Optics Communications 428 (2018) 251–257

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Design and simulation verification an environmental change metamaterial sensor

Li Shengyong *, Ai Xiaochuan, Wu Ronghua, Chen Jiajun

Naval University of Engineering, Wuhan 430033, China

ARTICLE INFO

OCIS:
160.3918
160.4236
260.1180
260.3910
160.5298

Keywords:
Metamaterials
Absorbers
FOM

ABSTRACT

We designed and simulated a composite structure metamaterial absorber involving a metal particles array embedded in the dielectric layer. An absorption peak (83%) is achieved at 703 nm which is excited by the local surface plasmon (LSP) modes resonance between metal particles and the metal bottom substrate. Simulated results indicate that the absorption property of the metamaterial absorber can be modulated through optimizing the horizontal distance between metal particles. The electric field enhancement effect is found between metal particles and the metal substrate, which leads to the absorption property enhanced. The electric field intensity of LSP modes of the proposed structure is higher than that of the pure metal particles structure. The electric field enhancement factor is adopted to reveal the electric field enhanced effect. The application of the metamaterial absorber is revealed based on the figure of merit (FOM) value.

1. Introduction

The negative refractive index of metamaterial is first proposed by *V.G. Veselago* in 1968 [1]. However, it is difficult to prove this in experiments due to the requirements of the experimental equipment is too high to meet. Metamaterials researching has grown enormously since metamaterials with negative refractive index had been verified in experiments [2–4]. The metamaterial can be applied in many exotic field based on its novel electromagnetic resonance responses in a large frequency range, such as invisibility cloaks and perfect lenses [5–12]. Due to its unique property, one of current application field of metamaterials is that revealing of metamaterial perfect absorbers based on high absorption efficiency [13–20]. High absorption and thin metamaterial absorber is demanding in practical applications, including thermal emitters, microbolometers, solar cells, etc [21–24]. Recently, the researching of high performance metamaterial absorbers at terahertz or microwave frequency regions attracts much attention [25–28]. On the one hand, many typical structure metamaterial absorbers have been proposed and confirmed. For example, the typical hole array structure metamaterial absorber [29]. Another typical structure metamaterial absorber contains metal particle array, for example, *C.W. Cheng* et al. [30] designed and verified a wide-angle polarization independent absorber based on metallic disk arrays. The third typical structure design is open-loop electromagnetic resonance structure absorber [31]. With the further studying of absorbers, more of novel structure designs are proposed and confirmed. *W. Withayachumnankul* et al. [32] designed and verified a metamaterial absorber contains hole array and metal particle array. *P. Bouchon* et al. [33] designed and verified a wide-band omnidirectional infrared metamaterial absorber with four metal–insulator–metal patches. *F. Ding* et al. [34] designed and verified a microwave ultra-broadband metamaterial absorber with 25 metal layers. Moreover, only dielectric and metal films alternately structure metamaterial absorber is also designed [35]. Further more, a series of metamaterials equipment are reported based on embedded structure design strategy. For example, Kravets VG et al. reported an absorption enhanced metamaterials equipment which is based on embedding metal nanoparticles in a dielectric matrix [36]. Debao Zhang, et al. embedded aluminum nanodisk arrays in dielectric film to enhance light absorption [37]. A.W. Powell et al. researched the effect of a thin dielectric film on the optical scattering properties of metal nanoparticles embedded structure [38]. D Diedrich et al. proposed a 3D metamaterials device based on embedding metal nanoparticles in a dielectric layer and investigated its applications [39]. To achieve a novel metamaterial absorber, a composite structure is proposed and simulated which contains a metal particle array embedded in a dielectric layer in this paper. On the other hand, the effect of the localized surface plasmon (LSP) mode on the absorption property attracts researchers' attention [40–42]. Many metallic particles structures are optimized to achieve the resonance of LSP mode [43]. The LSP mode resonance is applied in many areas, including sensors, spectroscopy, and so on [44,45]. The property of the LSP mode is defined by many

* Corresponding author.
E-mail address: lttpff@163.com (L. Shengyong).

https://doi.org/10.1016/j.optcom.2018.03.011
Received 28 August 2017; Received in revised form 27 February 2018; Accepted 6 March 2018
Available online 22 March 2018
0030-4018/

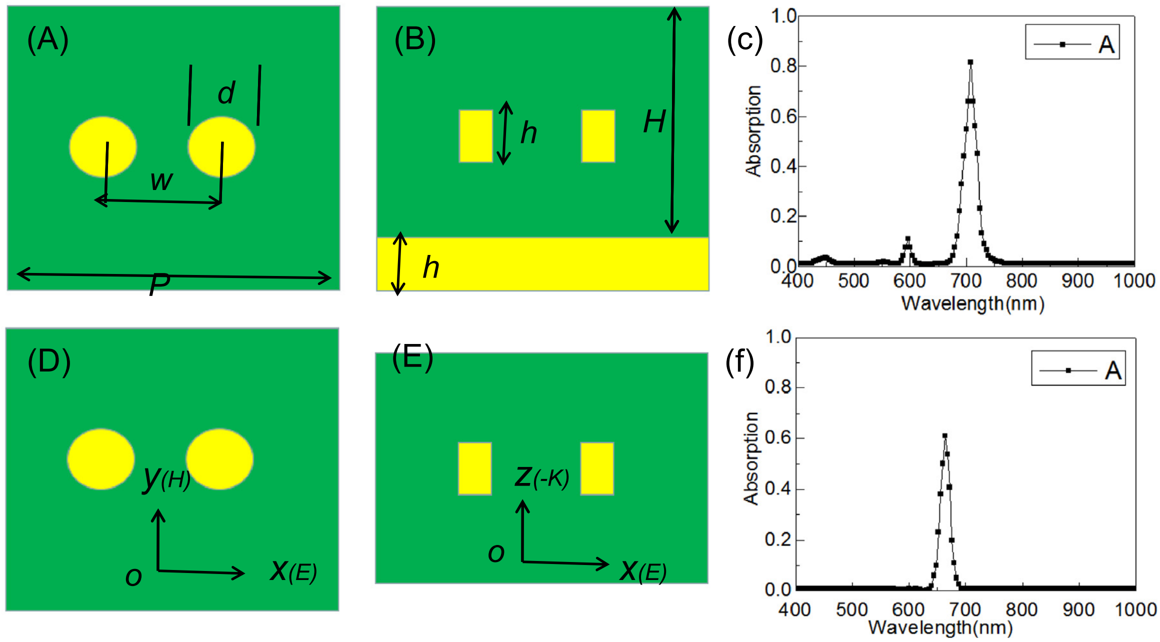

Fig. 1. (a) Top view of the designed structure. (b) Side view. (c) The simulated absorption spectrum of the designed structure. (d) Top view of the metallic particles array embedded in the middle of the dielectric layer with the same structural parameters. (e) Side view. (f) The simulated absorption spectrum of the metallic particles structure. The yellow part is gold layer, and the gray part is MgF_2 layer. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Dimensional parameters of the designed structure.

Parameter	*P*	*d*	*w*	*H*	*h*
Value (nm)	500	100	160	520	110

factors, such as the shape, size, material of particles [46,47]. Moreover, the interaction and coupling between resonance of LSP modes will be applied in exploiting high performance metamaterial absorber in this paper.

In this paper, a metamaterial absorber is proposed and simulated, which contains a metallic particles array embedded in a dielectric layer. For most metamaterial absorber structures, metal particles usually exposed to air or environmental media, which are easily oxidized and corroded, is not conducive to practical application. The proposed structure is not the same as most structures that metal particles are embedded in the dielectric layer. This proposed structure is conducive to the protection of metal particles in applications. A high absorption peak is obtained. The property of the designed metamaterial absorber can be modulated through optimizing the horizontal distance between metallic particles in the dielectric layer. Moreover, the absorption properties of the designed structure and the pure metallic particles without metal substrate are also compared. It is found that the metal substrate also plays an important role in enhancing the strength of LSP modes.

2. Structural design and physical mechanism

2.1. Structural design and theoretical model

The proposed structure is shown in Fig. 1(a–b). The gold layer is follows the Drude mode with the damping constant $\omega_c = 4.08 \times 10^{13}\ \mathrm{s}^{-1}$, the plasma frequency $\omega_{pl} = 1.37 \times 10^{16}\ \mathrm{s}^{-1}$. The dielectric layer is used magnesium fluoride (MgF_2) [48]. Simulations are revealed by the Ansoft's HFSS 11.0, which is usually applied in simulated periodic structures based on only considering one of unit cells. Electromagnetic waves are incident perpendicular to the designed metamaterial absorber alone the-Z axis in air. In simulations, two ideal electric conductor planes were set up as the boundaries normal to x axis, while two ideal magnetic conductor planes were set up as the boundaries normal to y axis [49]. Two perfect matched layers were applied above and below the proposed metamaterial absorber. The frequency step of the program scan is 0.05 THz. Structural parameters of the proposed structure are shown in Table 1. Due to the bottom metal layer is thick enough, the transmission of the proposed structure is close to 0. Therefore, the absorption rate can be given as following:

$$A(\lambda) = 1 - R(\lambda). \tag{1}$$

In the above equations, the $A(\lambda)$ is the simulated absorption rates, while the $R(\lambda)$ is the simulated reflection rates. The simulated absorption spectrum of the proposed structure is shown in Fig. 1(c). Two short-wavelength absorption peaks and a long-wavelength absorption peak (83%) at 703 nm are achieved. For the metal particles structure with same structural parameters, as shown in Fig. 1(d–e), only an absorption peak (62%) at 656 nm is obtained, as shown in Fig. 1(f). The main absorption peak of the proposed structure is higher than that of the pure metal particles structure.

2.2. Physical mechanism

To reveal the physical mechanism of absorption peaks in Fig. 1(c, f), electric field distributions are calculated, as shown in Fig. 2. For the proposed structure, it is found that local surface plasmas (LSP) modes are excited near edges of metal particles, as shown in Fig. 2(a). These resonance modes result in the long-wavelength absorption peak in Fig. 1(c). For the metal particles structure, the excitations of LSP modes are also found, which lead to the main absorption peak in Fig. 1(f). However, the resonance intensity of LSP modes in Fig. 2(a) is higher than that in Fig. 2(b), which results in the maximum absorption rate in Fig. 1(c) is higher than that in Fig (f). It should be noted that the proposed metamaterial absorber contains a metal substrate in Fig. 1(a–b), while the structure in Fig. 1(d–e) without metal substrate. Therefore, both the resonance intensity of LSP modes and the metal substrate are two key roles on the absorption property of the proposed metamaterial absorber. To achieve a better understanding of the effect of two factors