A 3D-printed metamaterial with electromagnetically induced transmission

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Abstract: Metamaterials have recently enabled coupling electromagnetic transparency due to interference effects in coupled sub-wavelength resonators. In this work, it presents a three dimensional (3D) metamaterial designed with hollow cube whose simulation shows electromagnetically induced transparency in GHz regime with polarization insensitive to the incident electromagnetic wave due to the ultra-sharp resonance line width as a result of interaction between the constituent meta-atoms. Influences of various parameters including incident angle and frequency have been investigated numerically in detail. The simulation shows significant transmission magnitude of 99.8% at ~12GHz.

1. Introduction

The electromagnetically induced transparency (EIT) effect is a nonlinear effect which occurs in the interaction process between light and material[1]. According to the Wikipedia’s interpretation, Electromagnetically induced transparency (EIT) is a coherent optical nonlinearity which renders a medium transparent window over a narrow spectral range within an absorption line. Extreme dispersion is also created within this transparency "window" which leads to "slow light". It is in essence a quantum interference effect that permits the propagation of light through an otherwise opaque atomic medium[2]. Due to strong material dispersion caused by quantum interference, a transparency peak will emerge in the absorption curve and the group velocity of light can be rapidly slowed down[3]. Therefore, the EIT effect has shown great potential in various promising applications, including slow light control, quantum information processing and sensing technology[4]. However, the realization of EIT in atomic systems is a tough task since some restrictions must be strictly fulfilled. Recently, researchers have found that the EIT-like spectrum can
also be generated in some other structures which are easier to realize, such as optical resonators\cite{5} and Fano metamaterials\cite{6-8}. For the case of EIT, the transparency window is caused by the reduced absorption, due to the quantum destructive interference between the transitions from the two dressed states, into a common energy level. Similarly, the EIT-like effect generated by optical resonators works by means of coherent interference between the resonating modes which produces optical transparency inside the absorption window.

Compared to the EIT in atomic systems, the analogue of electromagnetically induced transparency with optical resonators has many remarkable advantages such as simpler structure, smaller device size and being easier to design, which mean it has enormous potential for applications in optical sensors and optical delay lines\cite{9}. The optical EIT-like effect has been experimentally realized in many optical structures including coupled fiber systems\cite{10}, coupled fused-silica spheres and optical parameter oscillator cavities\cite{11}. In these structures, the line widths of the induced window can be extremely narrow.

The EIT phenomenon has been mimicked by solid-state, on-chip all optical and optomechanic systems. In the past decade, MMs which are artificial electromagnetic structures provided an excellent platform to study EIT effect from microwave to visible light region. Using MMs to mimic EIT phenomenon was first proposed by Zhang et al\cite{12}. The drawback of these devices is the bulky and incompact structure which is hardly present for integrated applications. The on-chip integrated all-optical analogue of EIT effect has been realized in photonic crystals and silicon microrings\cite{13, 14}.

In this paper, it proposes and experimentally demonstrates an electromagnetically induced transparent metamaterial, which is based on GHz regime, consisting of hollow cube array by three-dimensional printing. Amplitude manipulation in GHz regime was achieved at the resonance frequency in the transmission spectra.

2. Structure and Design

By changing the resonant frequency features of MMs, in order to realize the metamaterial structure with multiple transmission peaks, it has established resonant units with different structures in the same region. According to the resonance principle of resonant cavity, the unit cell of the planar MM in this paper is illustrated in Figure 1 (a). The purposed metamaterial is conducted with a square array(6X6) by a unit cell composed of hollow cube. The structure is made up of polytetrafluoroethylene (PTFE) covered with a layer of 0.1-mm-thick copper. Meanwhile, the structure can be fabricated by using three dimension printing technology and a subsequent burnishing process. The electric field $\mathbf{E}_n$, magnetic field $\mathbf{H}_n$ and the wave vector $\mathbf{K}_n$ of the incidence are along the x, y, and z axis, respectively.

As shown in the Figure 1 (b), it is a single array of 6X6, each cell is closely linked, so the periodicity $P=15$mm. And from the Figure 1 (b), you can see that the structure’s width is $w=2.5$mm, $L=10$mm, $w_1=2.5$mm, $w_2=1.25$mm, $h=15$mm. Periodic boundary condition is used both in x and y directions. In simulations, the refractive index of the copper is assumed to be $\varepsilon=2.1+0.005i$. The light is normally incident onto the MMs with polarization along z direction.

The light is normally incident onto the MMs with polarization along z direction. Latter, our research shows that the peak value does not change with the angle of incidence. The simulated transmission spectra in our interested frequency range of 4GHz-14GHz are shown.
in Figure 2 (b) for cavity's length \( L=10 \text{mm} \).

Figure 1 Schematics of the metamaterial. (a) The structure array; (b) unit cell.

3. Simulation and Discussion

To demonstrate the nature of the EIT-like effect clearly, it firstly study the transmission spectra under the various incidence with TM polarization (its magnetic field is perpendicular to the x-z plane) for the pure copper structure array and the copper covered PTFE structure array, as shown in Figure 2 (a),(b) respectively. As an example, when the incident polarization changed while the other parameters are as the mentioned above. A narrow band transmission peak centered at 11.44GHz, 11.53GHz, 11.77GHz, 11.89GHz, 11.59GHz by the degree of 0°, 15°, 25°, 35°, 45° respectively, are observed for the copper covered PTFE array in Figure 1 (b). And the pure PTFE array shows the transmission are relatively smooth curves beyond about 90% in Figure 1 (b), and have no steep transmission peak. From the simulation result, you can observe that the incident angle’s change lead to the transmission peak’s change, and this change is no that significant. The difference of the surface coating of the material can greatly affect the transmissivity. Thus, the proposed metamaterials present high transmission for wide incident angles at certain frequency.
4. Conclusion
In this paper, it proposed an EIT-like metamaterial structure and fabricating method, which is consisted of 3D printed PTFE with copper covered array. The electromagnetic transmission through the metamaterial was studied by changing the parameters, such as incident angles, different material, and the simulated results reveal that this metamaterial has a significant electromagnetically induced transmission for a normal incident polarized wave in GHz regime. The peak of the EIT amplitude could be achieved nearly 100%. The proposed metamaterial structure can be easily applied to different frequency ranges by scaling the structure sizes. The proposed novel metamaterial will easily find practical applications in active plasmonic switch, ultra-high resolution sensors and active slow-light devices.

5. Acknowledgements
This study was supported by National Natural Science Foundation of China (51302196) and State Key Laboratory for Hubei New Textile Materials and Advanced Processing Technology (ZDSYS201711).

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