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THz Waves Generated by Oxygen Implanted GaAs

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We report the THz wave (Pulse and CW mode) generated from antenna-type devices made by using oxygen implanted GaAs. Under Pulse mode, the output power is about 100μW (measured by Si Bolometer with lock-in amplifier). Under the CW mode, we take sampling in the range of 0.25 to 0.5 THz (focusing on 0.35THz range), Our results show that the Multi-implanted GaAs:O material is suitable for THz wave generation and can get relative high output power.

1. Introduction:

THz wave is the lightwave between microwave and infrared light. It has some advantages of microwave, such as the relative long wavelength and transparent to some materials. It also has some advantages of light, such as good directionality and high capacity for information. Recent decade, lots of funding were provide to investigate THz waves and its application in Fundamental Physics, Home Security, Biomedical, Astronomy and High Speed Communication areas. Normally, THz waves generation methods can be classified into two big branches. One is Pulse mode and the other is CW mode. For Pulse mode, the THz waves is generated by fs laser pumped semiconductor (LTG-GaAs [1], GaAs:As [2]) or nonlinear crystal (ZnTe). For CW mode, there are about more than three approaches, such as Quantum cascaded laser, Free carrier laser, BWO (Back Wave Oscillator) and Difference Frequency Generation on Semiconductor or nonlinear crystals (LTG–GaAs, PPLN).

As showed above, the semiconductor materials are very interesting materials which fit both generation modes. Among them, normally, the LTG-GaAs is largely used in the THz wave generation for its advantages, such as high dark resistance, short carrier lifetime, high mobility of carriers and high breakdown voltage. But one of its disadvantage is that, its characteristics will be some degree different between each two growth processes (not easy for making repeatable). So, some possible alternate method was studied by scientists, such as ion implanted semiconductors (GaAs:As, GaAs:H, GaAs:O). The ion implanted method can easily repeat the process parameters and make the products sameness from different grown time. Ion like As^+, H^+, N^+ are all been demonstrated on changing the characteristics of GaAs for THz waves generation purpose in some papers[2-5]. Recently, **Salem et al.** [6] introduce O+ ion as the dose to optimize the characteristics of GaAs substrate and generated THz wave from it. Normally, oxygen ion is looked as dust (not good

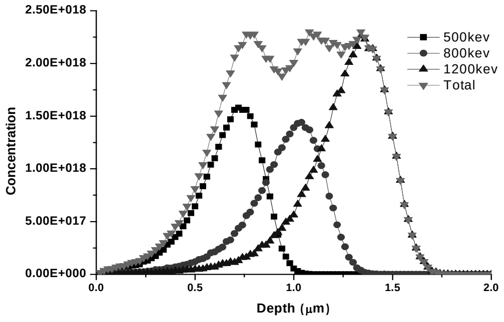

Figure 1. Ion distribution of Oxygen ion implanted GaAs

thing) for electrical devices fabrication during the process, as its existence should make the contacts be not Ohmic-contact. But, in this case (material for THz wave generation), it looks its advantages are more than its disadvantages. As the electrical level formed by oxygen ion in GaAs is close to Femi-level, it makes the oxygen ion implanted GaAs close to electrically neutral and has comparative high resistance.

In this paper, we used multi-implanted GaAs:O as the substrate and fabricated dipole antenna on it. The Fourier power spectra of our THz pulses show the most power of THz waves generated by this kind device is located in the range of 0.1-0.5THz. By adding 0.35THz band-pass filter, we can get about 8.3% of total power left. Under the CW mode (in 0.35THz range), the power of single frequency is in sub-mV range. From these experiments, the GaAs:O is further studied. They show that this kind of material really has some advantages for THz wave generation.

2. Material Preparing and Devices Fabrication:

For the case of oxygen ion implantation, to getting implantation depth close to the absorption depth of GaAs for 800nm light, RBS (Rutherford backscattering spectrometry) facility with 2MV tandem accelerator is utilized. Normally the absorption depth of GaAs for 800nm light is close to 1μm. To getting uniform ion distribution, multi-implantation is used to replace mono-implantation. Considering the cost of time for RBS facility, in this paper we try the highest implanted dosage as 1e14 for 1200kev. The other two energies and corresponding dosage are 800kev/6e13 and 500kev/6e13. The ion distribution (calculated) after implantation is showed in figure 1. The largest concentration of ion should be around 2.3e18.

We used commercial high-resistivity (>10^8 Ωcm), (110)-oriented, semi-insulating GaAs substrates as the start materials. After implantation process, we did the thermal annealing by RTA (Rapid Temperature Annealing) under N_2 gas environment and used a GaAs cap to prevent As ion desorption. In this paper, the parameter of RTA is 550℃ for 60s.

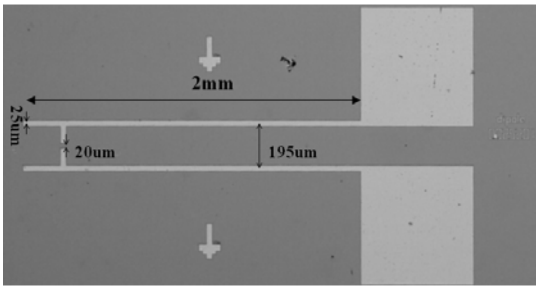

Figure 2. Structure of dipole antenna.

Figure 2 shows the structure of the dipole antenna. The gap of dipole antenna is 20μm and the width of stripline is 25μm. Two striplines are separated by 195μm, and their lengths are both 2mm. The electrode patterns were made using a conventional photolithography technique. The Ti (500Å)/Au (2000 Å) metallization is deposited on the substrate of GaAs:O by E-beam process.

3. Experiment setup and testing Results:

For THz wave generation by Pulse mode, the light source was a mode-locked Ti:sapphire laser (λ=0.8μm) which generates 130-fs optical pulses at a repetition rate of 82MHz. The pump beam was focused to the gap of dipole antenna. (The spot size will be smaller than 10μm.) For CW mode, A Heterodyne-Beating System composed of two 810nm laser diodes (VCSEL) was used for CW THz wave generation. In this paper, we measured generated sub-THz wave intensity in both Pulse and CW mode by using a liquid-helium-cooled Si bolometer. The generated THz spectrum of the device is measured by a Martin-Puplett-type Fourier Transform infrared Spectrometer (FTIR) System.[7]

Figure 3.(Insert Window) shows the output power of dipole antenna under Pulse generation mode. Under Gain=200 channel for Bolometer, the power of THz wave (in Pulse mode) is about 0.31V when the pump power and the dc bias are 35mW and 70V respectively. After optimizing the position of Si Bolometer and Parabolic mirror and let the most of power couple to Bolometer, the total power in that condition should be about 1V. (As showed in Figure 3. insert window, A 0.133V output power of THz wave for the condition of 15mW pump power and 40V bias after optimization, comparing the 0.0414V output power under the same condition before optimization. In other conditions, the ratio should be the same.)

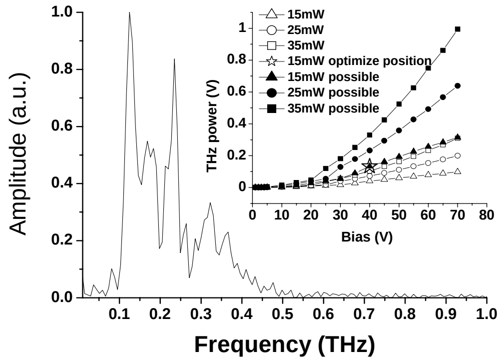

Figure 3. Spectrum of THz wave (In pulse mode) and its power vs dc bias (Insert window, Gain=200 channel for Si bolometer.)

Figure 3. shows the spectrum of Pulse mode generated THz wave measured by FTIR system. The mostly power are located in the range of 0.1-0.5THz. From the structure of dipole antenna, we can find the half-wavelength resonance frequency is about 0.18THz (f=c/2nL)[8], as the overall length of dipole antenna is 245um. So the measured spectrum agrees with the design of dipole antenna in some degree. We also measured the power of THz waves in the range of 0.3THz by adding the 0.3THz band-pass filter[9] before the Si bolometer, the total power of THz waves will decrease to 0.027V (Gain=200 channel for Si Bolometer.), close to 8.3% of the total output power.

After carefully calibrated by using a blackbody source, we can get the relationship between the output data of Si Bolometer and the common THz power in Watt unit, 1mV≅0.02μW under Gain=1000 for Si bolometer. Then from the figure 3.(insert window), we can know the possible power of this device is around 100μW. If considering the losses during the measurement, such as chopper lose, propagation lose, the output power of THz waves (Pulse mode) should be even higher.

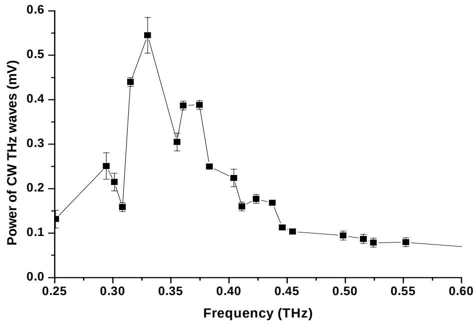

Figure 4. Power of CW THz wave. (Gain=1000 channel for Si bolometer)

As the 0.3THz range is more interesting to researchers than those lower frequencies. So we test the CW mode generation focusing in this range. By adjusting the difference between the wavelength (Δλ) of those two 800nm laser diodes, we generated corresponding CW THz wave from this dipole antenna which fabricated on GaAs:O substrate through difference frequency generation mechanism. We took sampling from 0.25THz to 0.6THz and get the relationship between the power of CW THz waves and the frequency (See Figure 4.). Comparing with Figure 3., in the range of 0.3THz, we can find their spectrum are well matched.

From Figure 5. we can clearly see that, under condition what we tested, the power of THz wave (either in Pulse or CW generation mode) is not saturation. This means the dipole antenna which fabricated on GaAs:O substrate has the potential to generate even higher power.

4. Conclusion:

THz wave have been measured from Oxygen ion implanted GaAs with dipole antenna device on it. Pulse and CW mode generation have both been tested. The results show this kind of material is suitable for THz wave generation and can get more than 100μW in pulse mode. Although the frequency is not higher enough, but it could be improved by optimizing the implant dosage[10] and annealing temperature, and adopting some antenna structures for high frequency purpose.

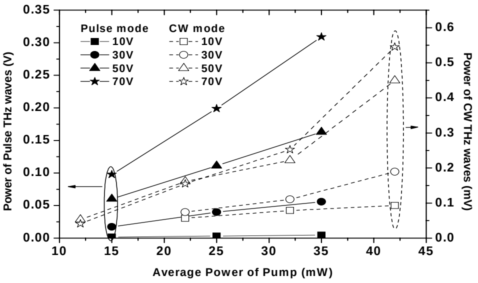

Figure 5. Power of THz wave vs Pump power. Pulse mode (solid lines) and CW mode (Dotted lines).

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