Tunable Fano-Resonance in Terahertz Metamaterials

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Introduction: Metamaterials are designed with metal and semiconductor inclusions. The asymmetric shaped transmission dip in metamaterials, called “Fano-resonance,” can have high quality and high field enhancement. We designed a metamaterial with tunable Fano-resonance for terahertz radiation. It can be used to do nonlinear THz spectroscopy at tunable Fano-resonance frequencies.

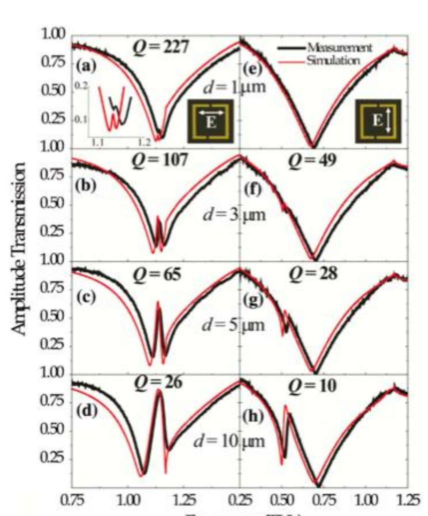

Figure 1. High quality THz Fano-resonances.

Unit cell type	Center frequency [THz]	Quality factor	Reference
Asymmetric square SRR	1.72	93	Optics Express **18** 13044 (2010)
Asymmetric square SRR with an extra cut	1.14	227	Optics Letters **37** 3366 (2012)
Ring with two asymmetric cuts	0.86	50	Optics Express **19** 6312 (2011)
Concentric two ring slots	0.42	40	Optics Express **22** 3747 (2014)

Table 1. Literature survey of the existing Fano-resonances in metamaterials.

Computational Methods: We used RF module of COMSOL® for the simulations. We created a CAD for the metamaterial unit cell with concentric ring pads of Gold on GaAs substrate. We used periodic boundary conditions along x and y directions and shone light using port boundary condition with electric field

$$\vec{E}_i = E_o\left[\cos(\theta)\hat{x} + \sin(\theta)\hat{y}\right]\exp(-ik_z z).$$

We solved for the S parameters at various frequencies to get THz wave transmission and reflection.

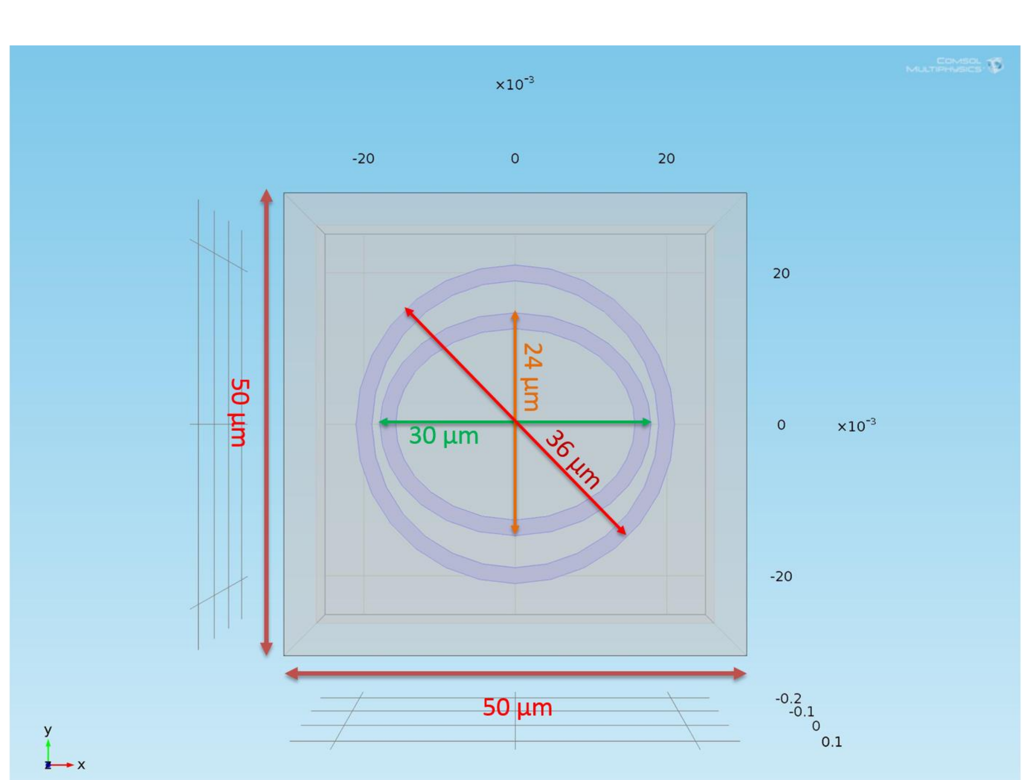

Figure 2. Metamaterial unit cell: Gold ring pads on Gallium Arsenide. Width of Gold Pads=2 µm. Height of the pads=150 nm.

Results: We fabricated the designed metamaterial by electron beam lithography and characterized it by terahertz time-domain spectroscopy.

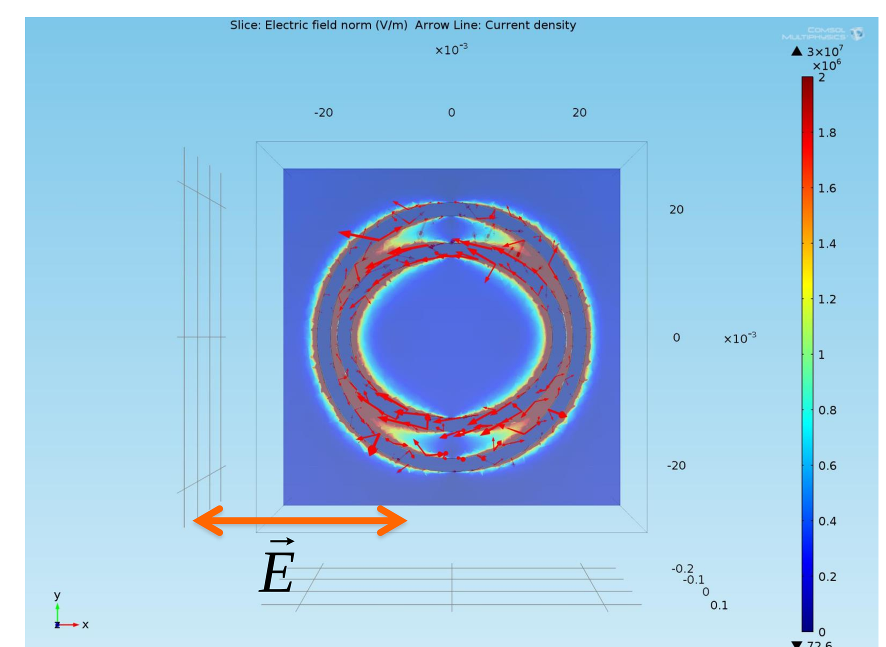

Figure 3. Electric field norm and current density at 1.25 THz.

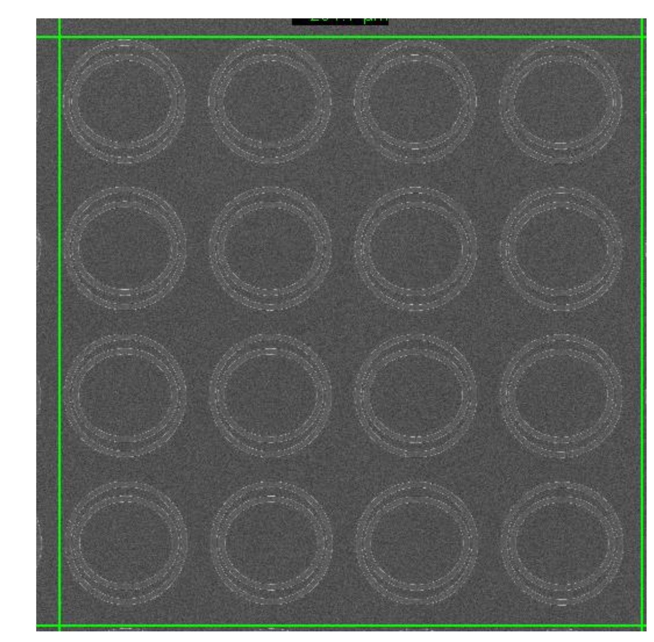

Figure 4. An SEM image of the metamaterial.

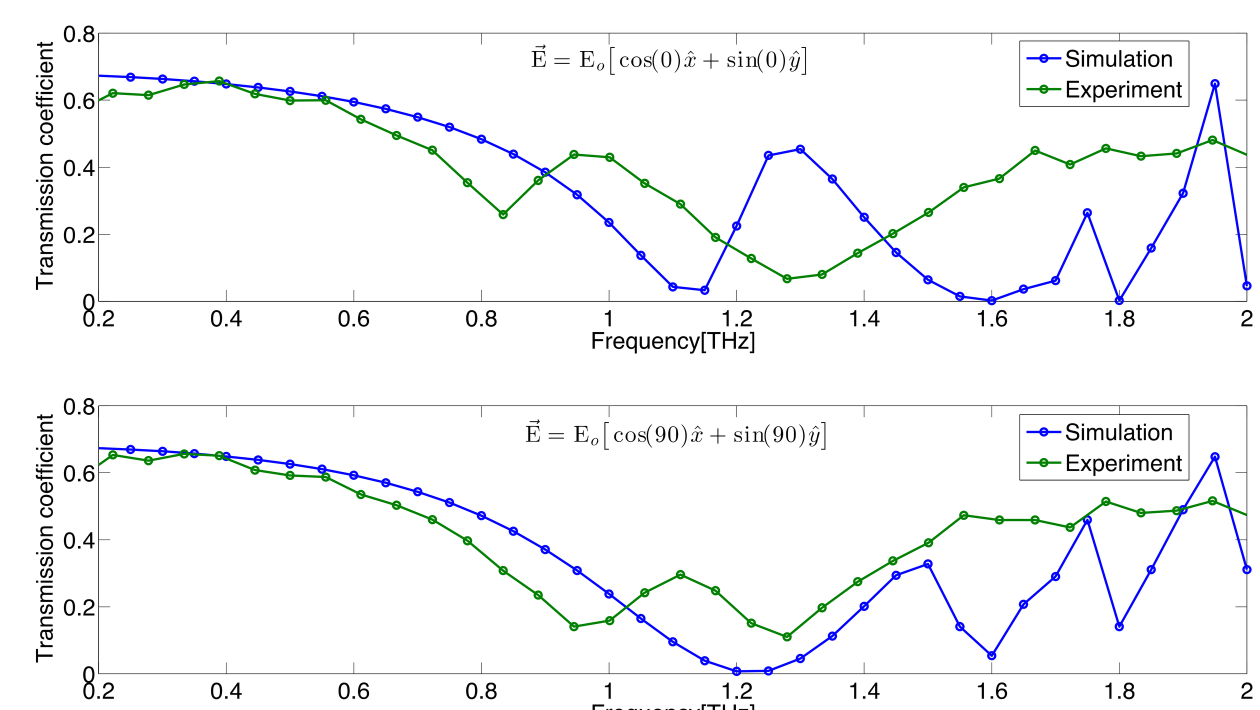

Figure 5. Comparison of terahertz transmission from COMSOL® simulations and terahertz time-domain Spectroscopy for two orthogonal polarizations of the incident terahertz radiation.

Conclusions: In simulations, the Fano-resonances occurs at 1.25 THz and 1.5 THz for x and y polarized lights and in the experimental data, they occur at 1 THz and 1.1 THz respectively. The discrepancy in experimental and simulations results could be due to change in the material properties. An enhancement of the field by 10^6 was observed at Fano-resonance in some parts of the metamaterial.

Reference:

1.Jie Shu Weilu Gao et al., Optics Express **22** 3747 (2014).

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore