Fabrication and Measurement of LT-GaAs Photoconductive THz Broadband Antennas

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Abstract—**This paper presents fabrication and experimental measurements of broadband terahertz (THz) photoconductive antennas (PCAs), based on the conventional low temperature gallium arsenide (LT-GaAs) material. Various antenna electrode geometries, that were previously designed through computer simulations, are fabricated using the electron beam lithography (EBL). The generated time domain pulse is measured using a time domain spectroscopy system (TDS). The bandwidth of each emitting device is obtained using the fast Fourier transform of the generated electric field pulse.**

I. Introduction

THz generation utilizing photoconductive antennas (PCAs) has seen significant growth in recent years. Many industries, such as cancer detection, pharmaceuticals, spectroscopy, and communication have use for THz PCAs, motivating further investigation into this topic [1].

Generating THz emissions using PCAs is realized through the use of a femtosecond laser pulse with pulse width less than 100 fs incident in the antenna gap. This excited photocarriers in the LT-GaAs substrate are accelerated using an applied bias voltage to the metallic electrodes.

There are important characteristics of the semiconductor substrate used in the fabrication of THz PCAs to consider. The well-established sub-picosecond carrier lifetime and the high mobility of the LT-GaAs make it an ideal material for use in THz -PCAs [2].

The fabrication method used for all PCAs in this work is the electron beam lithography (EBL). This technique is utilized to allow for rapid design changes and multiple rounds of fabrication without the prerequisite of having a unique photomask manufactured for each change, as would be the case if traditional photolithography was used.

II. Design and Fabrication

Each device included in this paper was designed through a model within COMSOL Multiphysics to simulate the effect of different electrode geometries on the resulting THz signal amplitude and bandwidth. The modeling work was performed and is detailed in [3], [4]. The results of the measured antennas will be compared to that of the simulated devices in this work.

After modeling and simulating, the antenna geometries are exported as CAD files to be used in the EBL fabrication, which begins with the growth of a wafer. Two different wafer growth are being investigated. The difference between the two wafers lies in their growth temperatures and the substrate and active layer thickness. These parameters contribute to the resulting mobility and carrier lifetime of the LT-GaAs layer, and therefore the performance of the devices fabricated here. The wafer details for each growth can be seen in table 1.

Table I. Wafer Growth Parameters.

LT-GaAs Wafer Growth Parameters		
Parameter	***Wafer 1***	***Wafer 2***
GaAs Substrate Thickness	500 µm	350 µm
LT-GaAs Layer Thickness	500 nm	250 nm
Growth Temp.	258°C	250°C
Annealing Time/Temp.	10 min. / 590°C	10 min. / 525°C

After growth, the wafer is sectioned in samples that each hold a single device. The samples are cleaned of any contaminates via consecutive baths in acetone and isopropyl alcohol (IPA), both done in an ultrasonic bath. Poly(methyl methacrylate) (PMMA) is spin coated onto the samples, then baked at 180°C for 4 minutes. Now prepared, a single sample is loaded into the EBL machine to be patterned with the CAD model created during modeling. Once patterned, the sample is developed by bathing in methyl isobutyl ketone (MIBK) for 60 seconds before metalizing. Thermal evaporation is utilized to metalize the electrodes, depositing 5/100 nm of Cr/Au respectively. Standard lift off procedure in acetone is followed to complete the device [5].

In order to measure the antenna performance, it is mounted in a leadless chip carrier and wire bonded using 1 mil Al bonding thread to establish connections between the carrier and device.

III. Measurments

The THz signal of each device is measured through use of a time-domain spectroscopy (TDS) system manufactured by TeraView in the UK. The TDS system uses a single femtosecond laser from Menlo Systems with optical pump power of ~86 mW. The beam is split into two paths, one for emitter, one for detector. Due to different distances of the two optical paths, delay lines are utilized to ensure the laser pulse meets the emitter and detector at the same time. The incident laser power measured at the emitter is 6 mW, while the detector is pumped at 5 mW. The bias voltage applied to the electrodes of the emitter is 63 V. The laser power and bias voltage are not critical, but through experimentation, the mentioned values have produced the most consistent results.

The devices are mounted in the TDS system and the laser is initially aligned and focused by sight to the electrode gap. Then, a motorized delay line sweeps its entire range (-339 ps to 461 ps) to locate the THz pulse in time. Once located, a galvanometer oscillates a prism that creates an approximately ~40 ps window to view the THz pulse as in figure 1.

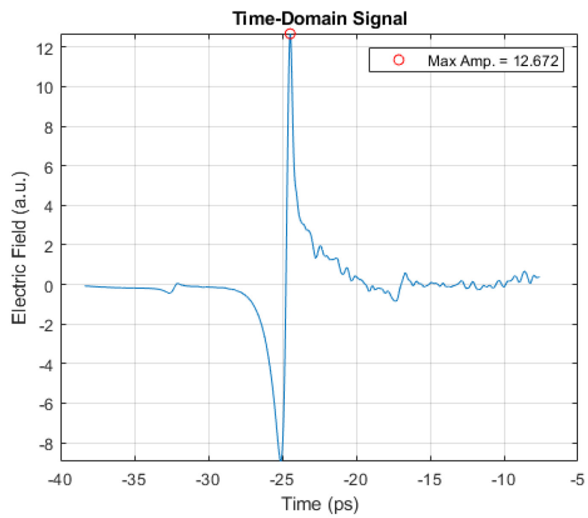

Figure 1. Time-domain signal of THz PCA with bowtie electrodes

Further alignment of the laser spot to the electrode gap is done by viewing the live THz pulse while moving the incident location via manually operated alignment stages that hold the THz PCA. Once optical alignment is complete, alignment of the emitted THz beam must happen, this includes the use of pinholes, inserted between the emitter and detector to ensure the signal is centered. The pinholes also aid alignment by cutting out low frequency components of the signal, allowing for precise alignment of only the THz frequencies.

After the emitter is completely aligned, data can be gathered form the TDS system. This includes time-domain plots of the THz pulse, as well as the spectrum, obtained by taking the fast Fourier transform of the time-domain data. One challenge faced during this work is removing the low frequency components from the THz emission. Ideally, the signal obtained from the fabricated emitters should be a broadband (up to ~5 THz) signal with little low frequency components according to the COMSOL simulations. However, in all measurements, more than expected level of low frequency components are detected alongside the THz signal, creating a bit different pulse shape,

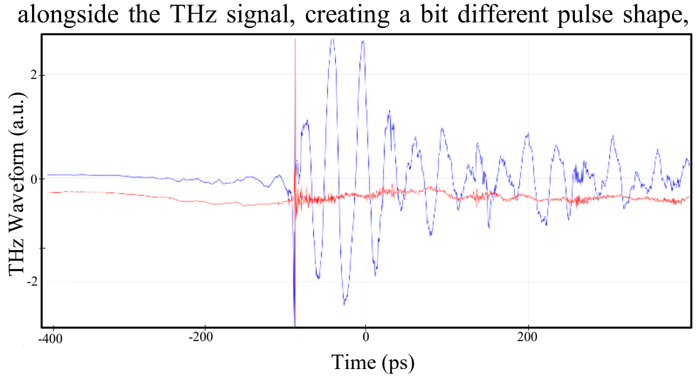

Figure 2. Superimposed slowscans using 1mm pinhole (red) and in air (blue)

This can be emphasized when viewing two overlaid slowscans, one utilizing a pinhole while scanning (red trace), and the other scanning in air (blue trace). The large blue oscillations after the initial ultrashort THz pulse are due to unwanted low frequency components within the signal. However, when scanned with the pinhole in the TDS system, the process cleans the signal of almost all low frequency components.

IV. Conclusion and Future Work

The fabrication and measurement of THz PCAs in this work show successful THz pulses, even with the unwanted low-frequency components. The presented results utilize a single electrode geometry (bowtie) from the model work in [3]. The electrode shape plays a large role in the bandwidth of the PCA, as shown in the modeling work [3]. Therefore, more electrode designs will be fabricated and tested in an identical manor to the bowtie emitter covered here. The electrode shapes will follow those modeled in [3]. The bandwidth results of the various fabricated geometries will be compared with the modeling results.

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