Progress In Electromagnetics Research Letters, Vol. 25, 127–134, 2011

ENHANCING TERAHERTZ RADIATION FROM DIPOLE PHOTOCONDUCTIVE ANTENNA BY BLENDING TIPS

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Abstract—We study the rectangular tips of the dipole photoconductive antenna, which has been widely used for terahertz radiation and detection, with different blend radii effect on the emission performance of terahertz (THz) radiation. For the amplitude of THz radiation pulse is proportional to the local electric field in the gap, the increased maximum bias electric field by blending tips is able to achieve higher THz radiation power. Both considering the influence to the maximum bias electric field and the emission efficiency, the blend radius of the rectangular tips is suggest to be larger than 5 μm and the radiation power is largely enhanced. Comparing to the previous work, our method has better THz radiation performance.

1. INTRODUCTION

Terahertz (THz) radiation, which lies in the frequency gap between the microwaves and infrared, has been drawn great interest in many fields, e.g., information and communications technology (ICT) [1], security [2], biology and medical sciences [3], earth and space science [4], and basic science [5]. Among the THz community, the photoconductive antenna is one of the most widely used emitter and detector for the THz pulse. However, the low emission intensity significantly limits such attractive applications. Therefore,

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Received 7 July 2011, Accepted 1 August 2011, Scheduled 7 August 2011

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it is necessary to enhance the THz radiation power from the photoconductive antenna by optimization design [6–13].

The THz emission amplitude is believed to be proportional to the local bias electric field in the optical illuminated region [14], whereas the breakdown field of the material limits the maximum applied bias field [15]. That means the material would be damaged when the bias field beyond the material breakdown field, so the breakdown effect is limited by the bias field. Since the bias field distribution in the gap only depends on the shape of the electrodes, reducing the highest field is expected to increased the bias voltage and enhance the THz radiation power. In the previous works, one of the effective methods is to reduce the fringing electric field on the electrode tips, where the field is much higher than that in photoexcited region [8, 16]. However, none of the researches have been focused on the rectangular tips of the dipole photoconductive antenna with different blend radii effect on the THz emission performance. Here, we investigate the bias electric field near the tips varied with different blend radii and their effects on the THz radiation performance. In our simulations, we find that both the bias electric field near the tips and the emission efficiency decrease as the radius keeps increasing. After taking these factors, the optimum blend radius should be larger than 5 μm for the dipole photoconductive antenna design. Finally, the analysis between our work and Y. Cai [8] is presented and the radiation performance of our work is expected to be better.

2. BIAS ELECTRIC FIELD

As shown in Fig. 1, the dipole photoconductive antenna with the width W, the length L, and the blend radius R is fabricated on low-temperature-grown GaAs (LT-GaAs) substrate. The gap distance, the laser spot diameter, and the bias voltage is equal to 5 μm, W, and 20 V, respectively. The length and the width of the dipole photoconductive antenna is assumed to be 80 μm and 20 μm, and then we study the bias electric field in the gap with R varying from 0 μm to 15 μm. Because the strongest bias electric fields are found near the rectangular tips and the electric fields is almost uniform in the laser excitation region, what we only concern is the ratio of the strongest electric field strength E_R near the rectangular tips to the electric field strength E_L in the laser excitation region.

From the results of our simulation, when $R = 0\,\mu\text{m}$, E_R, E_L and the ratio of them is equal to 502 kV/cm ,40 kV/cm, and 12.55, respectively. However, the ideal rectangular tips is not exist due to the conventional photolithography [8], so we assume $E_{R=0.1}$ and $E_{R=0}$ to have the same value that is equal to $E_{R=0.1}$ in our following discussion. Additionally, the bias electric field E_L is found to be constant and invariably smaller than E_R when R is varied. In Fig. 2, E_R/E_L decrease largely as R increases originally, whereas this decreasing trend comes to be much slow when R is over 5 μm. Moreover, when we changes the length L and the width W of the dipole photoconductive antenna, the curve that E_R/E_L varies with R is almost the same as before. This indicates that the bias electric field distribution is mainly depend on the blend radius R.

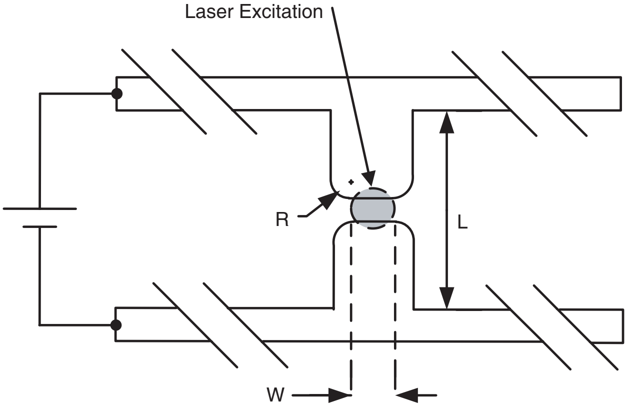

Figure 1. Structure of the dipole photoconductive antenna.

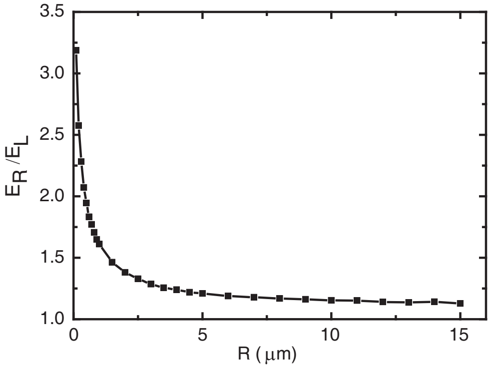

Figure 2. Calculated ratio of the strongest electric field strength E_R near the rectangular tips to the electric field strength E_L in the laser excitation region when R varies.

3. EMISSION EFFICIENCY

For the increasing width would decrease the emission efficiency of the dipole antenna [11], we study the radiation power correspond to the different R values. In our simulation, the model is the same as before. The rising and the falling time of the input excitation current is 200 fs and 500 fs, respectively. The total laser excitation power and the bias voltage is constant. As shown in Fig. 3, we present the calculated emission spectral of the THz pulse radiated from the dipole antenna with R varying from 0 µm to 15 µm. The ratio of the radiation power P_R with different R values to the radiation power $P_{R=0}$ when $R = 0$ µm is a function of R as shown in Fig. 4. The radiation power decreases obviously as R increased from 0 µm to 5 µm, which mainly attributes

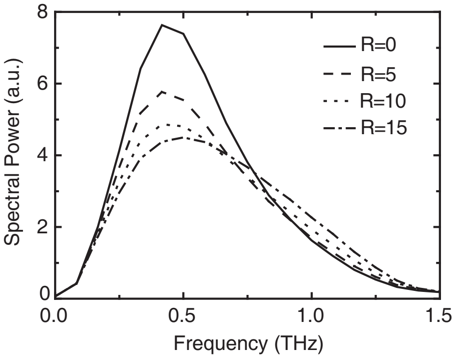

Figure 3. Calculated spectral power from dipole antennas with R ranging from 0 to 15 µm.

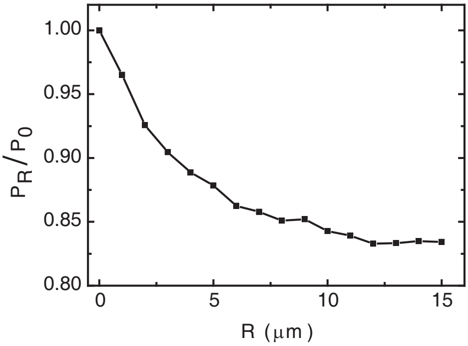

Figure 4. Calculated ratio of the radiation power P_R with different R to the radiation power $P_{R=0}$ when R equal to 0 µm when R varies.

to the increased imaginary part of the input impedance of the dipole antenna that leads to the emission efficiency decreased. However, at the same time the dipole antenna would have lower input impedance and quality factor, which is supposed to have wider frequency response that is useful to the wide band excitation signal and is believed to achieve higher radiation power. These two factors are counteracted when R is beyond $12\,\mu m$, so that the radiation power comes to be constant. Additionally, this curve is almost the same when we change the width and the length of the antenna.

4. OPTIMIZE BLEND RADIUS

In this discussion, we assume the screening effect induced by the space charge effect is ignored. This assumption is available when the injected carrier density in the LT-GaAs material is smaller than a few $10^{18}\,\mathrm{cm}^{-3}$, so the amplitude of the far field radiated from the photoconductive dipole antenna is a simply linear function of the applied bias electric field [17, 18].

Since the maximum safe bias electric field determines the maximum applied bias voltage, the decreasing bias electric field E_R is able to enhance both of the maximum bias electric field E_L and the maximum amplitude of the THz radiation pulse. Hence, E_R is inversely proportional to the maximum amplitude of the radiated THz field. In order to investigate the enhancement of the maximum radiation power affected by both of the bias electric field and the emission efficiency as R varied, η is used to represent the ratio of the maximum radiation power with different R values to the maximum radiation power as R equal to zero:

$$\eta = \left(\frac{E_{R=0}}{E_R}\right)^2 \frac{P_R}{P_{R=0}} \tag{1}$$

Figure 5 shows the maximum radiation power with $R = 5\,\mu\mathrm{m}$ increases nearly six times than that with $R = 0\,\mu\mathrm{m}$, whereas this increasing trend is not significant when R keeps increasing. Therefore, for the practical photoconductive dipole antenna design, the blend radius R should be larger than 5 μm to get higher THz radiation power.

Additionally, compared to the previous works conducted by Cai et al. [8], who enhanced THz radiation mainly based on high electric field, we have several advantages: (a). In Cai's work, the laser spot size is much smaller and must closed to the tips of the electrodes (without blending tips) to get high electric field, the experimental system would become more complicated. In our work, what we only change is the shape of the electrodes. (b). The focused laser spot in [8] leads to high

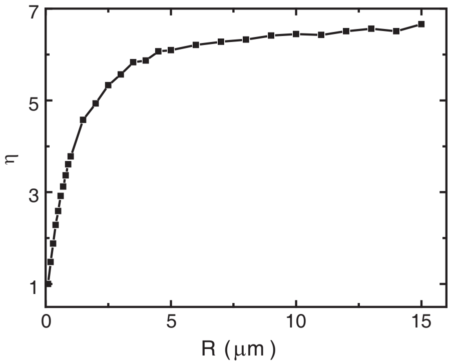

Figure 5. Calculated ratio of the maximum radiation power with different R to the maximum radiation power as R equal to 0 μm when R varies.

photocarrier density that would have detrimental effect on the carrier mobility and thus decrease the bandwidth of the THz pulse. The carrier mobility is not changed in our work. (c). The local photocurrent density in [8] is much large and would have serious Joule heating effect. The optical excitation power should be limited to avoid reducing the device lifetime or even damaging the device. The optical excitation power in our work is less limited due to the much larger exciting area because the thermal energy could be easily diffused. Since the bias electric field near the tip area and the optical excited area is almost the same (shown in Fig. 2), the THz radiation power in our work is higher due to the more optical excitation power.

5. CONCLUSION

In summary, we have studied the dipole photoconductive antenna's THz radiation performance correspond to the rectangular tips with different blend radii. As the blend radius are varied, we analysis both the bias electric field at the rectangular tips and the dipole antenna's emission efficiency. We find that all of them are decreased as the blend radius increased. Compared to the conventional dipole photoconductive antenna, the maximum THz radiation power from the dipole photoconductive antenna with blend radius is enhanced due to its increased maximum bias voltage. We have also given the optimum blend radius for the practical dipole photoconductive antenna design. Additionally, our method has better radiation performance than the previous work.

ACKNOWLEDGMENT

This work was supported by the postdoctoral Science Foundation of China (No. 20090461325, No. 201003690), the Natural Science Foundation of China (No. 10876007), the Fundamental Research Funds for the Central Universities (No. 103.1.2 E022050205).

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