Terahertz Beam Steering and Frequency Tuning by using Difference Frequency Mixing

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***Abstract*—Terahertz (THz) beam steering by using difference frequency mixing and phased array antenna principle was demonstrated. The THz radiation was generated by pumping with spatially dispersed beams produced from an ultrafast laser. And the THz beam could be steered by tilting one of the incident pump beams so as to change their relative phase relation. The steering range was 187 times as wide as the tilting angle. In addition, both the direction and the frequency of the THz beam were simultaneously and independently controlled. The frequency tuning was achieved from 0.3 to 1.7 THz.**

I. Introduction

Terahertz (THz) imaging holds a high potential for non-destructive inspection and other applications due to the property of THz radiation to pass through various materials. Conventionally, the THz images are acquired by moving the samples through the focused beam. The measurement speed is mainly limited by the speed of the mechanical devices. On the other hand, the quick scanning of the beam focus on the fixed sample will improve the measurement speed.

We propose the novel methods of the terahertz beam steering and the frequency tuning. The propagation direction of the THz radiation, which generated by difference frequency mixing, was changed by using the phased array antenna principle without any antenna array and phase shifters. And frequency tuning could be independently achieved by a simple method. This method can be utilized for not only the THz imaging, but also the beam tracking as adaptive antennas in THz wireless communications.

II. Principles

A spatially dispersed beam, with a linear distribution of frequencies, is produced from an ultrafast laser, for example using a diffraction grating. The beam is split in two equal parts and overlapped again with a relative spatial shift (Fig. 1). Note that the frequency difference between the pump beams is constant along the overlapping area. When a strip line photoconductive antenna is pumped with these beams (Fig. 2), narrow band THz radiation is generated from the entire overlapping area, even if the frequencies along strip-lines are not constant. Moreover, the frequency difference, and thus the THz wavelength, can be controlled by shifting one of the beams.

Furthermore, the phase difference between the two pump beams is continuously varied at each position on the device when one of the pump beams is tilted (Fig. 3). In the mixing process, the local phase of the THz radiation is identical to the local phase difference of two pump beams. The wave front of the THz radiation is, therefore, also tilted. This means that the THz beam can be steered by changing the incidence angle of

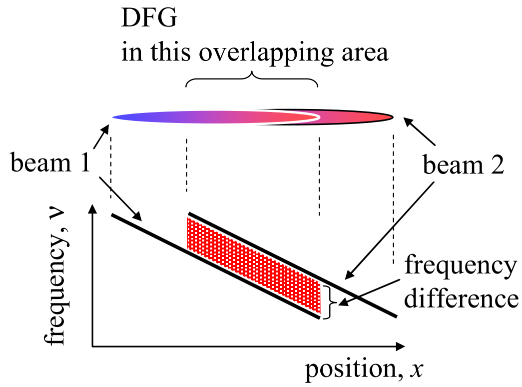

Fig. 1. Principle of generating narrow band THz radiation. Two spatially dispersed beams are produced from an ultrafast laser and are overlapped with a relative shift.

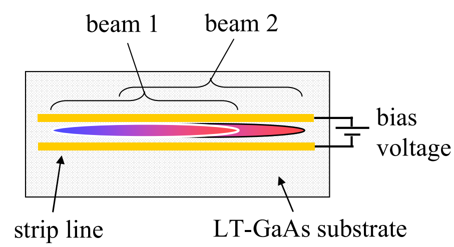

Fig. 2. Illumination of a strip-line photoconductive antenna with the spatially dispersed beams for difference frequency mixing.

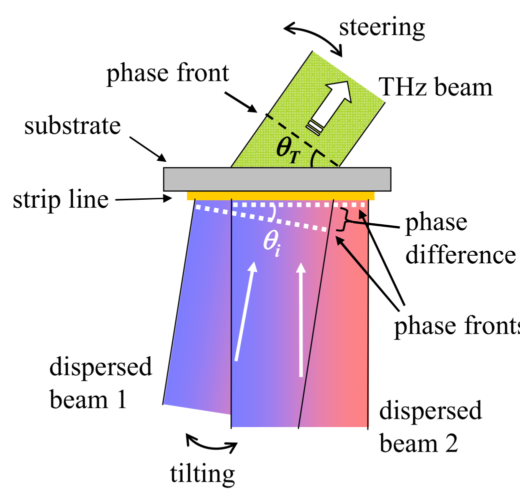

Fig. 3. Proposed method of THz beam steering. The phase front is tilted by changing the direction of one pump beam. This plays the same role as the phase shifters used in phased array antenna.

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one pump beam. In this case, the relation between the incidence angle (θ_i) of one pump beam and the THz radiation angle (θ_T) is derived by

$$\sin\theta_T = \frac{k_i}{k_T}\sin\theta_i \quad (1)$$

where k_i and k_T are the wave number of the pump beam and the THz radiation, respectively. Thus the THz beam can be steered within an angle several hundred times as wide as the tilting of the incident pump beam, the angular magnification being given by the ratio between the THz and pump wavelengths, when near infrared radiation is used as the pump beams [1].

III. Results

Fig. 4 shows a typical spatial distribution of the wavelength and the intensity of two pump beams for a radiation frequency of 0.7 THz. The shift between the beams is 2 mm. Two lines appear in the figure. The features of the distribution were close to the drawing in Fig. 1.

Fig. 5 shows the normalized THz beam patterns for different incidence angles of the adjustable pump beam measured by the knife-edge method. The horizontal axis indicates the angle of the direction from the strip line photoconductive antenna. The spots of the pump beams on the emitter were set for an output radiation frequency of 0.6 THz. We can see in Fig. 5 that the whole pattern of the THz radiation was shifted when the pump beam was tilted. The steering range of the THz beam was 29 degrees when the incident pump beam was tilted within a range of only 0.155 degrees, which represents an angular magnification factor of 187.

Fig. 6 shows how the spectra of the THz radiation depend on the shift between the two spatially dispersed beams; one of the pump beams is fixed while the other is shifted. The frequency of the THz radiation was found to be tunable from 0.31 to 1.69 THz. The average linewidth was 65 GHz.

IV. Discussions And Conclusions

Although in this experiment a manually rotated mirror was used for tilting the incidence of the pump beam, non-mechanical steering can also be achieved by a conventional electro-optic or acousto-optic deflector. The steering angle of the THz beam will be magnified, even if the deflection ranges of them are very small. This means that a high-speed and high-resolution imaging system could be realized using the beam steering technique described here. Furthermore, our method of using spatially dispersed beams allows us to utilize many components of the wavelengths compared to that of the pump laser used for the conventional difference frequency mixing.

In conclusion, we demonstrated the methods of THz beam steering and the frequency tuning based on the difference frequency mixing and the phased array antenna theory. The principles of the proposed methods were verified in this demonstration and these have possibility to improve the steering speed compared to the conventional mirror rotation. This method will contribute to the high-speed THz spectroscopic imaging system.

[1] D. Saeedkia, R. R. Mansour, and S. Safavi-Naeini, “Analysis and design of a coutinuous-wave terahertz photoconductive photomixer array source,” IEEE J. Ante. Prop **53**, 4044-4050 (2005)

[2] K. Maki, and C. Otani, “Terahertz beam steering and frequency tuning by using the spatial dispersion of ultrafast laser pulses,” Opt. Express **16**, 10158-10169 (2008)

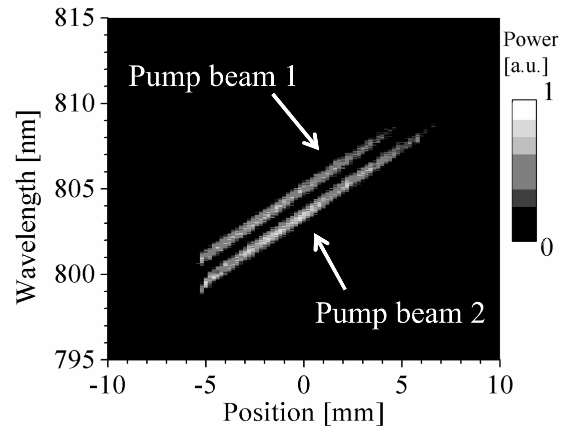

Fig. 4. The spectral distribution of the spatially dispersed beams for generation with a frequency of 0.7 THz measured with an optical spectrum analyzer.

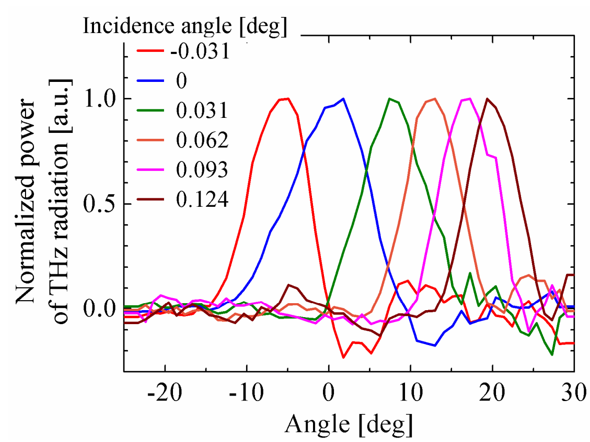

Fig. 5. Normalized THz beam patterns for different incidence angles of one pump beam. The spots of the pump beams on the emitter were set for an output radiation frequency of 0.6 THz.

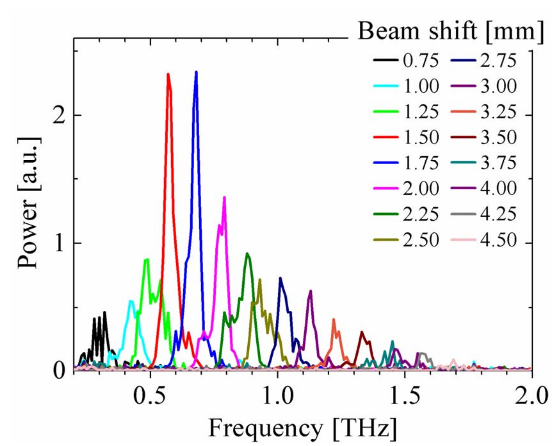

Fig. 6. Spectra of the THz radiation for different relative positions of the pump beams.