Terahertz Signal Generation Measurements in Photoconductive Antennas using Time Domain Spectroscopy System

Jose Santos and Magda El-Shenawee
Department of Electrical Engineering
University of Arkansas
Fayetteville, AR, United States
jisantos@uark.edu, magda@uark.edu

***Abstract*—This paper presents the signal generation measurements of LT-GaAs photoconductive antenna (PCA) emitters. These measurements were developed in an open-bench time-domain spectroscopy (TDS) system. The main challenges presented here are associated with the alignment of the PCA devices and the location of the terahertz (THz) pulse with respect to the optical delay in the system. The position of the slow delay line was crucial for the location of the THz pulse, which helped in the correct alignment process of the emitter and detector devices.**

Keywords—terahertz measurements; photoconductive antenna.

I. Introduction

Photoconductive antennas (PCAs) are optoelectronic devices used to produce time-domain pulses that carry terahertz (THz) frequencies in their spectrum [1]. The goal of the research is to correctly align PCAs emitters to the optical signal, therefore, it is extremely important to measure their signal generation performance accurately. Some researchers use ZnTe crystals as detectors through electro-optic sampling, but the received signal bandwidth may be limited by the spectrum of the crystal as observed in [2]. The time-domain spectroscopy (TDS) system used in this work is based on LT-GaAs PCA detector, which provides a broader bandwidth. The bandwidth of the detector depends on the antenna geometry and the semiconductor material properties. Therefore, the goal of this paper is to present some of the challenges that were faced during measurements with this TDS system, and the solution that allowed the characterization of PCA emitters.

II. Methodology

The terahertz measurement presented in this work were obtained using the TeraAlign System at the University of Arkansas. This system was developed by TeraView Ltd. (Cambridge, UK). The TeraAlign System is an open-bench TDS system that allows the characterization of PCAs as both emitter and detectors (see Fig. 1). The first measurements obtained with the TeraAlign system were published in [3]. TeraAlign consists of four parts: the optical and terahertz part, and the software and electrical parts. The optical part is composed of the femtosecond laser source and several optical components and delays to provide the excitation to both the emitter and the detectors. The wavelength of the laser in this system is 780 nm and 1560 nm with a pulse width of 100 fs, a repetition rate of 100 MHz, and an output power of ~ 80 mW. All measurements in this paper were based on 780 BM of the femtosecond laser. In Fig. 1, the GVD stands for group velocity compensator, and it helps to accommodate any distortion to the femtosecond pulse width that may occur in the path of the beam. The optical part of the system possesses three delay lines with one in the emitter side (green laser path), and two in the detector side (dashed-blue laser path). The optical part of the system ends with one fiber port at the emitter and another one at the detector. Fiber optic cables are used to drive the laser beam to the terahertz part, where the device mounting, and alignment occurs.

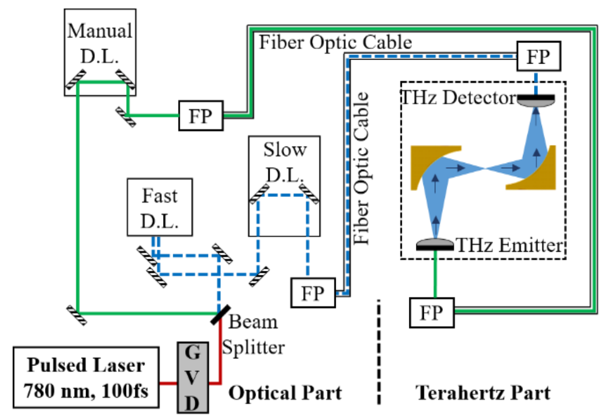

Fig. 1. Diagram of the TeraAlign system. D.L. stands for Delay Line, and FP stands for Fiber Port [3].

The other two parts of the TeraAlign system are the software and electrical part. The software part consists of two programs with the names TestPanel and TeraPulse [4]. The TestPanel software is used to control all the settings of the system such as emitter bias voltage and delay lines offset. The TeraPulse software is used to perform all the measurements and data acquisition from the system. The electrical part is responsible for the power supply for all the electrical components in the system including the fast and slow delay lines, and emitter bias voltage. The electrical part of the system also works as interface between the devices and the software for the data acquisition of the measurements.

This work was sponsored by the National Science Foundation (NSF) Award # 1948255.

III. Results

The first challenge in the terahertz measurements is the alignment of the PCAs with the optical signal (NiR). The PCA devices used in this work are based on LT-GaAs. They are mounted in two precise movable stages that provide the movement of the devices in the x-, y-, and z-directions. The top movable stage is used to move a NiR lens to focus the optical excitation to the gap of each device. Then, the bottom stage is used to align the THz pulse to the gap of the detector. This is performed with both the emitter and detector stages. To overcome the first challenge, we use a beam splitter to produce the reflected image of the device and align the laser to the gap by looking at the image with a NiR viewer. In addition, a good alignment of the laser beam to the gap of the devices eases the THz alignment of the devices.

Another important challenge in the measurement of PCAs in a TDS system is the location of the terahertz pulse in time. By recalling the mechanism of a PCA-based TDS system, both the femtosecond laser pump and the THz pulse should arrive at detector at the same time. In this way, the laser excitation generates carriers in the semiconductor, and the THz pulse induces an electric field across the gap simultaneously. As such the electric field drives the carriers in the semiconductor towards the electrodes producing the THz transient current [1]. To achieve this, the optical path of the laser excitation for the emitter and the detector side should be the same with reference at the detector device. This is achieved with the manual and the slow delay lines (See Fig. 1). The manual delay line accommodates for any difference in the path of the beam, and the slow delay line is used to scan the THz pulse in time by automatically move its position. The movement of the slow delay line is controlled by the software part of the system. Finally, the fast delay line provides sufficient delay (~ 45 ps) for the data acquisition of the pulse. The challenge emerges at the initial setup of the system when the devices are not aligned yet. Therefore, the THz pulse may fall out of the range of the fast delay line measurement. To solve this issue, the TestPanel software offers a measurement that allows the movement of the slow delay line over its complete range of movement. In this way, the user can locate the THz pule. This scan is shown in Fig. 2, where Fig. 2(a) shows the complete scanning rage for the slow delay line, which is ~ 800 ps (-339 to 461 ps). Then, this measurement can be used to locate the THz pulse, which is the first pulse that appears out of the noise level. Fig. 2(b) shows the zoomed-in version of the dashed black square in Fig. 2(a). From this plot, the offset of the slow delay line can be adjusted for the THz measurements with the fast delay line.

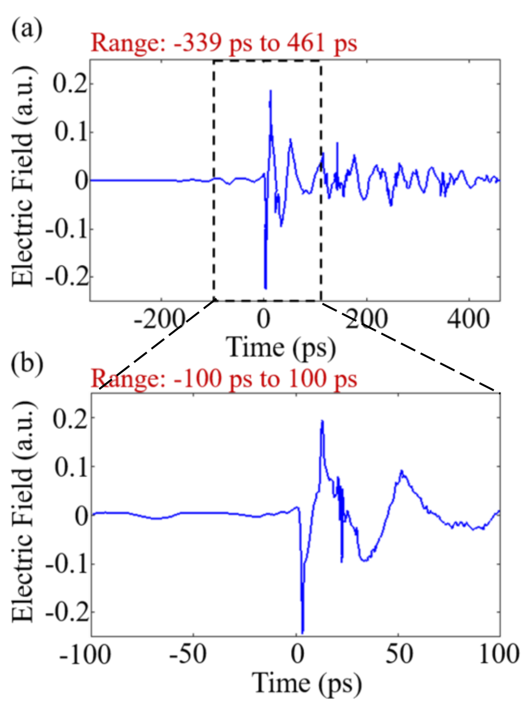

Fig. 2. Slow Delay Line Measurements. (a) Complete range provided by the slow delay line, (b) Scanning range focused around the first THz pulse.

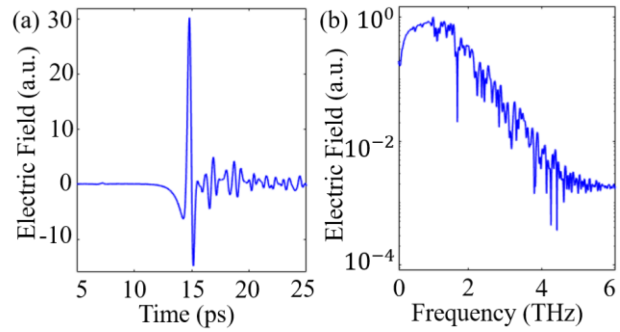

Fig. 3. TeraAlign System Measurements (a) Time-domain THz pulse. (b) Spectrum of the pulse in (a).

Once the laser excitation is aligned to the gap of the devices, and the devices are aligned together, a signal is detected as shown in Fig 3(a). This signal shows the PCA performance after the alignment of the devices with amplitude of ~ 30 a.u. (arbitrary units). This signal represents an optimum performance for the LT-GaAs emitter. Fig. 3(b) shows the spectrum of the THz pulse in Fig. 3(a) where the bandwidth of the emitter used in this experiment is ~ 4 THz regarding the system noise floor.

IV. Conclusion

This work presented some of the challenges that were faced during the terahertz experimental measurements of PCA LT-GaAs devices in an open-bench TDS system. The temporal location of the THz pulse represented a major challenge in the initial alignment of the devices, which was solved by using the slow delay line to scan the pulse along the rage of the delay line. This process contributed to the THz alignment of the devices, which was also another of the challenges faced in the experiment.

References

[1] N. Burford and M. El-Shenawee, "Review of terahertz photoconductive antenna technology," *Optical Engineering* , vol. 56, no. 1, 2017.

[2] W. Berry, M. R. Hashemi and M. Jarahi, "Generation of high power pulsed terahertz radiation using a plasmonic photoconductive emitter

array with logarithmic spiral antennas," *Applied Physics Letters,* vol. 104, no. 8, 2014.

[3] J. Santos Batista, H. O. H. Churchill and M. El-Shenawee, "Black phosphorus photoconductive terahertz antenna: 3D modeling and experimental reference comparison," *Journal of the Optical Society of America B,* vol. 38, no. 4, pp. 1367-1379, 2021.

[4] T. Ltd., "TeraPulse 4000 - User Guide," Cambridge, 2019.