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Improving the Efficiency of LT-GaAs Photoconductive Arrays on Optically Transparent Substrates for High Field THz Generation

C. Kidd[1], M. Rosamond[1], L. Chen[1], T. B. Gill[1], L.H. Li[1], E. H. Linfield[1], A. G. Davies[1] and J. R. Freeman[1]
[1]School of Electronic and Electrical Engineering, University of Leeds, LS2 9JT, UK

***Abstract*—An improved electrode geometry is developed for LT-GaAs photoconductive antenna arrays fabricated on transparent sapphire substrates to generate high field THz radiation. These improved geometries target more efficient field generation through supporting high biases, higher filling factors and supporting higher transient photocurrents. Each modification to electrode design is characterised for its effect on THz field generation.**

I. INTRODUCTION

Photoconductive Antenna Arrays (PCAs) have been shown to be a promising source of Terahertz (THz) radiation for generating high field THz pulses from amplified laser systems [1-4]. With the increased availability and popularity of chirped-pulse amplified and post compression laser systems, the ability to produce high-energy, ultrashort-laser pulses is more accessible . PCAs have several appealing features when used to generate high field pulses compared to nonlinear optical methods which are also frequently employed. They do not require phase matching and are used in a collinear geometry; PCAs also typically have greater efficiency than other forms of THz generation based on non-linear optics [5]. This greater efficiency is due to the fact that PCAs are not governed by the Manley Rowe limit [6]. However, the efficiency of these devices is still limited due to their ultrafast switching operation, as it can be seen from [7] that as devices scale in size, there is not a proportional scaling of the generated THz radiation. Currently there is no definitive reason for this observation. Attempts have been made to improve the efficiency of these devices at suspected areas causing reduced operation. A major improvement of efficiency was made by removing the LT-GaAs from the SI-GaAs bulk substrate and bonding it to an insulating substrate instead [1]. This produces a number of advantages compared to using the SI-GaAs substrate: (1) The parasitic current channel within the SI-GaAs is removed, reducing excessive heating and associated reduction in efficiency; (2) The transparent substrate allows for the optical excitation, rather than the generated pulse to travel through the substrate, thereby avoiding absorption and dispersion in the THz pulse; and (3) When used for arrays, there is no need to mask alternate gaps from the optical excitation.

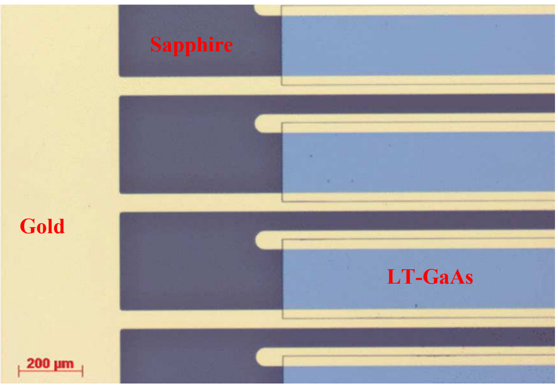

Fig. 1, Optical microscope image of THz LT-GaAs on quartz array structure with 200-µm-wide and 10-mm-long PC gaps from [2].

In this work we focus on improving the emitted field from these devices by optimizing the geometry of the metal electrodes. The aim of these modifications is to allow high biases, higher filling factors and support higher transient photocurrents.

II. IMPROVED ELECTRODE DESIGN

The main failure mode of the array devices as the applied bias is increased is where the electrode runs between the LT-GaAs strip and the contact pad. This is attributed to the amount of current that the electrode can carry and this 'bottle neck' causes the electrode to fail at this point (see fig.2). By implementing a triangular geometry of the electrodes, where the width increases as the electrode approaches the 'bottle neck' point, it is

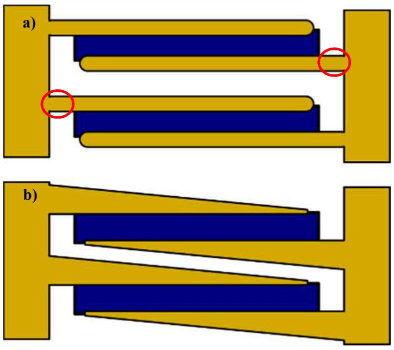

Fig. 2, (a) Normal rectangular electrode design, (b) Triangular electrode design. Gold areas are electrodes and blue regions are LT-GaAs. Red circle indicates 'bottle neck' region.

expected that the devices can be driven by larger biasing fields and in turn increase the amount of THz radiation generated, without increasing the thickness of the gold layer deposited.

A 5x5 mm device was made using the new triangular geometry, the electrode widths were determined to maintain the same area as original rectangular electrodes and maintain the filling factor of 0.5. Table 1 shows dimensions of the device. The device was characterized using a Spitfire Ace PA femtosecond laser, with 40 fs pulse width centered on an 800 nm frequency and 1 kHz repetition rate. Pulse energies up to 213 µJ were used to excite the device which was electrically chopped at 250 Hz to facilitate lock-in detection. The device is optically excited using a 2 cm collimated beam and detected using a 1 mm ZnTe crystal for electro-optic sampling. The results in Fig. 3, show the emission characteristics of the device as a function of optical power, indicating a consistent improvement of the triangular electrodes over the rectangular design. Further comparisons will be presented.

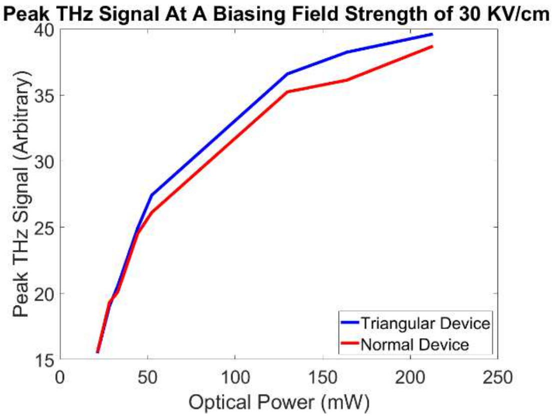

Fig. 3, (a) Optical pump power Vs THz output power (arbitrary) comparison for a 5x5 LT-GaAs PCA using a triangular electrode geometry and a 5x5 LT-GaAs PCA using a normal electrode geometry.

Electrode style	Electrode width (µm)	Gap size (µm)	Dark gap (µm)	Number of Pairs
Rectangular	70	180	50	13
Triangular	120 Max to 10 Min	180	50	13

Table.1, Dimensions of the two devices made.

To further optimize the device, we aim to increase the active area of the device. As mentioned above there is no need to mask alternate gaps; because of the transparent substrate the active LT-GaAs layer can simply be removed. However, it is still important to minimize the width of this 'empty' gap because it enables us to increase the filling factor of active pairs on the device, in-turn increasing the THz generation efficiency. Here, we have experimentally determined the maximum bias that can be supported by this 'empty' gap for different widths. The test was conducted by patterning small electrode arrays onto a sapphire substrate without LT-GaAs with each array having a varying empty gap width. These were then biased and the field increased until breakdown. Fig. 4 shows the results. It was found that the maximum bias before failure is only weakly dependent on the gap size over the range of values tested.

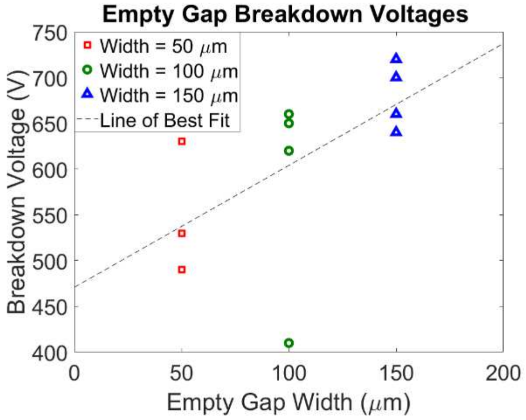

Fig. 4, Dark gap breakdown results, dark gaps width used 50 um, 100 um and 150 um.

Based on these findings we believe that failure mode for these electrodes at high bias is from field concentrations at electrode tips. Experimental results on mitigating this by encapsulating the electrodes with a high-k dielectric will be presented along with further results on optimized electrode designs.

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