Tunable Fano-Resonance in Terahertz Metamaterials

B. R. Sangala[1], H. Surdi[1], P. Deshmukh[1], G. Rana[2], A. Venugopal[1], S. S. Prabhu[3]

[1]Tata Institute of Fundamental Research, Mumbai, Maharashtra, India

[2]Indian Institute of Technology Bombay, Mumbai, Maharashtra, India

[3]Department of Condensed Matter Physics, Tata Institute of Fundamental Research, Mumbai, India

Abstract

Terahertz radiation (THz) is defined to have frequencies from 0.1-10 THz (1 THz=1e12 Hz). This radiation lies between microwave and infrared radiations in the electromagnetic spectrum. Metamaterials are designed periodic materials that show exotic properties to light and sound. Metamaterials are good candidates for manipulating THz because natural materials have a weak response to it. Several optical components were demonstrated for THz radiation including sources, filters, absorbers, detectors, etc. Fano-resonance occurs when a dark mode and bright mode interact giving rise to an asymmetric line shape in transmitted or reflected light. This was observed in asymmetric split ring resonators, concentric rings and found to be of very high quality resonance [1]. In this paper, we present a planar THz metamaterial based on concentric rings, which has tunable Fano-resonance. The unit cell of the metamaterial has two concentric Gold rings on a Gallium Arsenide (GaAs) substrate. The unit cell is shown in Figure 1 (a). The period of the unit cell is 50 µm along x and y-directions. The width of the Gold pads is 2 µm, outer diameter of the outer ring is 36 µm, outer major axis of the ellipse is 30 µm, and outer miner axis of it is 24 µm. The height of the Gold pads is 150 nm.

We used the RF module of COMSOL Multiphysics® software for designing the metamaterial. We shine THz normal to the GaAs substrate using port boundary condition. We apply the periodic boundary conditions along the two orthogonal directions of the unit cell. We computed the S-parameters for various THz frequencies and when THz electric field is along major and minor axes of the ellipse of the metamaterial. Figure 1 (b) shows the current density and electric field norm at the Fano-resonance (1.25 THz) when the THz electric field is along the major axis of the ellipse.

We fabricated the designed metamaterial using electron beam lithography and measure the THz transmission through it using terahertz time-domain spectroscopy (THz-TDS). Figure 2 (a) shows a plot of simulated $|S21|^2$ and experimental transmission coefficient when the THz electric field is along major axis of the ellipse and Figure 2 (b) shows them when the field is along the minor axis of the ellipse. The figures show the simulated Fano-resonances at 1.25 THz for former case and at 1.5 THz for later case. The trend of the experimental values matches with simulations but they are off may be due to variation in material parameters.

We designed, fabricated, and characterized a metamaterial with tunable Fano-resonance. It can be used to sense weak signatures of molecules. We can switch between detection and non-detection state by changing the angle of the metamaterial. It can also work as a angle tunable THz filter.

Reference

1. J. Shu, W. Gao, K. Reichel, D. nickel, J. Dominguez, I. Brener, D. Mittleman, and Q. Xu, “High-Q terahertz Fano resonance with extraordinary transmission in concentric ring apertures,” Optics Express, 22, 3747 (2014).

Figures used in the abstract

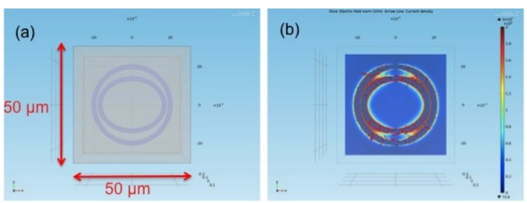

Figure 1: (a) Unit cell of the metamaterial. Period is 50 µm, outer diameter of outer ring is 36 µm, outer major axis of ellipse is 30 µm, outer minor axis of the ellipse is 24 µm, the width of the lines is 2 µm, and height of the Gold rings is 150 nm. (b) Electric field norm and current density at 1.25 THz when the THz electric field is along the major axis of the ellipse.

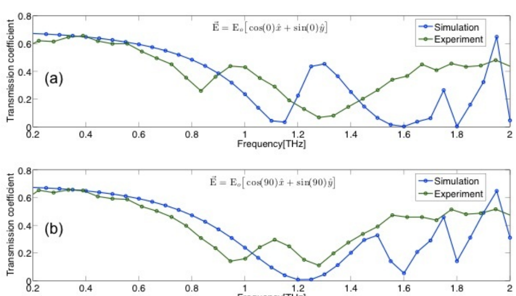

Figure 2: |S21|^2 from simulation and amplitude transmission coefficient from THz-TDS of the metamaterial: (a) when THz electric field is along the major axis of the ellipse. (b) When THz electric field is along the minor axis of the ellipse.