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Experimental and simulated study of a composite structure metamaterial absorber

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

Naval Univ. of Engineering, Wuhan 430033, China

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In this paper, a high performance metamaterial absorber is designed and experimental studied. Measured results indicate that a perfect absorption band and a short-wavelength absorption peak are achieved in the near-infrared spectrum. Current strength distributions reveal that the absorption band is excited by the cavity resonance. And electric field distributions show that the short-wavelength absorption peak is excited by the horizontal coupled of localized surface plasmon (LSP) modes near hole edges. On the one hand, the absorption property of the measured metamaterial absorber can be enhanced through optimizing the structural parameters (*a*, *w*, and *H*). On the other hand, the absorption property is sensitive to the change of refractive index of environmental medias. A sensing scheme is proposed for refractive index detecting based on the figure of merit (FOM) value. Measured results indicate that the proposed sensing scheme can achieve high FOM value with different environmental medias (water, glucose solution).

1. Introduction

Artificially prepared electromagnetic metamaterial has drawn a surge of attention over past decade due to its unique electromagnetic properties, such as negative refractive index, negative permittivity, negative permeability, etc. Since the negative refractive index is experimental demonstrated by *Smith* et al. [1], a large number of novel study on electromagnetic metamaterials are proposed in a wide range of applications, include optical black hole, sub-diffraction imaging, wavelength selective blackbody emitters, invisibility cloaking [2–8], and many more. To characterize these electromagnetic metamaterial devices, an effective medium technique [9,10] is usually adopted (including complex refractive, permittivity and permeability). Among these functional devices, metamaterial absorber has received the widespread attention [11–15]. Many studies prove that plasmonic nanostructure metamaterial absorbers are highly desirable for many practical applications with one or more perfect absorption bands, for instance, metamaterial absorbers [16,17], photodetectors [18] photovoltaic cells [19], and optical imaging devices [20]. In order to design and manufacture a perfect metamaterial absorber, the plasmonic nanostructure is always arranged by simultaneously minimizing the reflectance between the top metallic layer of the absorber and the free air layer, while eliminating the transmittance through maximizing the material loss of the absorber [21–25]. In these metamaterial absorbers, metallic/dielectric/metallic (MDM) structural absorbers demonstrate the potential value with perfect absorption bands, wide-angle incidence, and almost completely polarization insensitivity. The MDM structural absorber usually consists of a top periodically patterned metallic layer which serves as an electric resonator, an intermediate dielectric layer, and a thick enough bottom metal layer that serves as an optical mirror to reduce the transmittance. To date, perfect MDM metamaterial absorbers have been researched in a wide range, including single-band [26], dual-band [27], and triple-band [28] absorptions. Many single-band MDM metamaterial absorbers [26,29] are proposed in the near-infrared wavelength range, which exhibit excellent absorption properties, such as near-perfect

* Corresponding author.
E-mail address: lttpff@163.com (S. Li).

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absorption peak, wide-angle incidence, and polarization insensitivity. These metamaterial absorbers always operate at a narrow wavelength band. This fact greatly limits their practical applications in many devices, such as imaging and spectroscopic detection [30]. Therefore, single-band near-infrared metamaterial absorber with a wide and flat absorption band is in demand. On the other hand, many physical mechanisms are proposed in understanding the property of metamaterial absorbers, such as destructive interference mechanism, strong antisymmetric surface plasmons coupling, cavity resonance and electrical resonance [31–33]. However, few researchers focus on the role of the horizontal coupling of localized surface plasmon (LSP) modes on the property of metamaterial absorbers. In the previous work [34], the transmission of metamaterial is reduced and resonance frequency is shifted to lower frequency (longer wavelength) due to the intensity of the horizontal coupling LSP modes increasing. It is also worth studying the effects of the horizontal coupling LSP modes. In this paper, a composite patterned metamaterial absorber is suggested and manufactured. Measured results indicate that the designed single-band absorber reveals perfect absorption property in near-infrared range. A short-wavelength absorption peak is achieved due to the horizontal coupling LSP modes. The absorption property of the measured absorber can be modulated through adjusting dimension parameters, which results in the proposed absorber more attracting in designing and manufacturing near-infrared perfect metamaterial devices. The possibility of application of the measured absorber in sensing field is studied based on the figure of merit (FOM).

2. Simulation methods and experimental details

2.1. Simulation methods

The suggested metamaterial absorber is simulated through adopting a business Software Ansofts HFSS 13.0. As shown in Fig. 1(a-b), the proposed metamaterial absorber consists of three functional layers: a top patterned metal plane layer with a compound air hole array, a dielectric layer, and a metal plane layer which plays as the bottom reflector. The metal layers are selected as silver layers. The incident wave is assumed to be normally to the top surface of the proposed metamaterial absorber. In the unit cell, the periodicity is given by "*P*", the thickness of metal layer and dielectric layers are set as "*h*" and "*H*". Two 160 nm thick metal layers are separated by a 480 nm thick dielectric layer, which results in a total metamaterial thickness of $0.8\mu m$, as shown in Fig. 1. Geometric parameters are shown in Table 1. The silver layer is thick enough that results in the electromagnetic transmission closing to zero ($T(\lambda) \approx 0$). Therefore, the simulated absorption of the designed MDM metamaterial absorber can be calculated as $A(\lambda) = 1 - R(\lambda)$. Here, $A(\lambda)$ is the wavelength-dependent absorption rate, and $R(\lambda)$ is

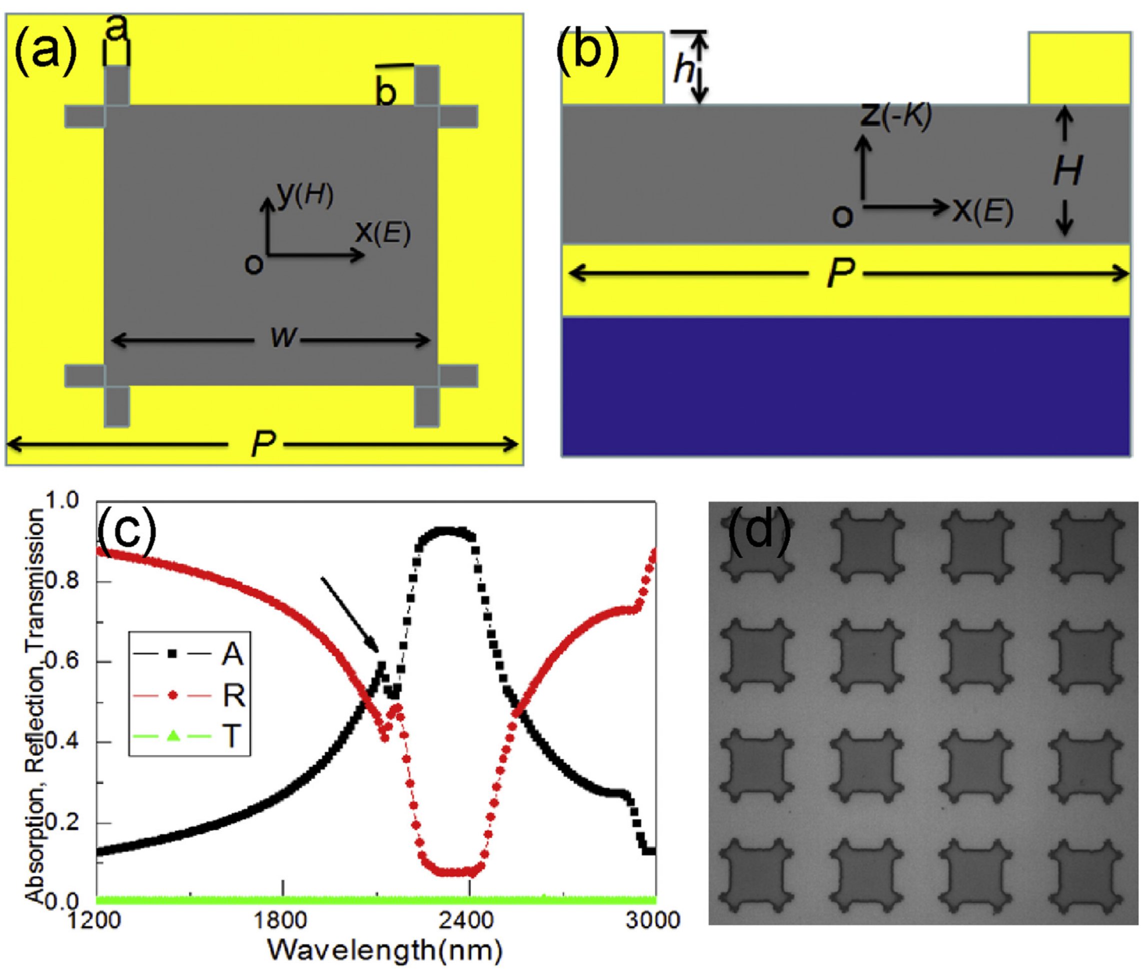

Fig. 1. (a) Top view of the unit cell on the xoy plane. (b) Side view of the unit cell on the xoz plane (the cross section of the unit cell). The yellow part is metal layer, the gray part is dielectric layer, the dark blue part is substrate. (c) Measured absorption, reflection, and transmission spectra. (d) photograph of samples. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)