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Dielectric metamolecules with ultra-narrowband light transparency behaviors

Zhengqi Liu*, Jian Chen, Zhenping Huang, Meidong Yu

Jiangxi Key Laboratory of Nanomaterials and Sensors, Jiangxi Key Laboratory of Photoelectronics and Telecommunication, School of Physics, Communication and Electronics, Jiangxi Normal University, Nanchang 330022, Jiangxi, China

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ABSTRACT

Materials with ultra-narrowband light transparent window are desirable for applications in optoelectronics. Due to the intrinsic loss in the traditional metallic nanostructures, the plasmonic or electromagnetically induced light transparent spectrum is with a typically broad bandwidth. In this work, a novel strategy for achieving ultra-narrowband optical transparent window is theoretically proposed and demonstrated based on the dielectric dimer resonators metamolecule array. Owing to the electromagnetic resonant coupling in this lossless all-dielectric metamolecule, a transparent window with the bandwidth down to nanometer scale and the spectral slope up to 71%/nm is achieved. The obtained optical properties can be manipulated in the spectral range by adjusting the structural parameters and dielectric permittivity. These findings pave a new way for sharp narrowband transparent window with potential applications in filtering, optical manipulation, etc.

1. Introduction

Over the past few decades, plasmonic metamaterials or the metamolecules [1–5] based on the metallic nanostructures have attracted much attention owing to the wide applications [6–10]. Electromagnetically induced transparency (EIT), a concept for the coherent process resulting from the quantum inference phenomenon in light-atom interaction systems, has also observed in the classical optical system such as the plasmonic metamaterials [11–13]. For instance, by utilizing a dielectric-film-coated asymmetric metallic T-shape slit, the plasmon-induced transparency was experimentally demonstrated [13]. As for many applications including the spectral manipulation, filtering and sensing [14–17], narrowband resonant spectrum is more desirable. Nevertheless, the inevitable light absorption in matter and the subsequent conversion of light into heat-an irreversible process has impeded the further applications for the plasmonic induced transparency or the EIT behaviors in the metallic systems. Recently, a different approach for EIT has emerged based on the all-dielectric and completely transparent building blocks [18–20], where strong electric and magnetic field coupling can be excited in the high-index dielectric resonators due to the Mie resonances [21]. Based on an all-dielectric high-index nano-ring and rectangular bar resonators unit cell, a classical analogue of EIT has been demonstrated, where the spectral bandwidth is of only 2.8 nm [18]. A broadband EIT-like effect has been observed in a dielectric resonator structure with a large permittivity of 114 due to the Mie resonances [22].

In this work, we propose and demonstrate an ultra-narrowband light transparent window in a relative low-index dielectric resonant platform due to the strong electric and magnetic resonant coupling effects. The transparent window with bandwidth (full-width at half-maximum) down to nanometer scale and the spectral slope up to 71%/nm is achieved. Moreover, in contrast to the relatively broadband EIT in the higher index dielectric metamolecule system, it is found that a narrower transparent peak can be observed in the relative lower index dielectric at the cost of the spectral modulation depth.

2. Materials and method

Schematic of the dielectric metamolecule consisting of hexagonally packed rod-triangle resonators array is depicted in Fig. 1(a). The geometry parameters such as the length (L) and width (W) of the rod are set to be 400 nm and 200 nm, respectively. The side length (l) of the equilateral triangle is 260 nm. The gap distance (d) between the rod and the triangle is of 30 nm. The thickness of the dielectric resonators is 40 nm. The hexagonally packed metamolecules array is with a period value of 800 nm. Simulations of the transmittance and the electric/magnetic field distributions of each structure were performed by using a three-dimensional finite-difference time-domain method [23]. A plane wave at normal

* Corresponding author.
E-mail addresses: zliu@jxnu.edu.cn, zliu-cn@qq.com (Z. Liu).

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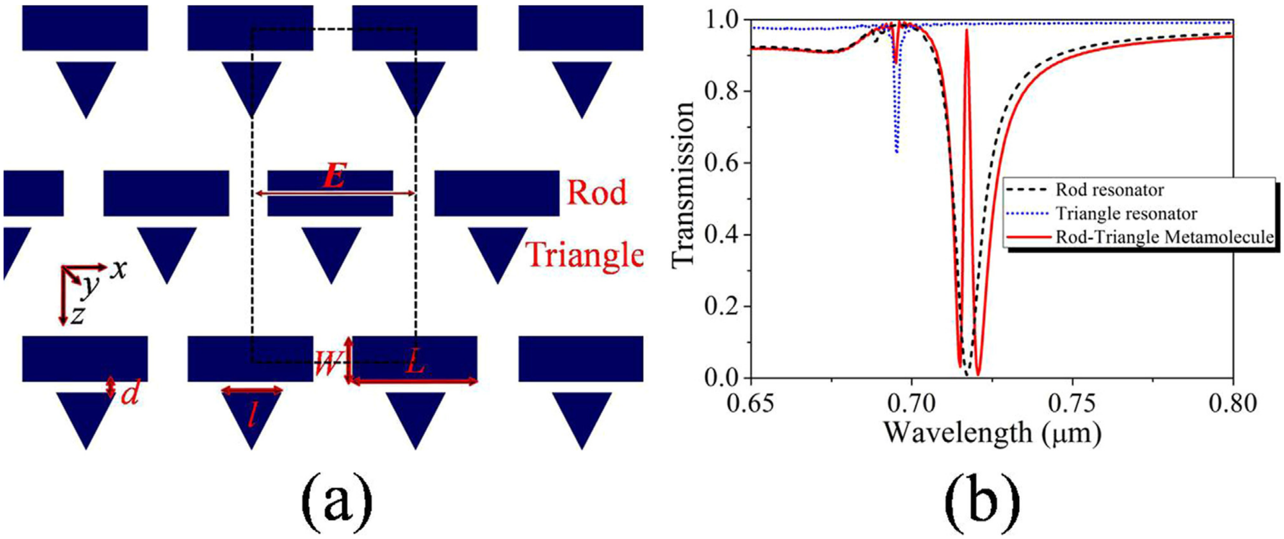

Fig. 1. (a) Schematic of the dielectric resonators array consisting of a hexagonally packed rod-triangle metamolecule array. (b) Transmission spectrum of the single rod resonator array (black dashed line), triangle resonator array (blue dotted line) and rod-triangle metamolecule array (red solid line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

incidence (positive *z* direction) was used as the light source, while field monitors placed below the structure and parallel to the *xoy* plane were used to measure the transmission power. Perfectly matched boundaries were applied to the *z*-min and *z*-max boundaries, while the periodic condition boundaries were used along the *x* and *y*-axis to reproduce the array. The unit cell comprised of one center metamolecule and four quarter parts is shown in Fig. 1(a). The refractive index of the dielectric is 2.6.

3. Results and discussion

Fig. 1(b) presents the transmission spectra of the structures. For the single rod resonators array, a transmission inhibited band centered at 0.717 μm with transmittance (*T*) of 0.008 is observed. Nevertheless, for the single triangle resonators array, there is no obvious transmission stop band at the wavelength range overlapping with that of the single rod resonators array except a narrowband transmission dip with a relatively weak transmission. For the composite rod-triangle metamolecules array, a sharp transparent window occurs in the original completely inhibited transmission band. For the transmission peak at 0.717 μm, the transmittance is up to 0.972, which is exceeding 100 times larger than that of the structure with a rod resonators array. On other words, by introducing additional triangle resonators array, the original transmission "dark" state is changed to be "bright" state with a near-perfect light transmission window. For the observed EIT-like transparent window, the light transmission behaviors have shown a sharp transition process from a transmission stop at 0.715 μm ($T=0.032$) to a transparent peak at 0.717 μm ($T=0.972$) to the other transmission inhibited state at 0.720 μm ($T=0.008$). In addition, the maximal spectral slop exceeding 65%/nm is obtained in this sharp transmission response. Moreover, near-unity spectral contrast is achieved in this dielectric metamaterial. These features are with great improvement than that of the conventional plasmonic EIT systems, in which the EIT response is usually with the

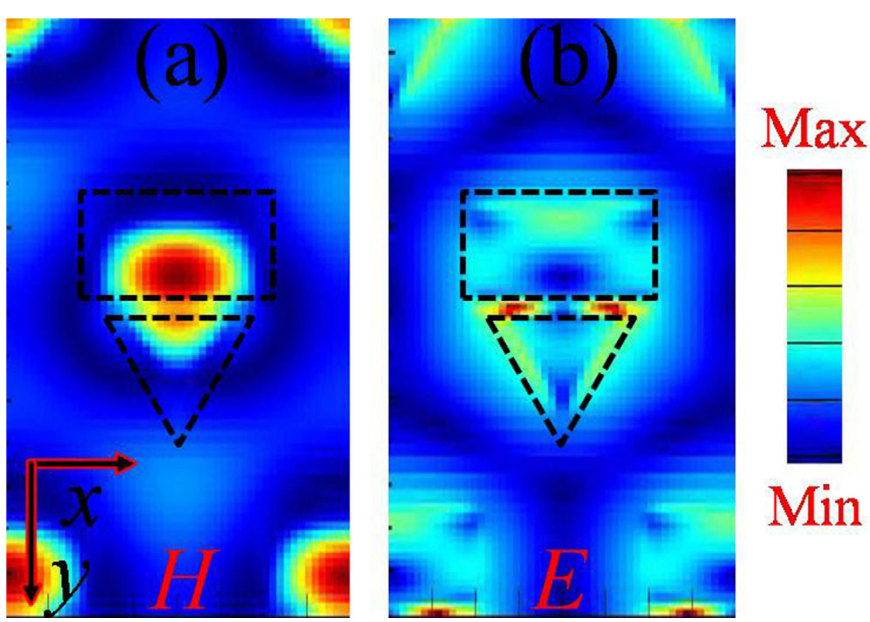

Fig. 2. Normalized magnetic (a) and electric (b) field magnitude distributions of the rod-triangle metamolecule array, respectively.