EXCITATION OF DARK MODE IN ASYMMETRIC DIMER METAMATERIAL

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Abstract

We study the excitation of dark resonance modes in a planar metamaterial nano dimer of unit cell made up of double asymmetric nano rods. In this study, experimental and numerical results show the presence of the dark and bright modes in the asymmetric nano dimer metamaterial, whereas only the bright mode is excitable in the symmetric dimer. The sharp asymmetric profile of the dark modes with a Fano-type resonance opens up potential applications of the dimer metamaterial as an optical nano sensor.

Keywords*: Metamaterial, nano dimer, dark mode*

Introduction

The way atoms are arranged in a solid can determine its properties. The flexibility in tailoring the structural units of Metamaterial and the advancement in material science and nano technology has led to the realization of exotic electromagnetic effects which are uncommon in nature, such as negative refractive index (Veselago,1968) by Shelby et al(2001) at microwave frequency, enhanced transmission(Di Genaro et al, 2010) and cloaking(Schurig et al, 2006), electromagnetically induced transparency(EIT) Liu et al. in 2009. Thus, the structural units of the metamaterial can be artificially designed and interactions between resonances can be controlled. In symmetric metamaterial structures, super radiant or bright modes couple to the incident field, thereby resulting in broad and lossy resonances. However, in an asymmetric metamaterial, trapped or dark modes which are not easily excited in the symmetric structure can be excited (Christ et al, 2008). The interaction of the bright and dark mode can result in a Fano type resonance, with an asymmetric spectral profile (Luk'yanchuk et al (2010), Fedotov et al, (2007)) and the induced resonance can concentrate electromagnetic field in small regions.

In this work, a numerical and experimental study of a planar metamaterial structure composed of nano dimers is studied. Experimental measurements of the fabricated metamaterial structure shows good agreement with the simulation results. The nature of the resonances in the device makes them suitable for nano sensors(Bukasov et al.; 2010, Larsson et al.; 2007).

Numerical Model and Geometry

The unit cell of the metamaterial dimer is composed of two gold nanorods separated by a gap of 50nm, on an indium tin oxide (ITO)-coated glass substrate, as shown in Fig. 1. For the symmetric dimer structure the gold rods are both of lengths 200nm, while for the asymmetric dimer structure the two gold nanorods are of lengths 200nm and 170nm respectively. The widths and thickness of the gold rods are 70nm and 30nm respectively. The Permittivity of gold is modelled according to the Drude model:

$$\varepsilon = 1 - \frac{\omega_p^2}{\omega^2 + i\omega\omega_c}$$

where plasma frequency $\omega_p = 1.37 \times 10^{16} s^{-1}$ and collision frequency $\omega_c = 1.2 \times 10^{14} s^{-1}$, which accounts for the scattering losses in gold (Liu et al., 2009). The index of the glass substrate is taken as 1.5 and the permittivity of the 25nm thick ITO layer is taken as 3.8. The periodicity of the structure is 300nm along both the x and y directions. Using a finite difference time domain (FDTD) solver, numerical simulation for wave propagation direction along the z-axis, normal to the plane of the metamaterial structure with polarization along the x-axis, was performed. The respective transmission spectra for the symmetric and asymmetric dimer metamaterial was obtained as depicted in Fig. 2.

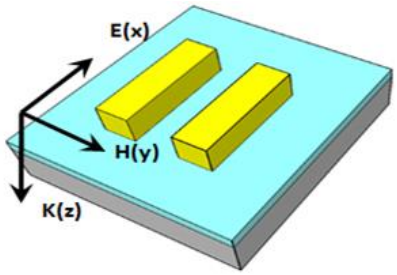

Fig. 1: Schematic of the metamaterial geometry. Incident light is polarized along the dimer length.

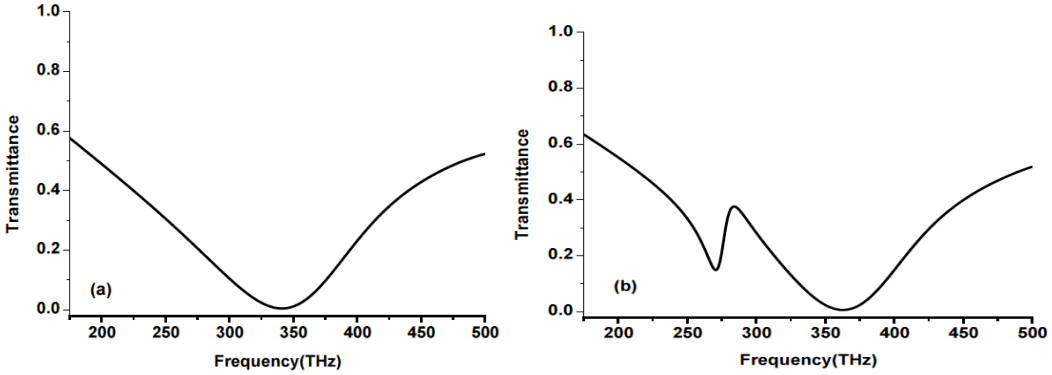

Fig. 2: (a) Amplitude transmission spectra for the symmetric and (b) asymmetric dimer metamaterial.

From the transmission spectra in Fig. 2(a), a broad dipolar resonance occurs at about 341.1 THz in the symmetric dimer metamaterial, with this bright resonance having typical characteristic of being lossy and strong coupling to free space. However, for the asymmetric dimer with transmission spectra shown in Fig.2 (b), aside from the bright broad high frequency resonance at 362.7 THz, there is an associated lower frequency resonance at 270.4 THz. This lower frequency resonance or dark mode due to asymmetry in the dimer has a characteristic of weakly coupling to incident light (Zhang et al., 2008). The interference of the higher frequency resonance and the lower frequency resonance results in the asymmetric Fano-type profile with a characteristic peak and dip, as shown in Fig. 2(b).

Fabrication procedure

The fabrication of the metamaterial was carried out as outlined in the scheme in Fig. 3. The ITO-coated glass substrate is spin coated with PMMA (polymethyl metacrylate) 495A8 at 3500rpm for 45 seconds and then soft baked at 180 degrees for 90 seconds in preparation for electron beam lithography. Using electron beam lithography with an exposure dose of 500mJ/cm^2, the metamaterial dimer is written into the photoresist. Next is a development procedure. The sample is place in a developer solution of Methyl isobutyl ketonebonds (MIBK) for 5 minutes and then rinsed in Isopropyl alcohol (IPA) for 3 seconds. Finally, the sample is rinsed in water and then dried. Fig. 4 shows an SEM image of the fabricated metamaterial.

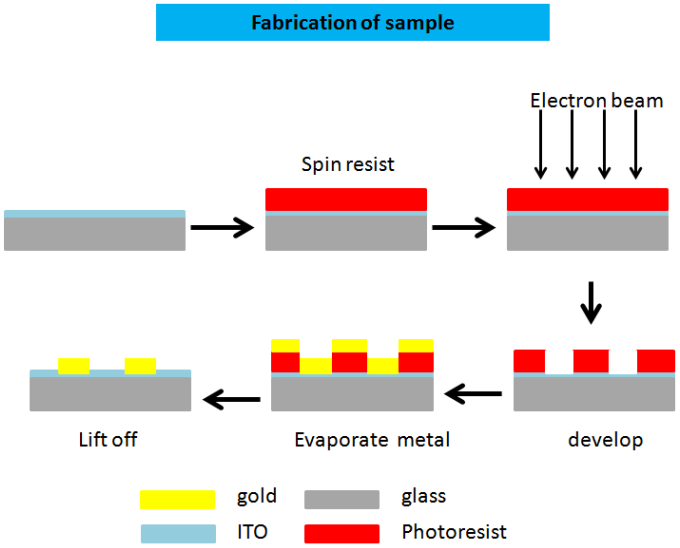

Fig. 3: Fabrication process for the metamaterial. Photoresist is spun on the glass afterwards the dimer structure is written in on the resist. Development of the photoresist and then evaporation of gold and finally a lift off process.

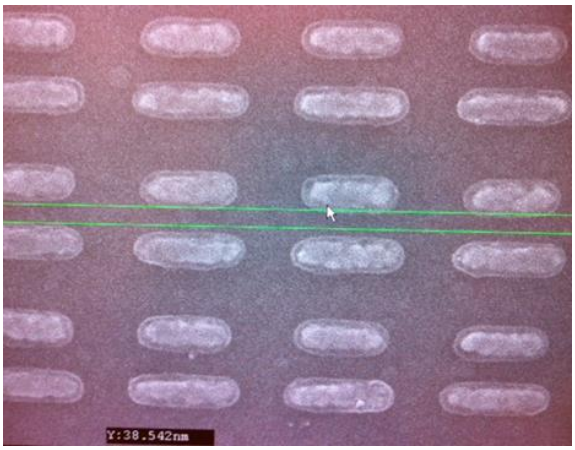

Fig. 4: SEM image of the fabricated metamaterial.

Results and discussion

Experimental measurements on the fabricated asymmetric dimer metamaterial (Fig. 4). Transmission measurements were obtained as shown in Fig. 5(a).

For light polarization as depicted in Fig. 1, transmission measurements on the fabricated asymmetric dimer metamaterial shows the presence of the two resonance modes. The higher frequency resonance at 437.5THz is the bright mode as predicted from the numerical simulations in Fig. 5(b) for the asymmetric dimer. The lower frequency resonance at 226.2 THz is the predicted dark mode from the simulation in Fig. 5(b). The experimental results show good agreement with the numerical simulated results for the dimer metamaterial as shown in Fig. 5(a) and Fig. 5(b). The discrepancy between the experimental and simulated results can be attributed to the fabrication process, where some of the gold nano rod as seen to show a slight variation from one unit cell to the next as seen in the SEM image of the fabricated metamaterial in Fig. 4.

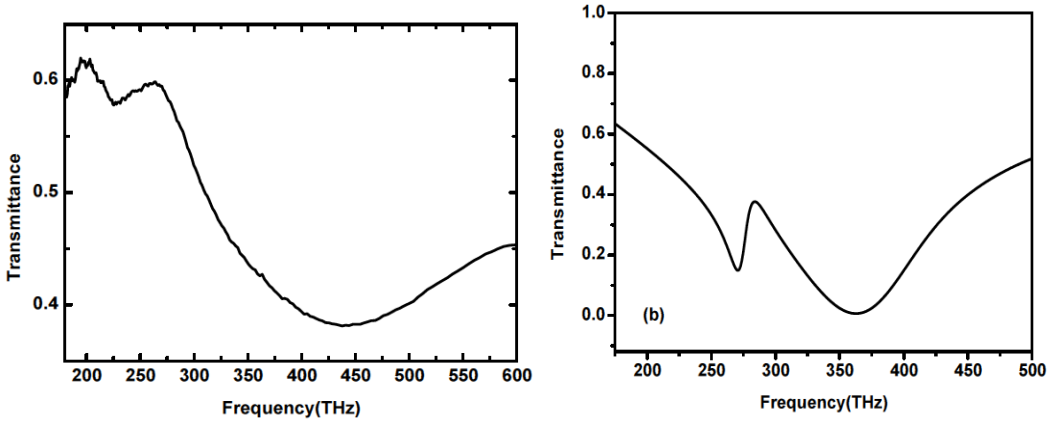

Fig. 5: (a) Experimental transmission spectra for the asymmetric and (b) numerical transmission spectra for the asymmetric dimer metamaterial.

Conclusion

In this paper, we have shown the excitation of dark resonance mode which is not usually excitable in symmetric dimer by the introduction of asymmetry. Experimental results from the optical characterization of the fabricated metamaterial dimer and numerical simulation show good agreement. Given the weak coupling to free space of the dark resonances they can confine electromagnetic energy in small regions, thereby making them useful in applications to bio and chemical sensing or analysis of nanomaterials.

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