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Single-band high absorption and coupling between localized surface plasmons modes in a metamaterials absorber

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ABSTRACT

In this paper, we design and simulate a metamaterials absorbers based on the resonance of the local surface plasmon (LSP) mode. The damping constant of gold layer is optimized in simulations to eliminate the effect of the inappropriate material parameters on the electromagnetic properties of the proposed metamaterial absorber. The horizontal distance between two metal particles is optimized in simulations and a perfect absorption resonance peak is achieved due to the strong coupling of LSP modes. A new absorption peak is obtained when the horizontal distance is 0 nm. The vertical distance between the new metal particles and the bottom metal layer is reduced, which leads to the absorption peak reduce based on the reduction of the intensity of LSP modes. A new absorption peak is obtained when the new metallic particle and the bottom gold layer form a whole structure.

1. Introduction

The metamaterial is a kind of artificially prepared material that has many properties that are not natural [1–6]. Because of its unique properties, metamaterials have been developed and applied with many fields [7–10]. In many applications, metamaterial absorbers attract the attention of many researchers [11–15]. There are many literature indicate that the high absorption of light in a thin metamaterial absorber is very particularly desirable and important for applications, such as of high sensitivity imaging, photodetectors, plasmonic sensing, microbolometers, surface enhanced Raman spectroscopy, etc [16–19]. Recently, the design and fabrication of terahertz (THz) regions metamaterial absorbers attract much researcher's attention [20–23]. Many researcher's efforts have focused on different properties, such as: the polarization of electromagnetic waves, or the insensitive to the incident angle, or the extending the resonance absorption to shorter wavelengths [24–27]. Yongzhi Cheng *et al* [28] proposed and simulated a polarization-insensitive and wide-angle metamaterial absorber, which can easy modulate its electromagnetic properties based on a pump beam. Moreover, an infrared non-planar plasmonic metamaterials absorber is also simulated verification, which can be applied in refractive index sensing [29]. Govind Dayal *et al* [30] numerical study of a multi-band metamaterial absorber based on stacking different combinations of metal-dielectric disks. Han Xiong *et al* [31] theory analyze the physical mechanism of absorption peaks based on a reflection theory. Moreover, the high absorption can be obtained through many structural design strategies, such as: structured metallic surfaces [32,33], and microcavities [34], which is based on the resonance of the localized surface plasmon (LSP) mode [34]. The LSP modes resonance receives a great deal of interest [35,36]. Moreover, the property of the LSP modes can be modulated through changing the designed structure. Many experimental and theoretical literature indicate that the LSP mode shows coupling with surface plasmon polariton (SPP) mode in a structure consisting of a metal particle array and a metallic film [37–39]. These coupling effects between LSP and SPP leads to these structures useful for applying in SERS, fluorescence extraction, bio-sensors [40,41]. However, few of researchers focus on the coupling effect between LSP modes on the absorption property of metamaterial absorber. Therefore, it is important to modulate the absorption property of the designed absorber based

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on the resonance of LSP modes. In this paper, a composite structure metamaterial absorber is designed and simulated. Due to the resonance of LSP modes, an absorption peak is obtained. A high performance absorption resonance is achieved when the horizontal distance between two metallic particles is optimized. The field distributions corresponding to the maximum absorption peak is investigated to explore the physical mechanism. It is found that the coupling intensity between LSP modes can be enhanced through optimizing the horizontal distance between two metallic particles, which leads to the maximum absorption peak. A new absorption peak is obtained when two metallic particles touch together and form a new metal particle. The absorption rate is reduced with the vertical distance between the new metallic particle and the bottom gold layer reducing. Another new absorption peak is achieved due to two new LSP modes are excited near edges of the new bottom metallic layer.

2. Structural design and optimization

2.1. Structural design and theoretical model

The proposed metamaterial absorber consists of three functional parts: a bottom gold layer, which works as an electromagnetic wave eliminator. A media layer on the bottom gold layer. A dual metallic particles array is embedded in the media layer, works as an electromagnetic resonator, as shown in Fig. 1(a-b). The commercially software Ansoft's HFSS 11.0 is applied in simulations. In Fig. 1(a-b), the lattice constant of the proposed unite cell is given by "*P*", the gold layer thick is set to be "*h*", the media layer thick is given by "*H*". Dimensional parameters of the proposed unite cell are shown in Table 1. The transmission of the proposed unite cell closes to zero due to the bottom metal layer is thick enough. Therefore, the absorption of the proposed unite cell is achieved as:

$$A(f) = 1\text{-}R(f) \quad (1)$$

where, the A($_f$) is the simulated absorption rates, while the R(f) is the simulated reflection rates. In simulations, gold layers follow the Drude mode with the damping constant $\omega_c = 4.08 \times 10^{13} s^{-1}$, and the plasma frequency $\gamma_D = 9 \times 10^{13} s^{-1}$ [42]. The simulated electromagnetic wave incident to the proposed unite cell in air. Ideal electric boundaries and magnetic boundaries are applied on normal to the x-axis and y-axis [43]. The dielectric constant of SiO_2 layer is set by 2.105 [44].

2.2. Parameter optimization

To reveal the physical mechanism of the proposed metamaterial absorber, the material parameter of gold layers in simulations should be optimized. A reported literature indicates that the damping constant of gold layer in simulations is lower than that in real system, due to the surface scattering and the grain boundary effects of gold film [45]. Therefore, it is reasonable that optimizing the damping constant of gold layer to eliminate the effect of the inappropriate material parameter on the electromagnetic properties of the proposed metamaterial absorber. Fig. 2 shows the calculated absorption spectrum of the proposed metamaterial absorber under different times of damping constants of gold layer. When the 1.0 time of the damping constants ($1.0^*\omega_c = 4.08 \times 10^{13} s^{-1}$ in the simulation) of gold layer is used in simulation, an absorption peak is obtained at 630 nm, the maximum absorption rate reaches to 48%, as shown in Fig. 2. For the 2.5times of the damping constants, the maximum absorption rate reaches to 74%, as shown in Fig. 2. However, for the 4.0times of the damping constants, the maximum absorption rate is reduced to 53%, as shown in Fig. 2. It is obviously that the high performance absorption peak is obtained at 630 nm when the 2.5times of the damping constants of gold layer in simulation is used. These simulated results reveal that the 2.5times of the damping constants of gold layer is the most optimization parameter in simulating the proposed structure in this paper. Thence, the damping constants of gold layer is adopted 2.5time in the following simulations.

Table 1
Dimensional parameters of the proposed unite cell.

Parameter	*P*	*L*	*w*	*r*	*h*	*H*	*D*
Value (nm)	600	280	100	30	30	400	230

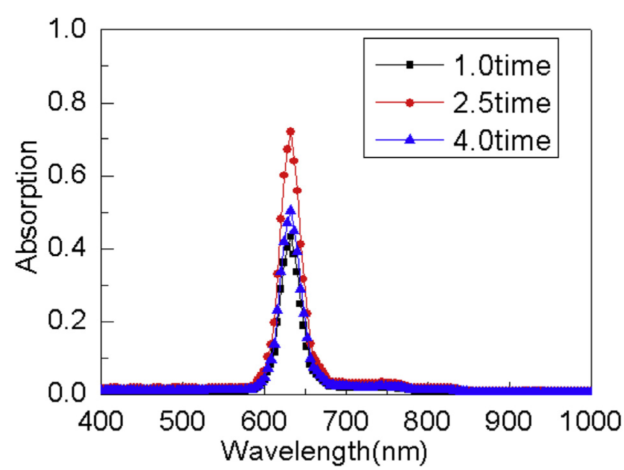

Fig. 2. Simulated absorption spectra with different damping constants.

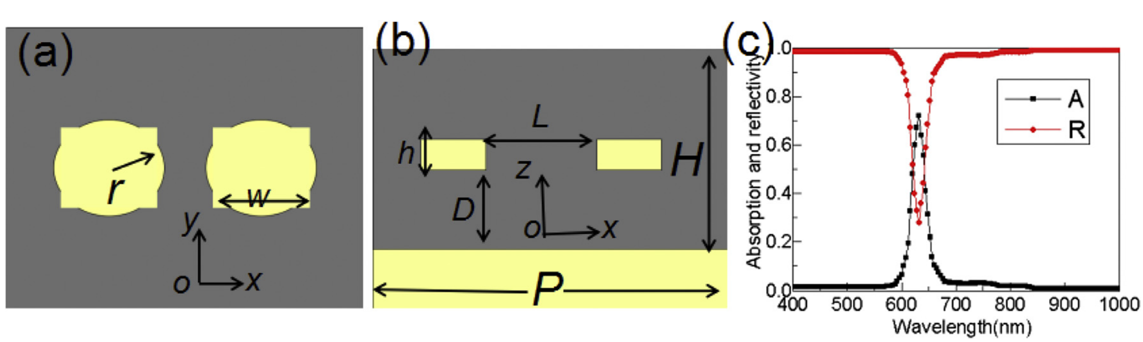

Fig. 1. (a) Top view of the proposed unit cell on the xoy plane; (b) Side view of the proposed unit cell on the xoz plane. The yellow part is gold layer, the gray part is media layer, (c) Simulated absorption and reflectivity spectra. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)