GENERATION OF CW-TERAHERTZ RADIATION USING A TWO-LONGITUDINAL-MODE LASER DIODE

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ABSTRACT

A coherent 163.5 GHz radiation has been generated by photomixing in a photoconductive antenna fabricated on the low-temperature-grown (LTG) GaAs film using a two-longitudinal-mode distributed Bragg reflector (DBR) laser diode (LD). The frequency of the emitted radiation corresponds to the difference frequency between the two modes of the excitation laser. We have found that the linewidth of the radiation is much narrower than that of the each laser mode. The narrowed linewidth is due to the common-mode rejection effect between the two modes oscillating in the

identical cavity. This property of the two-mode DBR laser, as well as the compactness and the ease for the optical alignment, make the device promising as an excitation laser source for the photomixing.

INTRODUCTION

For the high-resolution THz spectroscopy, a compact coherent cw-THz source is highly desired due to the restriction of the payload. Recently, the technique to generate coherent cw-THz radiation by using photomixing in low-temperature-grown (LTG) GaAs was exploited by several groups.[1,2,3] This technique enables to build a compact cw-THz source. For the photomixing, two independently tunable lasers were used, and by changing the difference frequency of the lasers, the oscillator frequency in a very wide range (0-5THz) could be tuned. However, the use of two lasers requires stabilization and the precise spatial mode matching of the two lasers. More optics and electrical components should be to the system added, thus, resulting in a larger system. A simultaneous two-frequency oscillation in the same laser cavity is a good alternative when we restrict ourselves to the fixed frequency sources. It simplifies the experimental set up and dose not require the elaborate optical alignment for the spatial mode matching. In addition, a narrowing of the radiation linewidth is expected from the common-mode rejection effect between the two modes, by which a large part of the frequency fluctuations of the two laser modes in the same cavity is canceled out and the beat frequency of the laser is stabilized.

In this paper we report generation of the coherent 163.5 GHz radiation by photomixing in low-temperature-grown GaAs using a two-longitudinal-mode distributed Bragg reflector (DBR) laser. We also confirm the narrowing of the oscillator linewidth due to the common-mode rejection effect from an interferometric measurement.

PRINCIPLE OF THE GENERATION OF CW-THz RADIATION

When two lasers with powers P_1 and P_2, and frequencies ν_1 and ν_2 are mixed, the power detected by a photoconductive device is given by

$$P(t) = P_0 + 2[\eta_m P_1 P_2]^{1/2}[\cos(2\pi(\nu_1 - \nu_2))t + \cos(2\pi(\nu_1 + \nu_2)t)] \qquad (1),$$

$P_0 = P_1 + P_2$ is the total power of the two lasers, η_m the mixing efficiency arising from the spatial overlap of the two laser beams. The η_m, ranging between 0 and 1, approaches unity when the beams have the same polarization and are completely spatially overlapped. Since material can not respond to the sum frequency ($\nu_1 + \nu_2$), the second term in Eq.(1) can be neglected. Thus, the photocurrent is modulated at the difference frequency of the two lasers, and the electromagnetic wave with the same frequency ($\nu_1 - \nu_2$) will be generated.

We used low-temperature-grown (LTG) GaAs as a photoconductive device material. This device, as compared to other semiconductors, has the short (sub-ps) photocarrier lifetime, the high photocarrier mobility ($200 cm^2V^{-1}s^{-1}$) and the high DC breakdown field larger than $5x10^5$V/cm. These properties satisfy the requirements for a THz photomixer. [4] Figure 1 shows the photomixer, which consist of a bow-tie antenna fabricated on the LTG-GaAs film. The radiation of the optical beat of the two laser modes illuminates the gap of the antenna biased with voltage V. The operation of such a device is described by an equivalent electric circuit shown in Fig.2. The capacitance across the antenna gap is expressed by C, which depends on the electrode geometry and the dielectric constant of the photoconductive material. A photoconductance is denoted by G (t), a function of the absorbed optical power. Z indicates antenna radiation impedance. The time-dependent conductance modulates the bias current (i) at the frequency $\nu = \nu_1 - \nu_2$ and thus delivers power to Z at the given frequency.

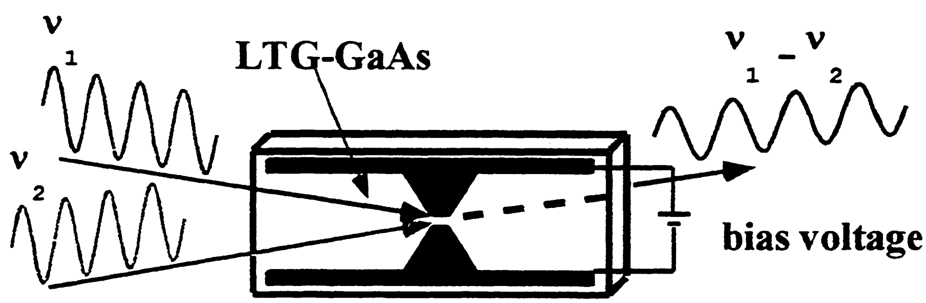

Fig.1. Schematic diagram of a photoconductive antenna device.

The power is found by solving the dynamic current equation for the circuit shown in Fig.2. From the Kirchoff current law, we write the time varying voltage v across the photoconductive gap as

$$\frac{dv}{dt} = \frac{V - v}{ZC} - \frac{v}{C} G(t) \qquad (2),$$

where $G(t) = G_0[1 + \sin(\omega t)/\sqrt{1 + (\omega\tau)^2}]$

is the conductance modulated at the

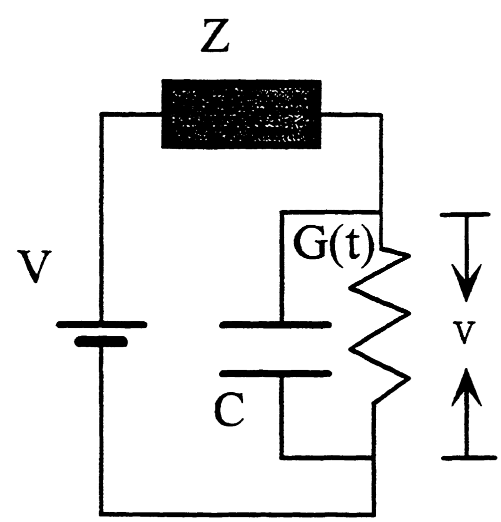

Fig.2. Equivalent circuit of the photoconductive antenna device.

frequency ω, and τ is the carrier lifetime. The power emitted from the antenna at frequency ν is written as [5]

$$P(\omega) \approx \frac{(G_o V)^2 Z/2}{[1+(2\pi\nu\tau)^2][1+(2\pi\nu Zc)^2]} \qquad (3).$$

$$(Z << 1/G_o(t))$$

From this equation we see that the output power is proportional to the square of the excitation bias voltage and laser power since G_o is proportional to P_o. If the impedance Z does not depend on the frequency, the carrier lifetime and capacitance of the gap limit the spectral bandwidth. That means if we want to generate the high power and wide band THz radiation, we should make a mixer with the carrier lifetime as short, and the capacitance of the antenna gap as small as possible.

TWO-LONGITUDINAL-MODE LASER DIODE

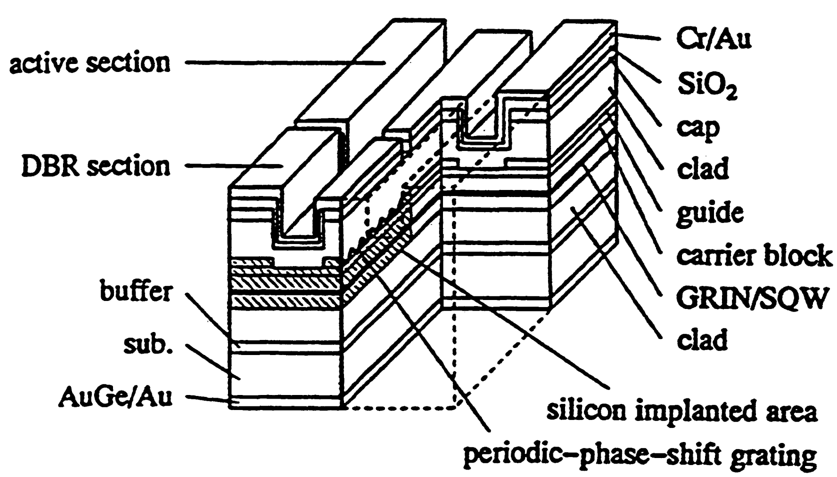

Fig.3. Schematic diagram of a two-longitudinal-mode DBR LD.

The grating in the DBR section has periodic phase shifts.

A simultaneous two-mode-oscillation DBR laser diode is a two-section DBR LD with a periodic-phase-shift grating adopted at DBR section.[6] The period of the grating and the interval of the phase shifts determine the center wavelength and the separation of the two modes, respectively. Figure 3 shows the structure of the two-mode DBR LD used in the experiment. Figure 4 shows the emission spectra of the two-mode LD. The diode power was about 10mW measured at 191mA bias current and at 19℃ by a double-monochromator with a resolution of 0.06cm^{-1} (1.8GHz). The difference of the center wavelength between the two modes was 0.39 nm (163.5 GHz). The full width at half maximum of the spectral width for each mode, estimated by a scanning Fabry-Perot interferometer with 50 MHz resolution, was 240 MHz as shown in Fig.5.

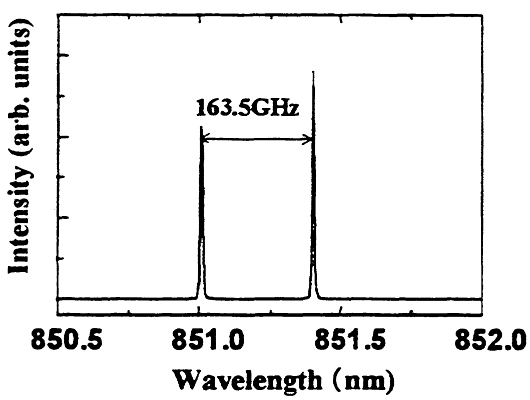

Fig.4. Emission spectrum of the LD.

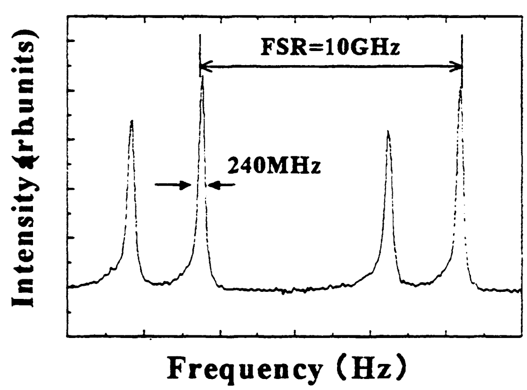

Fig.5. Spectral linewidth measured using a scanning Fabry-Perot interferometer.

EXPERIMENTS AND RESULTS

Figure 6 shows the experimental set-up to generate coherent cw-THz radiation using the two-mode DBR LD as an excitation source. The two-mode laser beam (15 mW) goes through an isolator and an optical chopper for lock-in detection. The beam was focused on a gap of the 1mm-long dipole antenna fabricated on the LTG-GaAs film. The radiation from the antenna was fed into a Martin-Puplett polarizing interferometer, which consisted of the two wire-grid polarizers with 45^0 polarization with respect to each other, a fixed mirror and a scanning mirror.

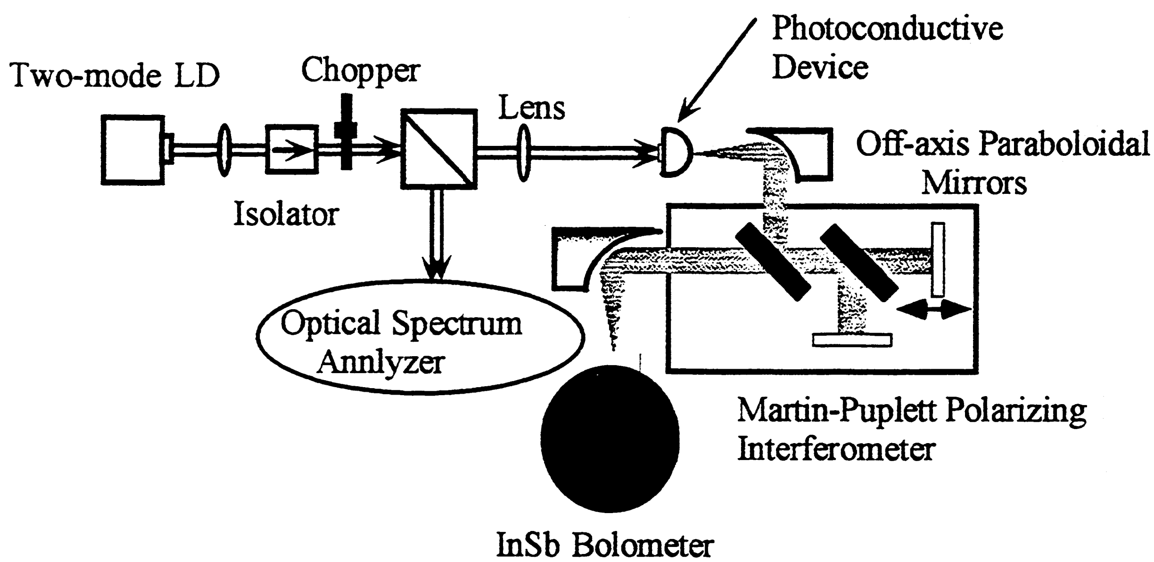

Fig.6. The experimental set-up to generate coherent cw-THz radiation and to measure the radiation properties.

The interference signal measured with an InSb hot-electron bolometer at 4.2 K is shown in Fig.7. The power of the radiation from the antenna is several nW. The conversion efficiency of this system is about 10^{-6}. The Fast Fourier Transform (FFT) of the interferogram is shown in Fig.8. The frequency of the main peak of the spectrum is 163.5GHz. The generation of radiation with the same frequency as the beat frequency of the two-mode LD (Fig.4) indicates that the radiation originates from the current modulated by the two-mode LD. The double and triple frequencies of the main peak also are observed shown in Fig.8. We suggest that the overtones may come from a nonlinearity of the antenna device.

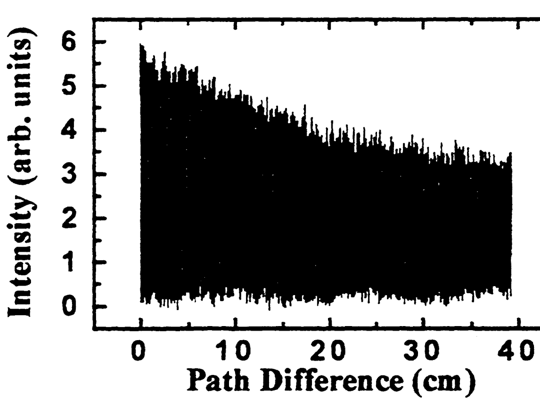

Fig.7. Interferogram of the radiation.

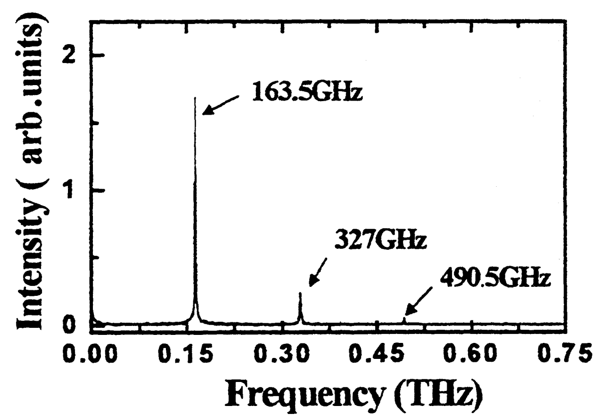

Fig.8. FFT spectrum of the interferogram

The scanning mirror of the interferometer could move only about 18 cm, limiting the spectral resolution to 0.8 GHz. Thus, we could not directly measure the coherence length of the radiation. However, from the decay of the interferometric component against the average detected power with increasing path difference, we can estimate the coherence length. First, we should subtract the average detected power from the interferogram shown in Fig.7 and then, fit to a damped cosinoidal function

$$I(t) = A\exp(-2x/l_0)\cos(\pi x \nu) \qquad (4).$$

Here, x is the path difference between the two arms, l_0 the coherence length of the radiation, ν and A the frequency of the interferogram and the interferogram intensity at $x = 0$, respectively. We estimated the coherence length of the radiation to be larger than 230 cm. This number means that the linewidth of the radiation is smaller than 130 MHz. The linewidth is 2 times narrower than that of each mode of the excitation laser. A large part of the frequency fluctuations of the two laser modes are canceled out and the beat frequency of the laser is more stable than that of the individual two-laser mode. This confirms the common-mode rejection effect of the two-mode oscillation in the same cavity.

SUMMARY

The coherent cw-THz radiation was generated by exciting photoconductive switch with a two-mode DBR LD. The linewidth of the radiation is narrower than that of the pump laser modes due to the common-mode rejection effect in the identical laser cavity. The system is more simple and compact than that with two individual lasers. Our results indicate that the two-longitudinal-mode diode laser is an excellent source for the generation of a stable THz wave by photomixing. We believe that by continuously changing the beat frequency of the two-mode laser in the same cavity tunable THz oscillations can be generated using the same technique as described in this paper.

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