A Folded Dipole Antenna for Terahertz Continuous-wave Power Enhancement

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Abstract

Folded dipole antennas are analyzed to increase the terahertz continuous-wave output power. The calculated input impedance of the folded dipole antenna was 3000 Ω. In order to verify the power increase of the proposed antenna, the antenna is fabricated and measured by using the liquid helium cooled silicon bolometer.

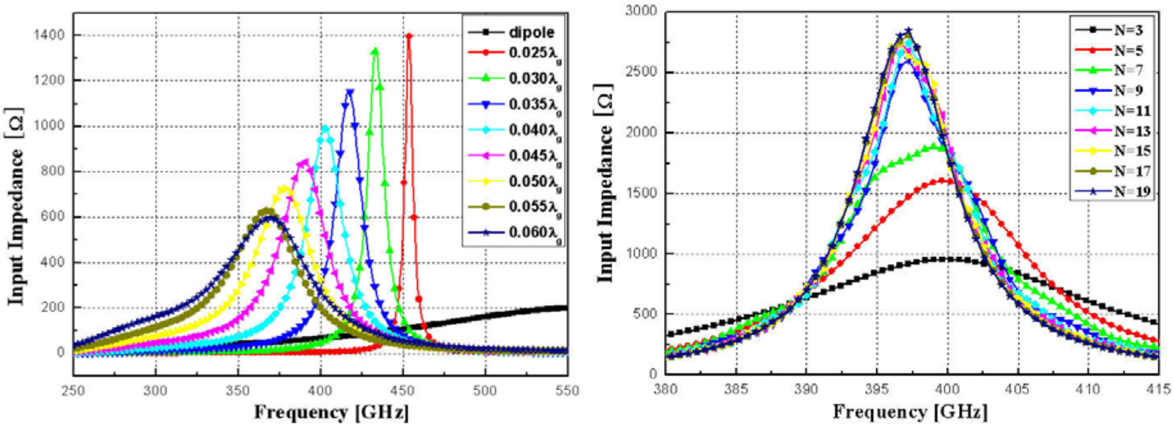
Keywords : CW Terahertz Photomixer Input Impedance Folded dipole antenna

1. Introduction

Photoconductive switches are widely used to generate terahertz (THz) transient waves by using voltage-biased photoconductors, such as low-temperature-grown (LTG) gallium arsenide (GaAs), and femtosecond (fs) laser pulses. Photomixer is alternative version to generate THz continuous-waves (CWs) by using the same voltage-biased photoconductors and two tunable laser diodes possessing slightly different frequencies. These THz CW generators offer the advantages of frequency selectivity and much higher frequency resolution that enable real-time measurements in the frequency domain [1~3]. Therefore, the integrated photomixer/antenna should be optimized to be used in the real applications. The most important optimizing factor of the integrated photomixer/antenna is to increase the output power. And the THz CW output power is proportional to the input impedance of the antenna. Improvement of the impedance matching by using a resonant antenna can increase the output power of an integrated photomxier/antenna [4]. In this paper, a resonant folded-dipole antenna was proposed to increase the input impedance of the antenna for the THz CW power enhancement.

2. Design of a folded dipole antenna

For the optimum design of the THz CW antenna, the input impedance of a folded dipole antenna is numerically calculated by electromagnetic simulation. There are several parameters to optimize for high impedance of a folded dipole antenna, such as width of line, length of line, distance between lines, and number of lines. The length of the folded dipole antenna line is chosen as $\lambda_g/2$(λ_g: guided wavelength) for the half wavelength dipole operation. The folded dipole antenna is calculated with varying the distance between lines from $0.025\lambda_g$ to $0.06\lambda_g$ and the number of lines. The GaAs substrate thickness was 350 μm and the electrode thickness was 150 nm. Figure 1 shows the input impedance of the folded dipole antennas having three lines with varying distance, and the impedance of the antennas having $0.04\lambda_g$ distance between lines with varying number of lines. The input impedance decreased from 1,400 Ω to 600 Ω as distance between lines increased from $0.025\lambda_g$ to $0.06\lambda_g$. The frequency of peak input impedance also decreased as distance increased. Even though input impedance characteristics of the folded dipole having the shortest distance between lines are suitable for the photomixers, the radiation pattern and stability of that antenna are not good and the bandwidth of that antenna is not enough to use. Thus the distance between lines is fixed at $0.04\lambda g$ in consideration of the radiation pattern, stability, frequency bandwidth, and operation frequency. The input impedance increased from 1,000 Ω to 3,000 Ω and the frequency of peak input impedance slightly decreased as the number of lines increased from three to nineteen. The folded dipole antennas having over thirteen lines have the similar input impedance. This small variation of the input impedance can reduce the side effect of the bias line.



(a) (b)

Figure 1. Input impedance of folded dipole antennas (a) having three lines with varying distance between lines from $0.025\lambda_g$ to $0.06\lambda_g$, (b) having $0.04\lambda_g$ distance between lines with varying number of lines

3. Results and Discussion

The photoconductive 1.5 μm thick LTG-GaAs layer was grown on 350 μm thick semi-insulating (SI)-GaAs (100) using a MBE system at the temperature of 275 ˚C for the integrated photomixer/antenna. The epi LTG-GaAs was annealed in situ at a temperature of 600 ˚C for 10 min in ambient As_4. The shape of the interdigitated capacitor (IDC) was used for the photomixer to increase the optical-to-electrical conversion efficiency. The gold electrode of the device was deposited to the thickness of 240 nm with a Ti adhesion layer of 40 nm thickness. The dimensions of the IDC are as follows: the total number of fingers = 2, the overlap length = 4.6 μm, the finger width = 0.3 μm, and the gap = 1.7 μm. The photograph of the integrated photomixer/antenna was shown in Fig.2. The bias line is directly connected to the farthest strip from the photomixer located in the center of antenna. The width of the photomixer was 6.3 μm, thus the width of the strip was fixed to the same width of the photomixer to connect the antenna with photomixer with no discontinuity. The spacing between the strips was 12 μm, and the length of the strip was 150 μm.

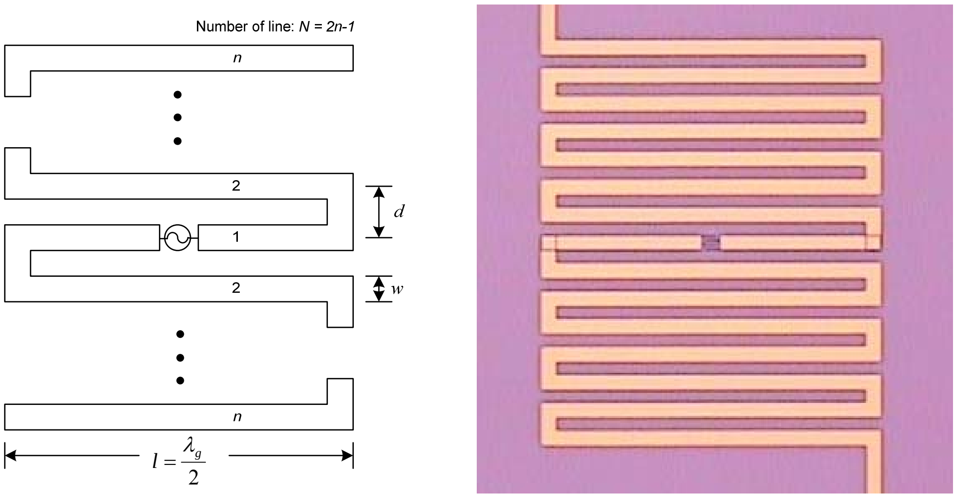
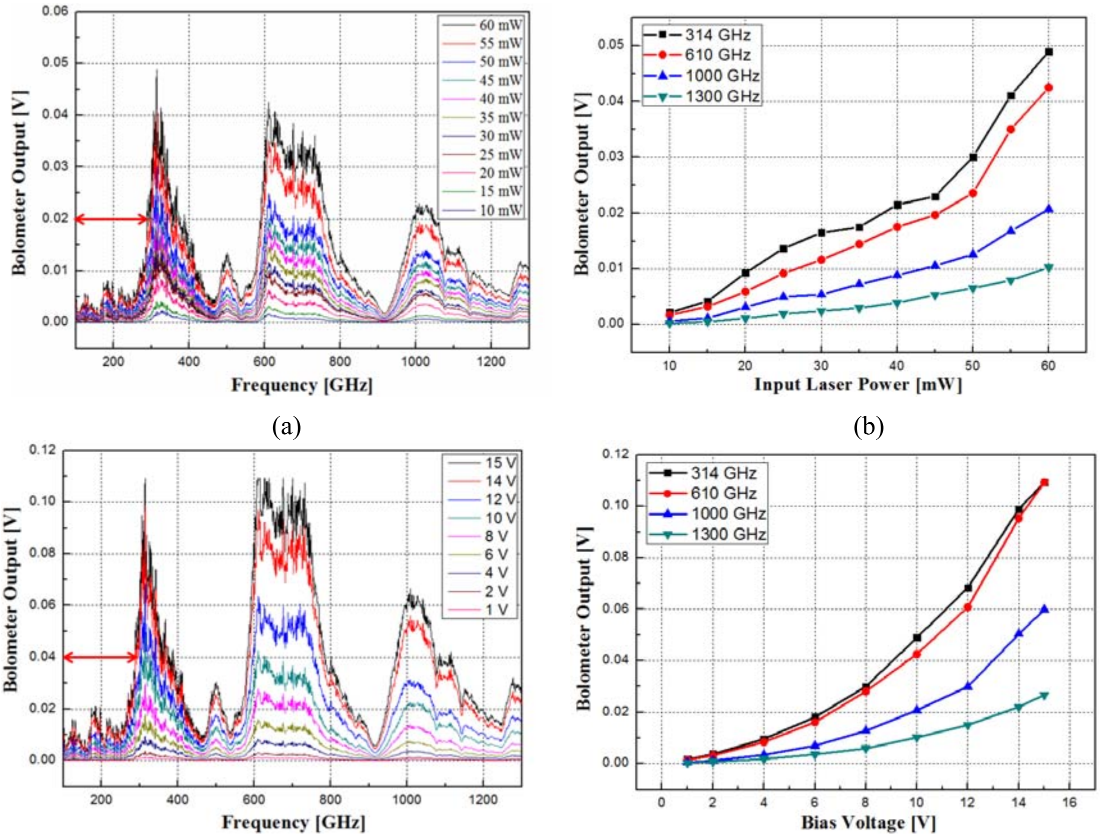


Fig.2. Schematic and photograph of the folded dipole antenna integrated with the photomixer



(a) (b)

(c) (d)

Fig.3. The measured bolometer output voltages (a) as a function of the scan frequency for the various incident laser powers (b) as a function of the input laser power at the specific frequencies (c) as a function of the scan frequency for the various bias voltages (d) as a function of the bias voltage at the specific frequencies

The folded dipole antenna integrated with the photomixer was measured by using silicon bolometer (IRLabs, USA) and the results were shown in Fig.3. The spectral range of the silicon bolometer is 300GHz ~ 18THz. The spectral characteristics of the bolometer near 300 GHz are not good because the bolometer is not calibrated. The designed folded dipole antenna is optimized at about 400GHz, where is the near edge of the spectral operation range of the bolometer. In order to measure the spectral characteristics of the antenna exactly near the optimized frequency, the bolometer working well from 100GHz to 2,000GHz, such as an Indium Antimonide (InSb) hot electron bolometer, should be used rather than silicon bolometer. The powers of the incident two lasers to excite the photoconductor are changed from 10mW to 60mW in the step of 5mW, and the two lasers are scanned from 100GHz to 1,300GHz in the step of 1GHz. The powers are stably controlled by using the feedback controller when the frequency is scanned under the conditions of various incident optical powers. The bias voltage is modulated at the 100Hz in the consideration of the bolometer frequency response and the lock-in detection, and the maximum and minimum voltages are 10V and 0V, respectively. The measured bolometer output voltages are shown in Fig.3(a) as a function of the scan frequency for the various incident laser powers. The measured power of the folded-dipole antenna reveals that the antenna has the resonant characteristics at the specific frequency bands. The three main peak bands generated near 300GHz, 700GHz and 1000GHz are closely related with the resonance or the impedance of our antenna. On the other hand, the measured data less than 300GHz are meaningless because the bolometer works above 300GHz. The estimated output power of the antenna less than 300GHz is higher than the power at the 300GHz. The detailed peaks of the THz waves generated by several incident optical powers in Fig.3(a) occur at the same frequencies, which means the frequency of the two lasers is identically controlled under the various scan conditions by using the feedback controller. Figure 3(b) shows the measured bolometer output voltages as a function of the input laser power at the specific frequencies. The frequencies are selected at 314GHz, 610GHz, 1,000GHz, and 1,300GHz based on the peak bands in the Fig.3(a). The generated power of the antenna increases as the incident optical power increases. The generated power could increase by increasing the incident optical power because the generated power is not saturated at the maximum incident power. And then, the THz power is measured as increasing the bias voltage. Figure 3(c) shows the measured bolometer output voltages as a function of the scan frequency for the various bias voltages. Maximum bias voltage applied to the photomixer varies from 1V to 15V. The measured power as a function of the bias voltage at the specific frequencies is shown in Fig.3(d). The incident laser power for the excitation of the photoconductor is set to 60mW and the modulation frequency of the bias is fixed at 100Hz. The peak bands of the measured THz CWs in Fig.3(c) occur at the same frequency with the Fig.3(a). The generated THz power increases as the engaged bias voltage increases. The output powers of the folded dipole antenna in the resonant frequencies are bigger than those of the broadband antenna in the frequencies. The design goal of the resonant antenna is to increase the output power at the resonant frequency by increasing the input resistance of the antenna. The simulation of the folded dipole antenna was focused on the frequency band around 400GHz. After the optimization of the input resistance around 400GHz, the resistance of the antenna increased to 2750Ω at 396Hz. However, the peak of the measured THz output power moved to lower frequency less than 300GHz out of the range in which the bolometer can measure. The ratio of the power enhancement by increasing the resistance was less than the expectations from the simulation. The bandwidth of the THz wave was broadened compared to the bandwidth of the input resistance of the simulated antenna. And the main peaks of the measured THz power occur close to the main peaks of the input resistance of the simulated antenna even though their absolute frequency position and the bandwidth are different each other. This difference of the exact frequency position and the bandwidth could be attributed to the radiation efficiency of the antenna and the interaction between the capacitance of the photomixer and the reactance of the antenna. Further researches about these factors causing the difference between simulated and measured results could enhance the THz output power of the resonant antenna.

4. Summary

Folded dipole antennas are analyzed to increase the terahertz (THz) continuous-wave (CW) output power. The calculated input impedance of the folded dipole antenna was about 3,000Ω. In order to verify the power increase of the proposed antenna, the antenna is fabricated by e-beam lithography and measured by the liquid helium cooled silicon bolometer. The measured power of the folded-dipole antenna reveals that the antenna has the resonant characteristics at the specific frequency bands. The ratio of the power enhancement by increasing the resistance was less than the expectations based on the simulation. This difference for the exact frequency position and the bandwidth could be attributed to the radiation efficiency of the antenna and the interaction between the capacitance of the photomixer and the reactance of the antenna. Further research about the factors causing the difference between simulation and measurement could enhance the THz CW output power of the resonant antenna.

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