Tunable Terahertz Modulator Using Graphene Split-ring Resonator

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***Abstract*—In this work, we study the graphene metamaterial split-ring resonators at far-infrared frequency band, the tunable resonant properties depend on the change of the Fermi level. We find the modulation depth of the frequency and transmission can reach 65.36% and 99.36%, respectively. The introduction of the asymmetry leads to two resonance dips at relative high Fermi level due to the dipolar resonant nature of the two arc arms, which is different from the resonance of the metallic split-rings. Combined with the asymmetry, the active control of the graphene split-ring resonator paves a new way for the design of the novel plasmonic devices such as modulator and sensor working in the THz gap.**

I. INTRODUCTION

THE terahertz(THz) region of electromagnetic spectrum whose frequency lies between 0.1THz and 10THz, has attracted increasing attention for its potential application, it is of very importance for spectroscopy and investigation of the molecular bonds, materials structure[1]-[3]. However, the study in THz region is lagging far behind its neighboring waveband. A great challenge in developing THz technology further is that it is difficult to find suitable materials to respond THz wave strongly. Fortunately, it can be eased by metamaterials (MMs), which is an artificially designed material that gains effective properties from its structure rather than inheriting them directly from the material it is made of [4], it allows for a control and manipulation of the light on sub wavelength scale. There has been rapid progress in the study of MMs recently, the most common unit cell is split-ring resonators (SSRs)[5-[6], recent works on metamaterials suggesting to break the symmetry of SSRs and demonstrating a sharp asymmetry Fano resonance, exhibiting a high Q factor associated with high field concentration and potential applications in label-free sensors, switches and modulators[7]-[8]. As a key device, THz modulator is required to meet the need of short-range wireless THz communication and ultrafast interconnections[9]-[10], for the current semiconductor modulator, there still exists many problems, for example, its modulation depth is very small and it required cryogenic temperatures[11], therefore, further improvements are needed for practical applications. Based on the MMs structure, some active THz modulators have been proposed over the past years, for example, Chen et al. have proposed an active THz modulator via incorporating semiconductor gap of the metallic SRRs, which can be designed to work at any frequency by changing the substrate and exhibit a good amplitude modulation[4]. Recently, with the merits of high carrier mobility and strong interaction with the light by structured patterning, graphene has attract increasing attention in both fundamental physics and its application[12-[13], by depositing graphene patterns on the SiO_2/Si layers, we can realize an active control of THz wave, because the permittivity of the graphene layer can be varied by the applied electric and magnetic field or chemical doping, in this paper, we study the THz modulator based on the SRR structure which is made of the graphene, which can realize the active control of the THz wave, and we compare the different physical mechanism of graphene SRRs and metallic SRRs.

II. RESULTS

The modulation depth of the frequency and transmission can reach 65.36% and 99.36% which is larger than previous study with the increasing of Femi level in symmetrical structure, for asymmetrical graphene SRRs structure, with the increase of the asymmetry, two resonant dips occur caused by the dipolar resonance, it is different from the metallic split-rings, and the amplitude remains almost unchanged which can be used as a frequency modulator.

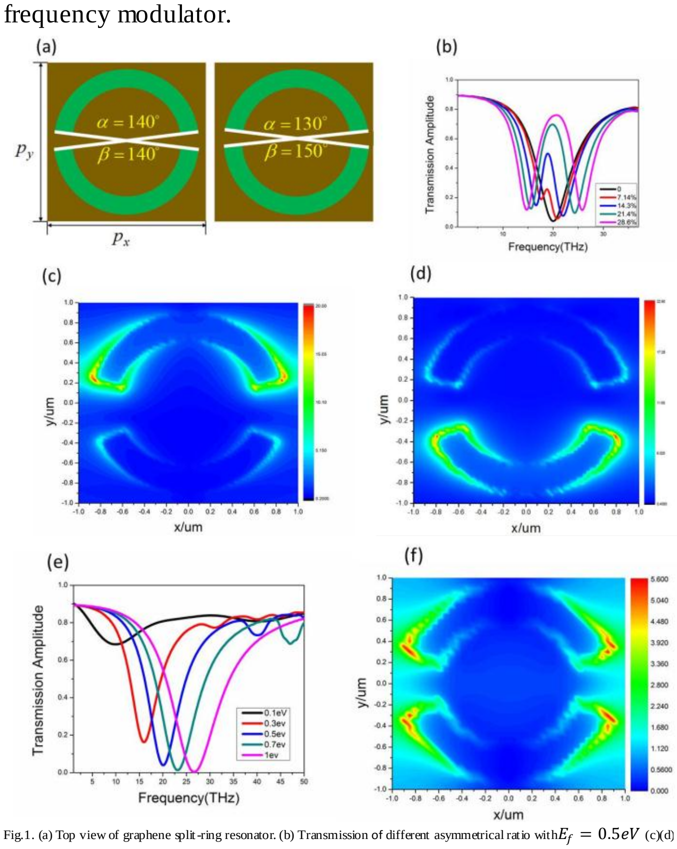

Fig.1. (a) Top view of graphene split-ring resonator. (b) Transmission of different asymmetrical ratio with $E_f = 0.5eV$ (c)(d) The electrical field distribution of the two resonance with the asymmetrical ratio of 7.14% at 17.56THz and 20.84THz when $E_f = 0.5$Ev. (e) The transmission of the symmetrical SRR under different Fermi level. (f) The electrical field distribution at the resonant frequency of 22.8THz under 0.7eV

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