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Multi-band near-perfect absorption via the resonance excitation of dark meta-molecules

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ABSTRACT

We numerically study a multi-band absorption based on electromagnetic-induced-transparency effect of metamaterial. By exploiting the coupling between bright and dark plasmonic modes of cut-wire triplet, which consists of a vertical wire and two horizontal wires, a dual-band absorption is realized at 243 and 266 THz. Then, the absorber structure is improved by adding two new horizontal wires which play role as second dark meta-molecules. Due to the dark–dark coupling, another absorption band arises so that a triple-band absorption is created at 240, 250 and 264 THz. The role of interaction between dark meta-molecules in triple-band absorption is investigated, revealing a specific non-monotonic characteristic of the second absorption peak. Finally, the influence of incident angle of EM wave on multi-band absorbers shows that the absorption of lowest frequency peak is robust while those of higher frequency peaks are strongly weaken with increasing of the incident angle.

1. Introduction

Artificial sub-wavelength materials, the so-called metamaterials (MMs), can exhibit desirable electromagnetic (EM) responses which are even not found in natural materials. By tailoring the unit-cell structure, a variety of fascinating phenomena are realized such as negative refractive index [1–3], invisibility cloaking [4,5], and super-resolution [6,7]. In 2008, another attractive phenomenon, which is perfect absorption, was discovered by Landy et al. [8] and made a lot of attention due to the considerable amount of applicability in devices including solar cells [9], imaging [10], and plasmonic sensor [11]. Since then, researches on MM perfect absorber (MPA) have been expanded, bringing many demonstrations in various frequency ranges [12–14]. Nowadays, multi-band and broadband absorption are still the focus of interest for real needs. A common approach is to design a geometrically gradient multi-resonator structure whose resonances, separated closely, can be directly and simultaneously excited by the incident wave [15–17].

Electromagnetic-induced transparency (EIT) is basically a quantum coherent process which requires very complicated and rigorous experimental conditions [18,19]. One of the superiorities of MMs is that the EIT effect can be mimicked in a much more easier way by using MMs [20–22]. In this work, a different approach to create a multi-band MPA is proposed by exploiting the EIT effect. Generally, there is single absorption peak when external EM field excites only one plasmonic resonance. The key idea is that dual-band absorption can be achieved by employing the near-field coupling between bright and dark plasmonic modes even though only one resonance can be directly excited by the EM field. An extended model inducing triple-band absorption is also provided by considering the interaction between dark meta-molecules. Finally, the role of dark–dark coupling in absorption spectrum is studied to comprehend the EM behavior of multi-band MPA. Our work might be useful for many applications such as multi-frequency filters and single/multi-mode switching devices.

2. Design and simulation

Fig. 1 illustrates the unit cell structures of designed cut-wire-triplet (CWT) and cut-wire-quintet (CWQ) absorbers. The CWT absorber (CWTA) structure is made of three different layers. The front layer is a metallic CWT which consists of a vertical cut wire (CW) and two horizontal CWs placed at a certain distance from the ends of the vertical. The geometry of these CWs is identical. The middle and back layers are continuous dielectric and metallic

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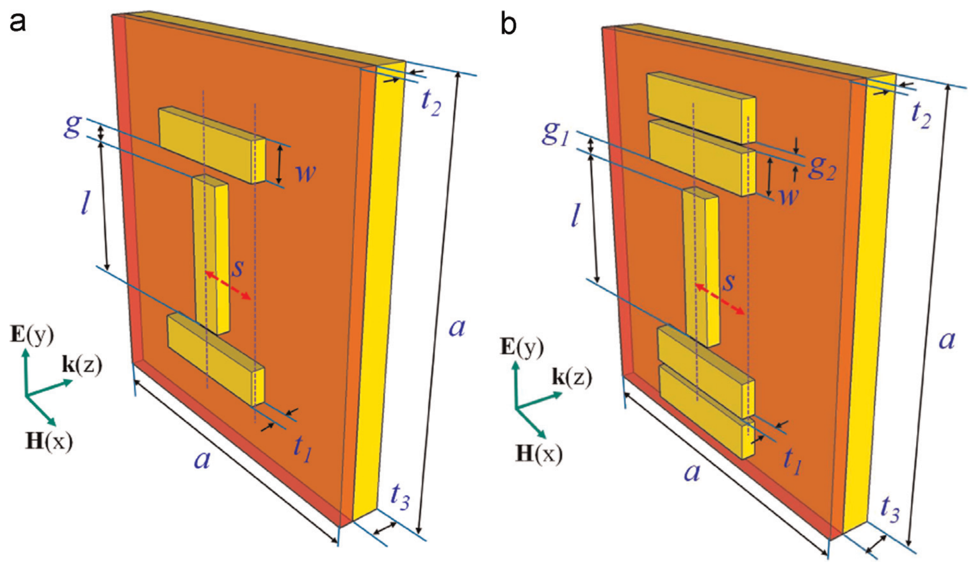

Fig. 1. Illustrations of the unit cell of (a) cut-wire-triplet and (b) cut-wire-quintet absorbers with the electromagnetic polarization.

plane, respectively. The detailed geometrical parameters of CWTA are $a=800$ nm, $t_1=t_2=30$ nm, $t_3=100$ nm, $l=190$ nm, $w=80$ nm, and $g=20$ nm. The CWQ absorber (CWQA) structure is an extended structure of CWTA by adding one more pair of horizontal CWs on the front layer. The CWQA has the same geometrical parameters as CWTA except two new parameters $g_1=20$ nm and $g_2=10$ nm. The parameter s defines the displacement of the vertical CW from the center position. This parameter is a key factor to achieve a multi-band absorption.

In our simulation, the metal was silver and described by the Drude model, with a plasmon frequency of 1.366×10^{16} rad s^{-1} and a collision frequency of 3.07×10^{13} Hz [20,23]. The dielectric was chosen as silicon dioxide with the function fitted from Ref. [24]. The simulations were performed using a finite-integration

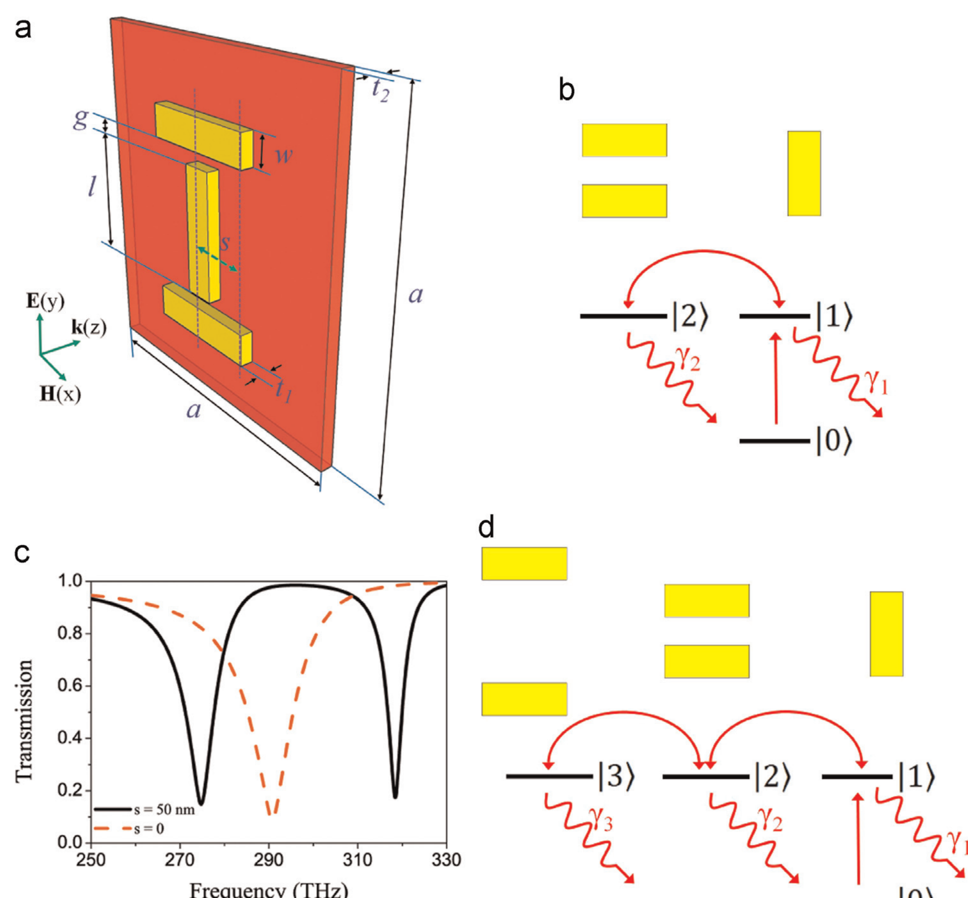

Fig. 2. (a) Illustration of the unit cell of EIT structure with the electromagnetic polarization. (b) Schematic energy-level diagram of the cut-wire triplet. (c) Transmission spectra of the EIT structure according to s. (d) Schematic energy-level diagram of the cut-wire quintet.