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Computed a multiple band metamaterial absorber and its application based on the figure of merit value

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ABSTRACT

A high performed multiple band metamaterial absorber is designed and computed through the software Ansofts HFSS 10.0, which is constituted with two kinds of separated metal particles sub-structures. The multiple band absorption property of the metamaterial absorber is based on the resonance of localized surface plasmon (LSP) modes excited near edges of metal particles. The damping constant of gold layer is optimized to obtain a near-perfect absorption rate. Four kinds of dielectric layers is computed to achieve the perfect absorption perform. The perfect absorption perform of the metamaterial absorber is enhanced through optimizing the structural parameters ($R = 75$ nm, $w = 80$ nm). Moreover, a perfect absorption band is achieved because of the plasmonic hybridization phenomenon between LSP modes. The designed metamaterial absorber shows high sensitive in the changed of the refractive index of the liquid. A liquid refractive index sensor strategy is proposed based on the computed figure of merit (FOM) value of the metamaterial absorber. High FOM values (116, 111, and 108) are achieved with three liquid (Methanol, Carbon tetrachloride, and Carbon disulfide).
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1. Introduction

Artificial prepared electromagnetic absorber is a widely applicability optical equipment in a wide regime, such as solar cell enhancement, signature control, thermal imaging, spectroscopy, and emissivity control [1–4]. In addition to these proposed structures above, metamaterial absorbers composed of separated electric and/or magnetic resonators attract a large number of researchers' attention [5,6]. High performance absorbers have been designed and experimental confirmed in visible and mid-IR spectral regimes [7–10]. It is regrettable that these confirmed absorbers can just offer limited flexibility in tailoring the electromagnetic response, such as polarization, incident angle, wavelength range. The absorption performance of electromagnetic absorber defines by the electric–magnetic loss of the incident electromagnetic wave. Many designing strategies are proposed to obtain perfect electromagnetic absorbers. The metamaterial absorber is always considered as a whole effective medium and integrating different shapes resonance elements to achieve highly imaginary parts of effective permittivity and permeability dispersion behaviors of the designed structure [11–13]. These electromagnetic dispersed behaviors lead to narrow absorption band when electromagnetic waves pass through the designed absorber. The absorption band is also expanded through optimizing different sizes of resonators and stacking they on a metal layer in a designed unit cell [14]. This is difficulty because preparation a nanoscale and multiple layers structure is complexly and time-consuming. Metamaterial designing approaches are used to achieve broad band absorbers. However, the impedance matching condition and the narrow absorption bandwidth of the individual electromagnetic resonator are always two limiting factors [15,16]. Many metamaterial absorbers have been demonstrated with near unity absorption, which display different properties, such as wide field of view, and polarization independence [17,18]. *Prakash Pitchappa* et al. [19] designed and experimental confirmed a dual-band absorber based on electrical resonance and cavity resonance in near infrared region. The designed structure is a complementary metamaterial structure. The two resonant modes correspond to two absorption peaks. And these absorption peaks can merge into a single band due to the strong coupling between two resonant modes. Multiple band metamaterial absorbers also can be realized through incorporating different separated resonators into a designed unit cell [20]. However,

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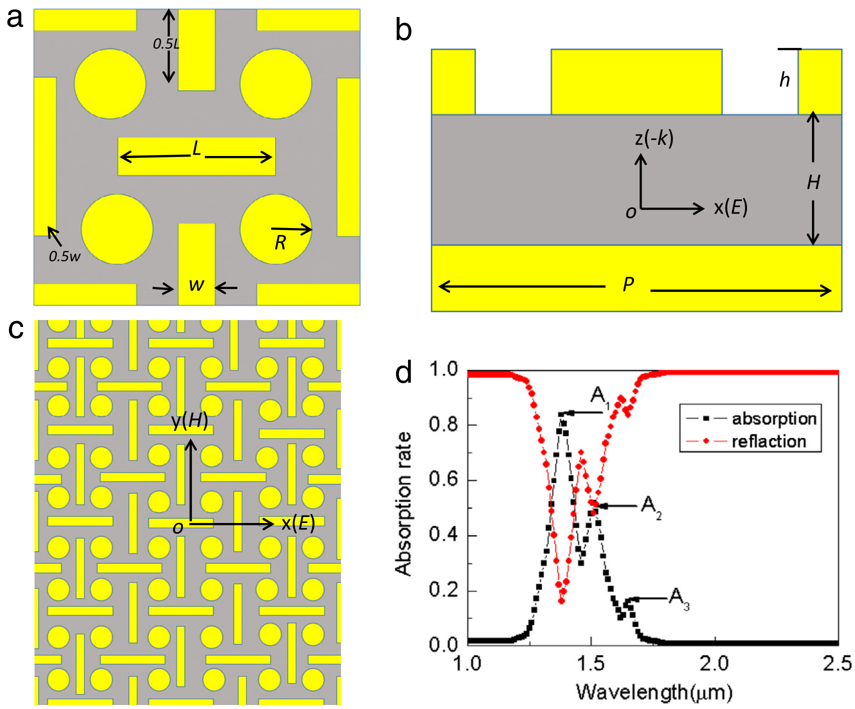

Fig. 1. (a) Top view of a unit cell on the *xoy* plane, (b) Side view of a unit cell on the *xoz* plane. (c) Top view of many unit cells on the *xoy* plane. The orange part is dielectric layer, the blue part is gold layer, (d) Simulated absorption and reflection spectra. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the number of absorption peaks of metamaterial absorber is always limited by the number of resonator types, which are patterned at dimensions compatible [19,21]. Moreover, the individual electromagnetic resonator element is an important factor on the absorption properties of the multiple band metamaterial absorber [15,16,20].

In this paper, a multiple bands metamaterial absorber is designed and simulated based on separated composite structure. The designed structure contains two different shape sub-structure (metal cylinders and strips). Many existing structures either focus on the single structure design (single metal hole or block) [22,23], or focus on the same structure with different sizes combined together [24,25]. There are not many researchers focus on designing a metamaterial absorber which contains two different shape sub-structure (metal cylinders and strips). Three absorption peaks are obtained based on two resonant modes, which is different with previous absorbers [19,21]. Moreover, these three absorption peaks can merge into a single band due to the plasmonic hybridization between two resonant modes, which is similar to previous literature [19]. The damping constant of the simulated gold layer and the dielectric constant of the simulated dielectric layer are optimized to obtain a perfect metamaterial absorber. The application possibility for liquid detection is also simulated based on a figure of merit (FOM) according to papers [26,27]

2. Structure design and simulations

Fig. 1(a–b) shows the proposed structure of the metamaterial absorber. The proposed structure is constituted with three functional layers. The top gold layer is constituted with metal cylinders and strips. The intermediate dielectric layer is SiO_2 layer in the initial simulated phase. The bottom gold layer is a complete metal layer. All of structural parameters are given in Table 1. The structural parameters (R, W) are two modifiable parameters. Simulations are performed by software Ansofts HFSS 10.0, which is used widely in researching properties of metamaterial. Two perfectly matched layers are adopted in order to eliminate nonphysical reflection losses at domain boundaries. Two ideal magnetic boundaries and two electric boundaries are adopted. In the initial simulated phase, the dielectric constant of the SiO_2 layer is set

Table 1
All dimensional parameters of the compound structure.

Parameter	*R*	*L*	*W*	*H*	*h*	*P*
Value (nm)	75	360	80	480	40	600

to be 2.1025 [28]. The dielectric layer of the designed structure can be replaced in the following optimization calculations. The relative intensity of the transmission is close to zero in simulations due to the bottom metal layer is thick enough. Therefore, the absorption of the designed structure in simulations is achieved as $A(\lambda) = 1 - R(\lambda)$, here, the $A(\lambda)$ is the absorption coefficients, and the $R(\lambda)$ is the reflection coefficients. The permittivity of bulk gold layer [29] follows the Drude model under the plasma frequency $\omega_{pl} = 1.37 \times 10^{16}$ s^{-1}, the damping constant is adopted $\omega_c = 4.08 \times 10^{13}$ s^{-1} in the initial simulated phase. Fig. 1(d) shows the simulated absorption spectrum of the initial simulation metamaterial absorber. Three distinct absorption peaks are obtained, which are named as "A_1" (85%), "A_2" (51%), and "A_3" (19%), respectively. The designed structure is simulated in air in the initial simulated phase.

3. Simulation results

For achieving a perfect absorber, especially for the proposed structure, there are two important factors affecting properties of the absorber, which are the damping constant of the simulated metal layer and the permittivity of the dielectric layer. Zhang et al. [30] indicated that there are differences between the damping constant of bulk gold and that of the gold film in the real system. Therefore, to achieve a perfect absorber, the damping constant of the simulated gold layer need to be optimized. Fig. 2 gives the absorption spectrum with different damping constants of the simulated gold layer. In the optimized simulation, the 1.0 times of the damping constant ($1.0^*\omega_c = 4.08 \times 10^{13}$ s^{-1}) is adopted firstly, three different absorption rates A_1 (85%), A_2 (51%), and A_3 (19%) are achieved, as shown in Fig. 1(d) and the black curve in Fig. 2. For the 1.4 times case, absorption rates are A_1 (94%, a high performed but not

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