Probe beam-free detection of terahertz wave by electroluminescence induced by intense THz pulse

J. Shin¹, Z. Jin², Y. Nosaka¹, T. Nakazawa¹, and R. Kodama¹,²,³

¹ Graduate School of Engineering, Osaka University, 2-1, Yamadaoka, Suita, Osaka 565-0871, Japan
² Photon Pioneers Center, Osaka University, 2-1, Yamadaoka, Suita, Osaka 565-0871, Japan
³ Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita, Osaka 565-0871, Japan
E-mail: jhshin@ele.eng.osaka-u.ac.jp

Abstract. Recently, a table-top fs laser system can generate MW terahertz (THz) pulse with its electric field higher than 100 kV/cm can be generated by several schemes. Such a strong THz field can directly drive electrons inside various materials. Here, we demonstrated a direct THz electric field detection method by measuring the electroluminescence induced by intense THz pulse inside commonly available light emitting diode. An intense THz wave obtained by the two-color laser scheme was focused onto LED along with an external DC bias to induce luminescence which we found proportional to the amplitude of the incident THz field. The scheme can be useful to realize a low-cost, probe-free THz detection and imaging system.

1. Introduction

Since the diagnostics of temporal profile of terahertz (THz) wave was demonstrated [1, 2], THz radiation has gained attention from a broad range of engineering and research areas including security, biomedical imaging, material physics and etc [3, 4]. Those coherent methods, electro-optical sampling or photoconductive switching, measure coherent portion of THz radiation, providing phase information of THz waves. However, they are difficult to setup, because they require a probe beam and we need to align both the probe beam and the THz wave precisely so that they are synchronized and spatially overlapped. On the contrary, incoherent detectors, such as bolometer and Golay cell, do not require a probe beam, but provide only THz power from all heat (incoherent) sources as well as the coherent sources. For that reason, the incoherent detectors have lower signal-to-noise. Still, they are convenient to use.

With recent research efforts pursuing strong THz radiation sources, MW THz pulse with an electric field higher than 100 kV/cm can be obtained with a table-top fs laser system by several methods such as two-color laser scheme [5] and tilted-pulse-front scheme [6]. Such a strong THz field can directly drive the electrons in various materials such as nitrogen gas plasma [7] and quantum well semiconductor [8], and the effects have been observed through luminescence phenomena.

Here, we demonstrate a direct THz electric field detection method by measuring the electroluminescence (EL) induced by intense THz pulse inside common light emitting diode (LED), as illustrated in the Fig. 1. The scheme has the advantage of both the coherent and incoherent method; it can be classified under coherent method, but does not require a probe beam to operate. Because it makes use of the conventional LED technology, it may be useful for realizing a low-cost, probe-beam-free THz detection and imaging system.
2. Experiments

Figure 2a shows the setup of experiments performed using the P-cube laser facility at the Graduate School of Engineering, Osaka University. It was adjusted to deliver 30 mJ of energy in ~100 fs long pulse with its spectrum centered on 800 nm. It was negatively chirped for optimal generation of THz wave. The laser was focused into ambient air by an f/20 lens. A 100-µm thick β-barium borate (BBO) crystal behind the focal lens generated the second harmonic (2ω) pulse by the type-I second harmonic generation from the fundamental laser pulse (ω). A polymer filter was put to allow transmit only the THz wave generated from the plasma channel, while blocking the residual ω and 2ω pulses. The THz pulse was then focused by an off-axis parabola (OAP) onto the LED chip at an incident angle of 45 degree. A GaAlAs LED manufactured by Toshiba (Model No. TLN1108) was used in our experiments, which emits near-infrared light with its central wavelength at 870 nm. The emitted luminescence is collected to a gated intensified CCD camera. To reduce the noise, the CCD gate was opened 5 ns before the arrival of the THz wave and closed after 50 ns. The entire LED emission measurement system is carefully enclosed and sealed in a black box with a long-pass THz filter window to ensure that no scattering light from the laser and plasma channel can arrive at the camera. The function generator DG535 (Stanford Research Systems, Inc.) provided the supporting DC bias (discussed in the Appx.) for the LED and the synchronized trigger signal for the CCD gate.

The generated THz wave had a single-cycle profile with a period of 1 ps, as shown in Fig. 2b, which is measured by a single-shot THz time-domain spectroscopy using a pair of reflective echelon [9]. The maximum THz energy of about 5 µJ was measured with our calibrated Golay Cell, corresponding to an electric field of ~0.77 MV/cm at the focal spot.

Fig. 3 shows the typical LED emission enhancement patterns with different supporting DC bias. 

![Diagram](image_url)

**Figure 1.** Electroluminescence driven by THz field.

![Diagram](image_url)

**Figure 2.** (a) Experimental setup. (b) THz waveforms measured by a single-shot time-domain spectroscopy method with different time delays of probe beam.
voltages of 3.78 V, 5.61 V and 5.81 V, with insets showing the CCD images of the LED chip after subtracting the image without incident THz pulse as the background. When the bias is lower than 3.78 V, the EL induced by THz field is too weak so that the counts on CCD are close to the noise level. Fig. 4 shows that different peak amplitude of the incident THz pulse changes the amount of EL enhancement proportionally. It is also clear that the EL enhancement becomes larger with higher bias voltages, which is consistent with the measurements using ns pulses as shown in the Appendix.

**3. Conclusion**

We showed that a direct THz electric field detection is possible by measuring the EL induced by THz pulses inside commercially available LED. This method is coherent with its signal sensitive to the electric field of the THz wave, but has an advantage over other coherent methods that it does not require a probe beam. Because our results rely upon the well-established LED technology, it may be useful for realizing a low-cost, probe-beam-free THz imaging system.

**Appendix**

The response of commercially available LEDs for electric signals shorter than ~ ns are not well investigated. Since the THz pulse from two-color scheme usually has a single-cycle waveform with a duration of ps level, it is necessary to investigate the LED’s response to a short voltage pulse. We used DG535, a digital pulse generator to apply drive pulses with various time durations from µs to 5 ns to the LED chip. The emission of the LED is collected and measured by a 16 bit CCD camera. Fig. A1 shows the response of the LED. If the pulse duration is longer than 200 ns the response is linear regardless of
the support bias. With shorter drive pulses, the emission intensity drops non-linearly and reaches to the noise level as the pulse duration becomes shorter than 25 ns which is comparable to the typical rise and fall time (15 ns) of this LED.

Figure A1. Pulse response of the LED. The black solid line shows a linear relation between the emission intensity and pulse duration. The red circles, blue triangles, and green squares show the measured results with an supporting DC bias of 0 V, 0.57 V and 1.48 V, respectively.

The pulse duration limit, however, can be overcome by applying a supporting DC bias, as indicated in the inset of Fig. A1. The effect of the pulse voltage is investigated by comparing the difference between the emission intensity with and without the drive pulse. The pulse response gets more close to linear decrease (black solid line) with the support of the bias.

It is noted that 5 ns, which is the limit of our pulse generator, is still much longer than the THz pulse duration. However, this measurement suggests that the EL induced by short THz pulses can be detected with a sufficient supporting bias.

References
[1] Zhang X C, Jin Y and Ma X F 1992 Applied Physics Letters 61 2764
[2] Auston D H, Cheung K P and Smith P R 1984 Applied Physics Letters 45 284
[3] Tonouchi M 2007 Nature Photonics 1 97–105
[4] Ferguson B and Zhang X C 2002 Nature materials 1 26–33
[5] Kim K Y, Taylor A J, Glownia J H and Rodriguez G 2008 Nature Photonics 2 605–609
[6] Hebling J, Yeh K L, Hoffmann M C, Bartal B and Nelson K A 2008 Journal of the Optical Society of America B 25 B6
[7] Liu J, Dai J, Chin S L and Zhang X C 2010 Nature Photonics 4 627–631
[8] Hirori H, Shinokita K, Shirai M, Tani S, Kadoya Y and Tanaka K 2011 Nature communications 2 594
[9] Kim K Y, Yellampalle B, Taylor A J, Rodriguez G and Glownia J H 2007 Optics letters 32 1968–70