Coupling Effect of Dielectric Metamaterial Dimer

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Abstract

In this paper we report on coupling effects of dielectric metamaterial dimer experimentally and numerically. With various configurations and alignment of dimer resonator, magnetic and electric resonance shows a red/blue shift, resulting from longitudinal or transverse coupling effects of dipoles. Beside, the emergences of quasi bound states between tightly stacked dielectric cubes are pointed out for the electric Mie resonance, which shows an unexpected frequency shift with a reverse variation.

1. Introduction

Metamaterials with unique property such as negative index have attracted increasing attentions during the past decade [1]. Generally, metamaterial behaviour can be interpreted by using effective parameters as the average response of individual element, while the coupling effect between elements has been neglected in most cases. However, depending on the interplay type and structure configurations, the interaction between neighbouring cells plays an important role for exotic properties [2-5]. In this paper, we propose a dielectric metamaterial dimer which consists of two identical ceramic cubes. Electromagnetic response of such dielectric dimer is investigated by changing the spacing and alignment of its constituents. It is shown that overall magnetic and electric resonance frequencies of dielectric metadimer can be tuned with red/blue frequency shift, arising from the longitudinal/transverse coupling effects of dipoles.

2. Dielectric Metamaterial Dimer

Dielectric metamaterial dimer, as shown in Fig. 1, consists of two identical Barium Strontium Titanate (BST) cubes with a high relative permittivity and moderate loss (ε=132, tanδ=0.015). These BST cubes are arranged on the Teflon template in proper distances and alignment. To investigate the coupling effect inside metamaterial dimer, the distance between two dielectric constituents along external wave **E**, **H**, and ***k*** directions, were varied independently. The transmission responses of single metamaterial dimer were studied inside X and Ku band waveguides and recorded by an HP8720 ES Vectorial Network Analyzer.

2.1 Dielectric Resonators stacked along E field direction

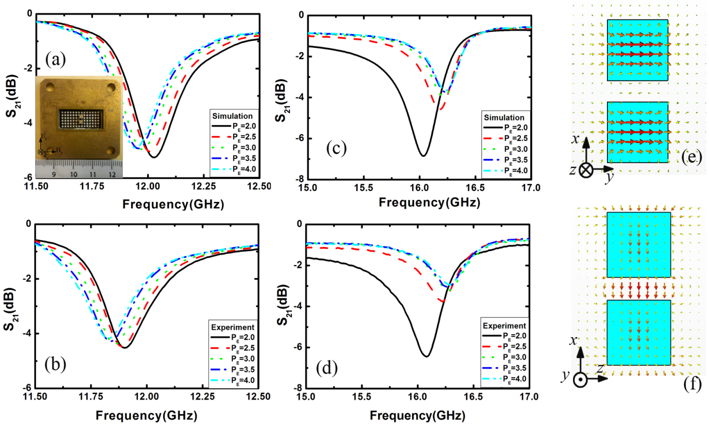

Figure 1 Simulated ((a), (c)) and experimental ((b), (d)) transmission spectra for the first and second Mie resonance of metamaterial dimer. (e) and (f) depict local magnetic and electric field around the magnetic and electric resonance frequencies, respectively. The inset shows dielectric resonators stacked along **E** field are illuminated inside waveguide. BST cube has a side length of 1.8 mm.

Dielectric metamaterial dimer, composed of two BST cubes separated by P_E=3.0mm along **E** field direction, exhibits two pronounced dip around 11.8 GHz and 16.2 GHz, corresponding to magnetic and electric Mie resonances, respectively (Fig. 1). Around these Mie resonances, effective parameters can be achieved below zero [6].When dielectric resonators are separated from 4.0 mm down to 2.0mm, magnetic resonance, ω_{MR} moves slight from 11.83 GHz up to 11.9 GHz, whereas electric resonance, ω_{ER}, shifts from 16. 29 GHz down to 16.08 GHz. To investigate this opposite frequency trend, numerical transmission spectra were calculated by using CST microwave studio. A good agreement between experiment and simulation can be observed. From local field monitored around these two Mie resonances, it can seen that, magnetic field induced from each resonator are aligned parallel to each other, forming a transverse coupling effect. As a consequence, tighter configuration of dimer leads to enhanced magnetic coupling effect and higher magnetic resonance frequency. On the contrary, the longitudinal electric dipole is responsible for the lower resonance frequency shift.

2.2 Dielectric Resonators stacked along H field direction

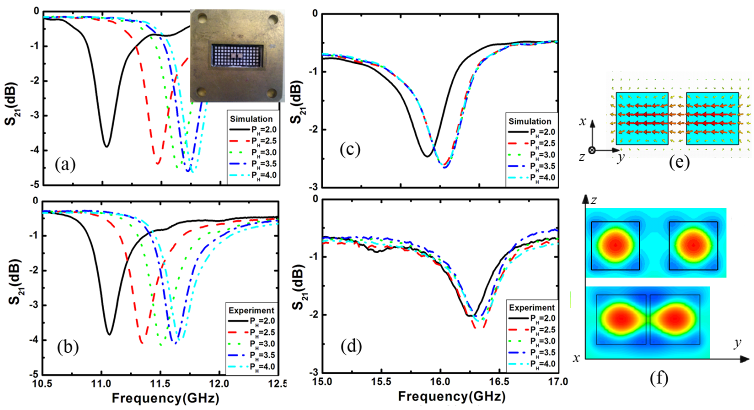

Figure 2 Simulated ((a), (c)) and experimental ((b), (d)) transmission spectra for dielectric metamaterial dimer with resonators stacked along **H** direction, respectively. (e) and (f) depict local magnetic and electric field around magnetic and electric resonance frequencies, respectively. The inset shows the dielectric resonators stacked along **H** field inside a standard waveguide.

In this section, we formed the metamaterial dimer by stacking dielectric resonators along H field direction. In Fig. 2, with smaller separation between these resonators, metamaterial dimer exhibits a large frequency variation from 11.67 GHz down to 11.07 GHz, due to longitudinal magnetic dipole interplay. For the electric resonance, metamaterial dimer shows a nearly independent property on the spacing variation until P_H decreases to 2.0 mm, indicative of weak coupling effect. The lower frequency shift is due to an emergence of quasi-bonding electric mode inside the dimer, as shown in Fig. 2 (f) [6].

2.3 Dielectric Resonators stacked along *k* direction

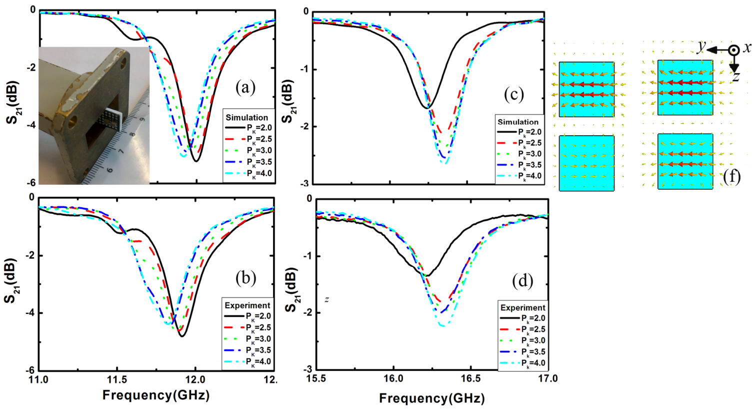

Figure 3. Simulated ((a), (c)) and experimental ((b), (d)) transmission spectra for dielectric resonator stacked along ***k*** direction. (f) depicts local magnetic field for lower (top panel) and higher (down panel) frequencies around magnetic resonance (P_k =2.5). The inset shows the dielectric resonators stacked along the ***k*** direction.

The response of metamaterial dimer with two BST cubes stacked along *k* direction is presented in Fig. 3. As two resonators approach to each other, original magnetic resonance dip moves to higher frequency, accompanied by an extra dip shifts towards lower frequency. This opposite trend is caused by in/anti-phase oscillation for these two dips, as shown in Fig. 3 (f). On the other hand, electric resonance frequency is more stable for the varied spacing inside dimer, except for P_k decreases to 2.0 mm.

4. Conclusion

In this manuscript, we presented the coupling effect inside dielectric mematerial dimer. It is verified that both magnetic and electric Mie resonances of dielectric metamaterial dimer can be tailored via different configurations of constitutive resonators, which is well interpreted with transverse /longitudinal coupling effect of magnetic/electric dipole. This work will provide more degrees of freedom to design metamaterials and control their unique electromagnetic behaviour.

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