can be seen Fig. 3(b). It is shown that the simulated distributions of the intensities of electric field ($|E|^2$) in $(PN)^5D(PN)^5$ at the frequency of complete absorption (86.5 GHz). When the electric field intensity of incident wave is taken to be 1, the intensities of electric field can reach 1.4×10^4 in the defect lossy layer. The broadband and high absorption is generated in the defect layer, which is easily understand. As shown in Fig. 3(b), the magnitude of the electric field at the left interface between the PC and $(PN)^5D(PN)^5$ is 1.01, which shows no reflection at the left interface. It indicates near all of incident TM wave can enter the structure. From Fig. 3(a), we can find that the broadband absorption is not flat, which contain five absorption peaks. In order

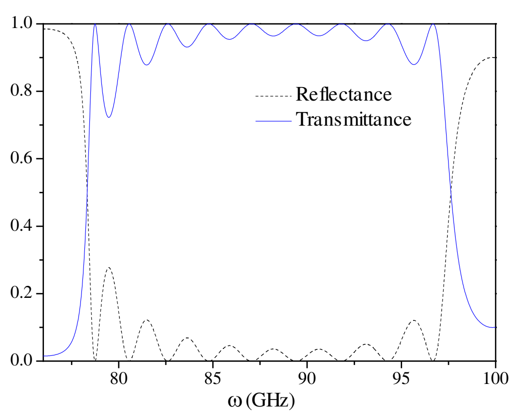
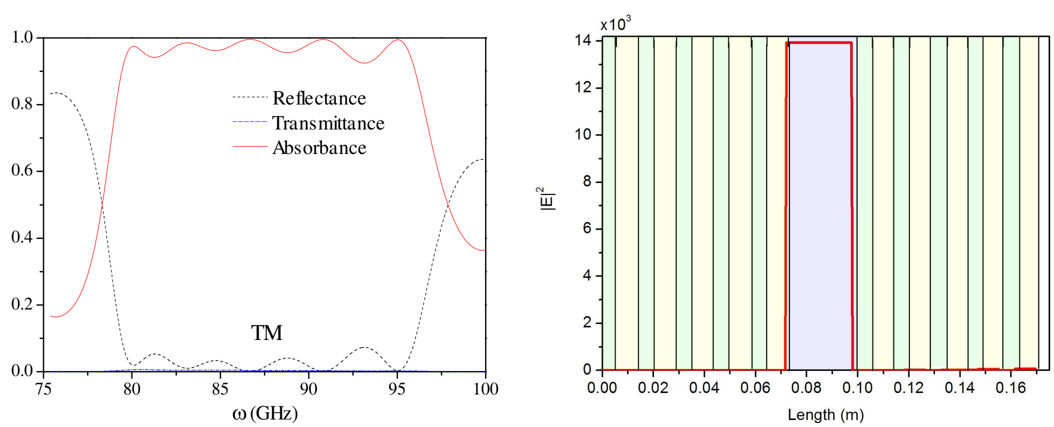


Figure 2: The reflectance (blue line) and transmittance (black dash line) of $(PN)^{10}$ as a function of frequency for TM wave. $d_P = 6.1$ mm, $d_N = 8.3$ mm, $\varepsilon_P = 1.7$, $\mu_p = 1$, $\omega_0 = 0.16\pi c/d$, $\omega_{ep} = \omega_{mp}$, $\omega_{mp} = 5.7\omega_0$ and $d = 6$ mm.



(a) (b)

Figure 3: (a) shows the reflectance (blue line), transmittance (black line) and absorption (red line) of $(PN)^5D(PN)^5$ as a function of frequency for TM wave. $dd = 25.6$ mm, $\varepsilon_d = 1 + 0.8i$ and $\mu_d = 1$. (b) The distributions of $|E|^2$ of $(PN)^5D(PN)^5$ at the frequency of 86.5 GHz. All of the other parameters are the same as those in Fig. 2.

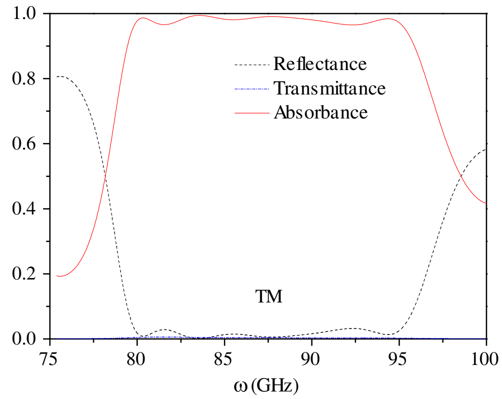


Figure 4: The reflectance (blue line), transmittance (black line) and absorption (red line) of $M(PN)^5D(PN)^5$ as a function of frequency for TM wave. $dm = 2.8$ mm, $\varepsilon_m = 1.32$ and $\mu_m = 1$. All of the other parameters are the same as those in Fig. 3.

to obtain more flatter absorption, a match dielectric layer M is put on the top of $(PN)^5D(PN)^5$. The reflectance, transmittance and absorbance of the structure $M(PN)^5D(PN)^5$ as a function of angular frequency for TM wave is showed in Fig. 4. Here, d_m represents the thicknesses of M.

A more flatter broadband absorption is gained in Fig. 4, which is due to the weak coupling of five independent absorption peaks. We know that the relative permittivity ε_m, the thicknesses d_m and intensities of the localized EM fields can influence the coupling strength of five independent absorption peaks. Fig. 4 show a weak coupling of five independent absorption peaks. So, a more flatter broadband absorption can be obtained. The frequency range of absorption is 80–95 GHz and the value of absorption is 97–100%.

3. CONCLUSIONS

In conclusion, a broadband, nearly total absorption is realized by heterostructure containing a impedance matching dielectric layer and truncated photonic crystals with a lossy dielectric defect. A impedance matching dielectric layer is put on the top of the truncated photonic crystals to get a relative flatter broadband absorption. The width of absorption band is connected with the pass band of the $(PN)^{10}$, which is different of some previous designs [10, 11]. Our proposed transmission-typed broadband absorber offer additional opportunities to design novel optoelectronic devices.

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