Slow Light by Hybridized Concentric-Twisted Double Split Ring Resonators and THz Application

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Abstract— **Here, we demonstrate that hybridizing two double split ring resonator (DSRR) leads to two distinct characteristics dependent upon the rotational direction of the small SRRs. The large SRRs are stationary while the small SRRs rotate equally. Counter-directional rotation of small SRRs results in a red shift of the first resonance and blue shift of the second one, while co-directional twisting of small SRRs brings about splitting of the first resonance into two distinct modes. Therefore, a terahertz plasmon induced transparency (PIT) window with a slow light characteristic is observed in between two split modes.**

I. INTRODUCTION

EVER-INCREASING demand for long distance communication requires networks with a larger bandwidth than available gigahertz ones. Future terahertz (THz) communication network has been predicted to meet this target. However, THz spectrum still needs to be technologically developed to access required THz communicating components such as sources, detectors and others. Among them, optical buffers has been envisioned as one of crucial elements of any high-bandwidth network to attain ultra-fast all-optical communication. The most successful approach to achieve an optical buffer is based on electromagnetically induced transparency (EIT) scheme where the speed of light is slowed in a narrow transmission spectrum. EIT is a quantum phenomenon where a narrowband transmission window is opened inside a wideband absorption spectrum as a result of a destructive interference between dark and bright states [1-2]. Various media including cold atoms, warm atoms, and plasmas have been introduced to observe EIT, but the cumbersome experimental conditions have often hampered its practical implementation. One of the alternative approaches to slow the speed of light is to mimic EIT by using metamaterials which w initially called PIT [3] where SRRs or cut-wires are used as dark or bright states. In this article, we hybridize two DSRRs into a single unit cell to exhibit two distinct observations dependent upon the rotational direction of the small SRRs. The large SRRs are fixed in their positions while the small SRRs rotate equally. The structure contains two resonance frequencies associated with small and large SRRs. Counter-directional rotation of small SRRs results in a red shift of the first resonance and blue shift of the second one, while co-directional twisting of small SRRs bring about splitting of the first resonance into two distinct modes. As a result, a terahertz PIT window with a slow light characteristic is observed in between two split modes.

II. RESULTS

A schematic representation of the unit cell of the designed structure has been demonstrated in Fig. 1a along with the corresponding dimensions. The unit cell is composed of two DSRRs which is hybridized into a single unit cell. Large SRRs are stationary and small SRRs rotate about axes passing through their centers. Comsol multiphysics was utilized to design the structure. SRRs are made of Cu and the substrate is made of polyimide. Each DSRR exhibits two resonances associated with small and large SRRs. However, two DSRRs couple into each other in the hybridized unit cell leading to new emerging states. Figure 1 (b) illustrates the frequency response of the designed device when small SRRs rotate counter-directionally with equal angles. It is observed that counter-directional twisting of small SRRs by equal angles leads to red shift of the first resonance and blue shift of the second resonance which can be explained by coupling of magnetic dipole moments of large and small SRRs in each DSRR.

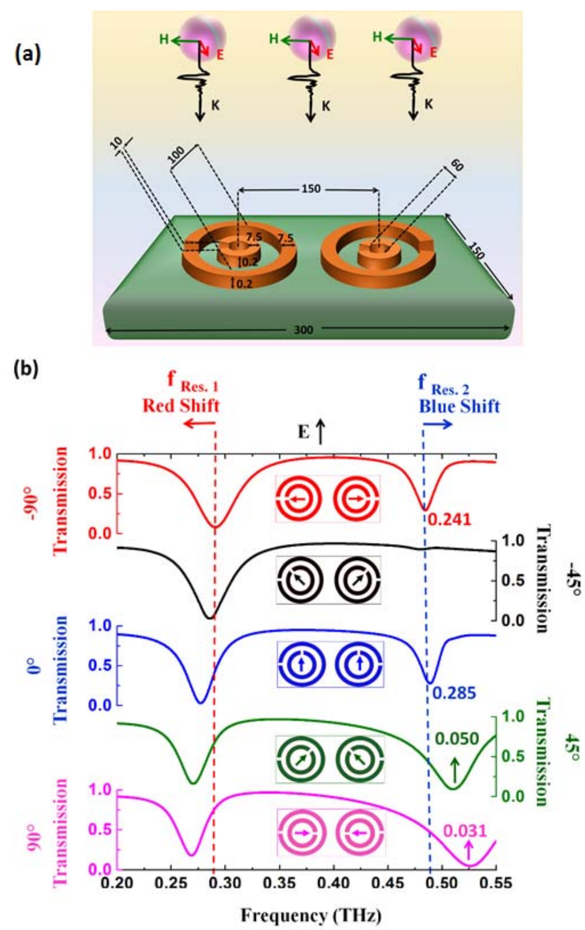

Fig. 1. a. Schematic illustration of hybrid concentric-twisted DSRRs. b. Transmission spectra of hybridized counter-directional twisted DSRRs with their corresponding structure in insets.

Figures 2(a), (c), (e), and (g) show the x component of electric current density for both resonance frequencies but just for -90 and 90 rotation cases. For clarity, the current directions along with magnetic field vectors (green centrifugal (×) and centripetal (.)) has been demonstrated schematically in Figs. 2 (b), (d), (f), and (h) for associated resonances and rotations. The first resonance should be originated from the large SRR. At this resonance in -90˚ case the current exists just in large SRR (Fig. 2(a)), therefore it creates a magnetic field as depicted in Fig. 2(b). However, at this resonance but in 90˚ case, in addition to the current in large SRR, a current flow exists in small SRRs in the same direction (Fig. 2(c)). Therefore, the magnetic field created by small and large SRRs in the area between them will be in opposite direction as shown in Fig. 2(d).

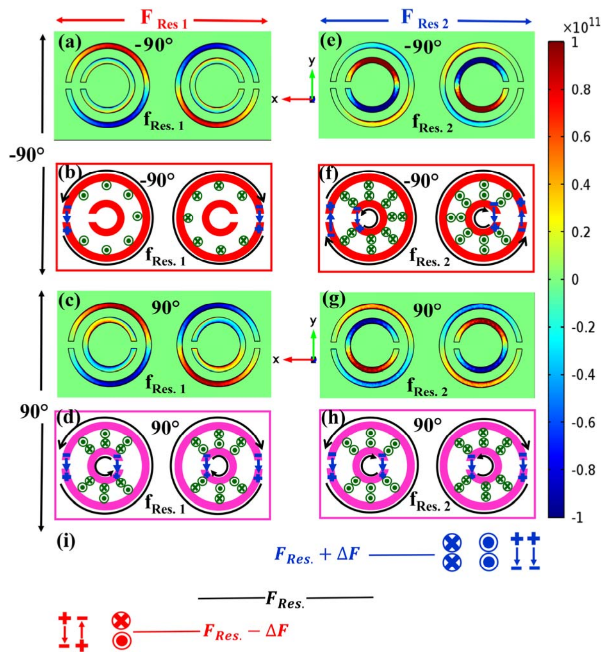

Fig. 2. Transmission (a) and phase (b) spectrum of co-directional PIT structure.

Contrarily, the second resonance comes mainly from the small SRRs. However, there is also an inducted current in large SRRs, opposite to that of small SRRs. The created magnetic field between two SRRs for -90˚ and 90˚ cases has been brought in Figs. (f) and (h), respectively. In -90˚ case magnetic fields of small and large SRRs in the area between them are in the same directions, while they are in opposite directions in 90˚ case. If one considers the energy level scheme depicted in Fig. 2(i), the red shift of the first resonance and blue shift of the second resonance can be interpreted. Parallel moments will repel each other eventuating to an increase in the restoring force between them and hence a frequency blue shift, while anti-parallel moments will attract each other leading to a decrease in the restoring force between them and thus a frequency red shift.

In contrast to counter-rotational twisting of small SRRs, if small SRRs are equally twisted in the same direction (co-directional twisting) the first resonance will split into two bright modes and thus a narrow PIT transmission window will appear at spectrum between them. Figure 3 depicts the emergence of PIT window in the course of twisting small SRRs from 0˚ to 90˚. Figure 3(a) demonstrates transmission spectrum and Fig. 3(b) shows phase spectrum of transmitted THz radiation. As seen from the figure, a transmission window eventually appears at 90˚ rotational case in the spectrum between two splitted resonance frequencies where a resonance is observed in the phase spectrum at this spectrum (between 0.27 THz and 0.30 THz). The calculated group delay and relative group velocity for 90˚ case is displayed in Fig 3(c) where THz radiation experiences a 3 times reduction in its group velocity relative to polyimide as the reference and a group delay of 7.6 [ps] is observed within PIT spectrum.

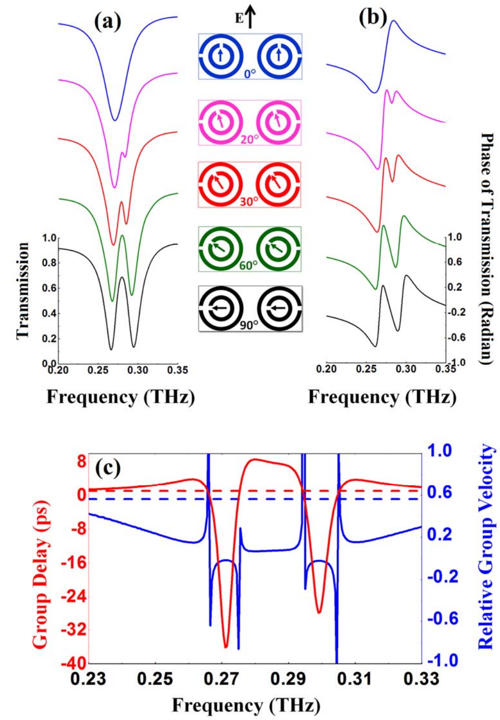

Fig. 3. Transmission (a) and phase (b) spectrum of co-directional PIT structure.

III. Summary

By hybridizing two co-directional DSRRs we achieve PIT and we reduce the speed of THz radiation by 3 times compared to that of in polyimide.

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