Simulation on absorption properties of Terahertz metamaterial/GaAs based photoconductive detector

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***Abstract*—Terahertz (THz) technology, used for astronomical observation, security check, material optimization and biomedical treatment, has attracted various attentions all over the world. Extrinsic GaAs photoconductive detector, as a typical THz detector, requires an enough thick high-purity GaAs epitaxial absorption-layer to get a good performance. However, such thick GaAs epitaxial layers are difficult to grow and would induce large dark current. A new structure designed by adding split ring resonator as Terahertz metamaterial on traditional GaAs based photoconductive device was proposed in this work, and its absorption spectrum was investigated by FDTD simulation. The simulation results indicated that by inducing metamaterial to GaAs photoconductive detector, obvious absorption enhancement effect occurs at the resonance frequency (0.75THz). This novel structure largely reduced the thickness of absorption-layer to 15μm, and enhanced the absorption of incident THz wave at about 400μm. Our design provides a novel device to solve the epitaxial growth bottleneck of GaAs epitaxial photoconductive detector.**

Keywords—GaAs based photoconductive detector, metamaterial, absorption properties, numerical simulation

I. INTRODUCTION

Terahertz (THz) detecting technology is suitable for the applications of astronomical observation, security check, and biomedical treatment (especially diagnosis of cancers such as breast and colon cancer et al.) (1,2). Extrinsic GaAs photoconductive detector, as a typical THz detector, has a larger detection wavelength (above 300μm) and a higher detection efficiency, for it owns a lower impurity ionization energy, compared with intrinsic GaAs detectors. To get an extremely high-performance GaAs photoconductive detector, one critical factor is to improve the detection efficiency by enhancing the quantum efficiency and photoconductive gain (3). In the past several decades, many researches have been done to grow a sufficiently thick GaAs epitaxial layer with low acceptor concentration to get high-performance THz detection (4-6). However, due to the low absorption coefficient of GaAs, the thickness of the absorption layer should be as large as possible. Kentaroh et al. use 270μm GaAs:Te epitaxial layer and 120μm GaAs:Si epitaxial layer to fabricate GaAs photoconductive detector (3,6). The extremely thick absorption layer is not only difficult to grow, but also induces large amounts of impurities and defects, leading to a high dark current value and low signal-to-noise ratio of GaAs detector. Therefore, the epitaxial process restricted the application of GaAs based photoconductive detector.

In this work, a novel metamaterial/GaAs based photoconductive detector with periodic split ring resonator array on the top of its absorption layer was designed and theoretically calculated. The simulation results show that for the conventional structure with a 100μm absorption-layer, the absorption ratio mainly depends on the absorption coefficient of the material of the absorption-layer and cannot be adjusted flexibly. While, utilizing the wavelength selective resonant absorption property of the metasurface, the absorption specrum of the novel device is significantly enhanced at the resonance frequency (0.75THz), the thickness of absorption-layer could be reduced to 15μm, the absorption peak could be adjusted by changing the size of the split-rings. Also, the electric field intensity at the metasurface is strongly enhanced, especially near the split. This work provides a novel device to solve the epitaxial growth bottleneck of GaAs epitaxial photoconductive detector.

II. SIMULATION

The absorption properties of conventional n-type GaAs photoconductors without any additional structure (device A) and metamaterial/GaAs photoconductor with periodic split ring resonator array (device B) are simulated by Lumerical FDTD Slution. The absorption thickness of Device A is 100μm. The structure of device B is shown in Fig. 1, the period of the split ring (Aurum) is 110μm, with 10μm width and 1μm thickness. Part (a) shows the sectional view, part (b) is the top view. The orange patterns represent the split rings.

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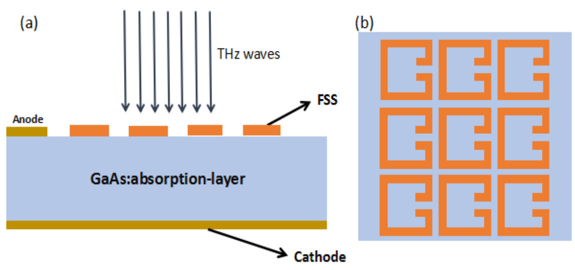

Fig. 1. Diagram of the GaAs device with periodic split-ring-shaped array.

The refractive index data of GaAs absorption layer is extracted from the published research work by Cardozo et al (7). The peak of the absorption coefficient is at 270μm.

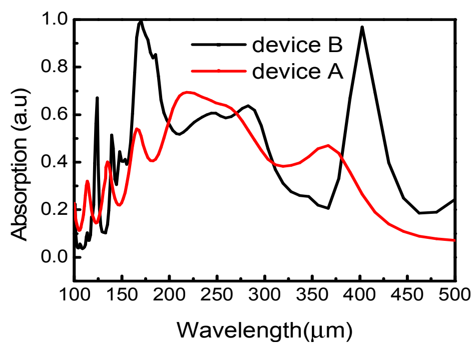

Fig. 2. The absorption spectra versus wavelength (100~500μm).

Fig. 2 shows the absorption spectra versus wavelength (100~500μm). Obviously, the large absorption peak (at about 250μm) of device A is mainly induced by the refractive index of GaAs absorption layer. The absorption of device B is significantly different. Besides the strong absorption peak near 250μm, absorption peaks appear at several resonance bands, especially at 400μm, which is of great importance for the GaAs photoconductive detector applications and hard to achieve in the normal structure. Our further simulation results show that the additional absorption peak could be adjusted by changing the period of the split ring resonator array.

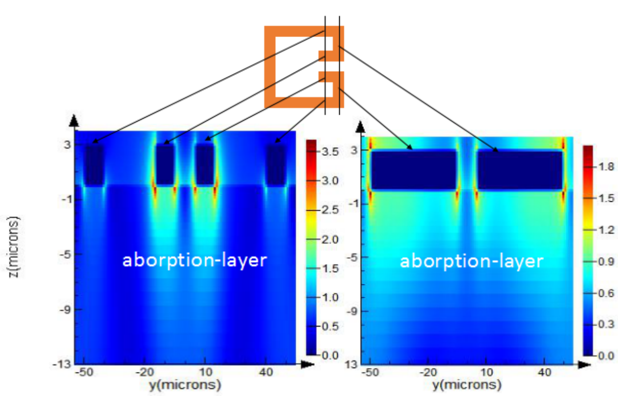

Fig. 3. The sectional view of electromagnetic field distribution at the split of the ring and the absorption-layer below.

In order to understand the physical mechanism of the absorption enhancement, we investigate the electromagnetic field distribution of the device (in this further simulation, we use Perfect Electrical Conductor as the material of the split ring). Fig. 3 is the sectional view of electromagnetic field distribution at the split of the ring and the absorption-layer below (the position is described in the top part of the figure, the wavelength of incident light is 252μm). Obviously, the electromagnetic field is significantly enhanced in the resonance ring structure, especially near the split and the outer edge of the ring.

III. Conclusion

A new metamaterial/GaAs based photoconductive detector is proposed, and its absorption properties at THz band is investigated by FDTD simulation. The simulation results indicate that obvious absorption enhancement effect occurs at typical resonance band. When the ring-period is 110μm, this novel structure can largely reduce the thickness of absorption-layer to 15μm and induce a significant absorption enhancement at about 400μm. Our design provides a novel metamaterial/GaAs based photoconductive detector with periodic split ring resonator array to solve the epitaxial growth bottleneck, which has affected the fabrication process and device performance of conventional GaAs based photoconductive detector for a long time.

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