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Photoconductive Arrays for High-Field Terahertz Generation

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***Abstract*— We report on the development of a large-area photoconductive THz array structure with an LT-GaAs active region fabricated on quartz substrates using a BCB bonding process. These are shown to generate high THz-fields greater than 100kV/cm, with a bandwidth greater than 6 THz.**

I. INTRODUCTION

WE introduce the use of large-area interdigitated LT-GaAs-on-Quartz (LoQ) array structures with semi-wide gaps for the generation of high-field THz radiation. When excited with an amplified Ti:sapphire laser, the device presented here generates a peak field of 100 kV/cm. This design differs from those previously published [1], [2] as its larger gap size and quartz substrate allows a later point of saturation and superior protection against optically induced damage. When compared with other methods of THz generation, such as optical rectification in non-linear crystals [3], the relatively low optical energies required to reach high-fields over large bandwidths makes these devices a viable source for non-linear THz spectroscopy. The short carrier lifetime of LT-GaAs also makes them convenient for high-field THz-pump-THz-probe experiments.

II. FABRICATION AND RESULTS

Recently, we demonstrated high power free-space emission of THz radiation using LT-GaAs transferred onto *z*-cut quartz substrates (LoQ) [4]. When compared with the widely used 'as-grown' devices on SI-GaAs substrates, they demonstrate a significant improvement in output performance. This is largely owing to the lack of joule heating within the quartz substrate, which becomes significantly more important when working with amplified laser systems where the parasitic current leads to heating and ultimately failure of the device. Here we apply this concept to fabricate large-area interdigitated array structures in order to generate high THz output fields. However, unlike in our previous work [4], where Van der Waals bonding is used, in this work the LT-GaAs sample is wafer-bonded to the quartz. This technique ensures a much more uniform and reliable bond between the LT-GaAs and quartz substrate over a significantly increased area. Once the SI-GaAs substrate is removed using a combination of lapping and a citric acid etch, the bonded LT-GaAs can be etched into strips, before Ti:Au metal contacts are evaporated onto the surface. An image of part of a 10x10mm device consisting of 26 identical 200um-wide gaps is shown in Fig. 1(a). As the THz field has been shown to be proportional the electrode width, this has been factored into the design [5]. Furthermore, the intentional use of curved electrode ends, compared with sharp rectangular points, is important in this structure as it prevents the concentration of localized electric field known to damage the device at high voltages.

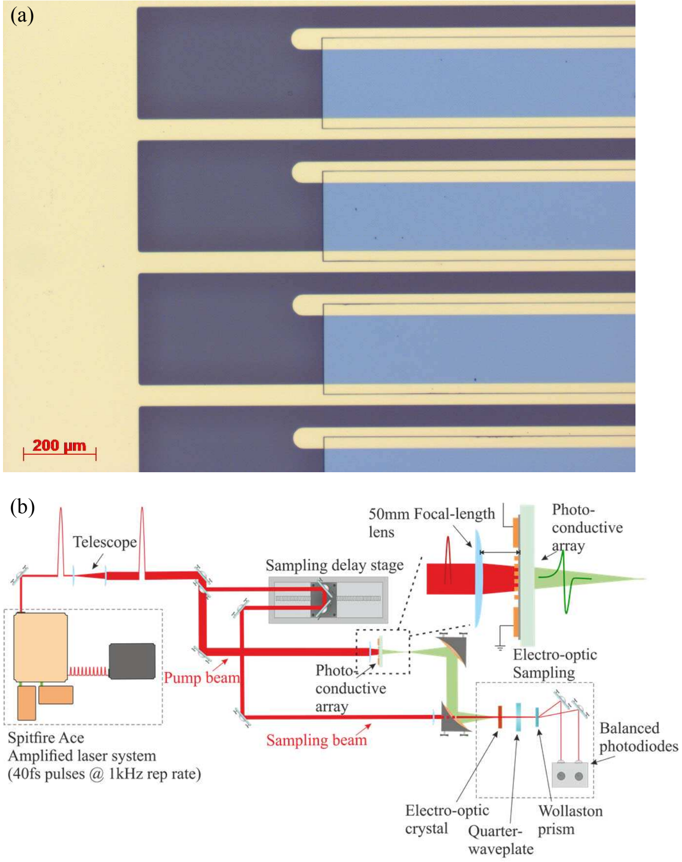

Fig. 1. (a) Optical microscope image of THz LoQ array structure with 200-µm-wide and 10-mm-long PC gaps. This device has a filling-factor of 0.55 (b) THz-TDS setup with 2 off-axis parabolic mirrors, sourced by an Ti:sapphire amplified laser system.

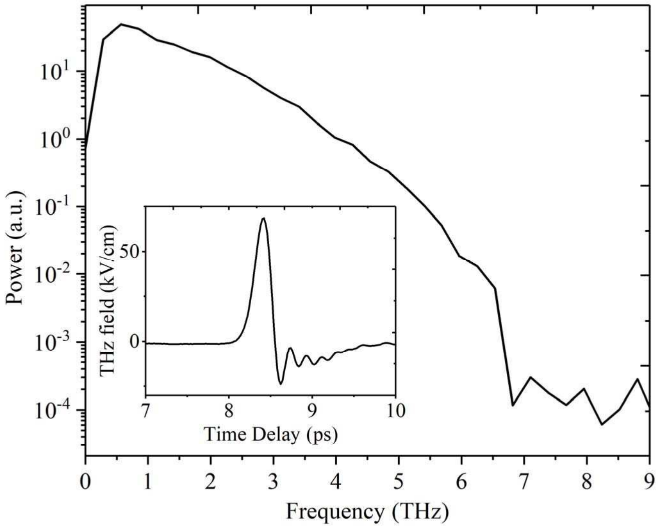

Fig. 2. Inset: Time-domain trace generated using a photoconductive array structure, employing a bias field of 22.5 kV/cm and an optical power of 88 mW. The main figure shows the FFT of the trace from the inset.

In order to generate and detect intense THz radiation, the structure is illuminated using a Spitfire PA amplified laser system, generating 40 fs-long pulses at a central frequency of 800 nm and a repetition rate of 1 kHz. The beam is first expanded from 8 mm to 16 mm-wide then focused through the device using a 50 mm focal length optical lens. The distance between the lens and the device is adjusted to fill the active area. The resulting electron-hole pairs are accelerated by applying a bias across each photoconductive gap. This generates multiple phase-matched pulses, which constructively interfere to form a single intense THz pulse. The emitted THz radiation is known to follow the excitation beam, leading to both beams having the same focal point. A knife-edge measurement was used to extract a minimum THz focused spot size of 1 mm. Fig. 1(b) shows two off-axis parabolic mirrors used to collect, collimate and focus the THz radiation onto a 150-μm-thick GaP detection crystal, where EO-sampling is employed.

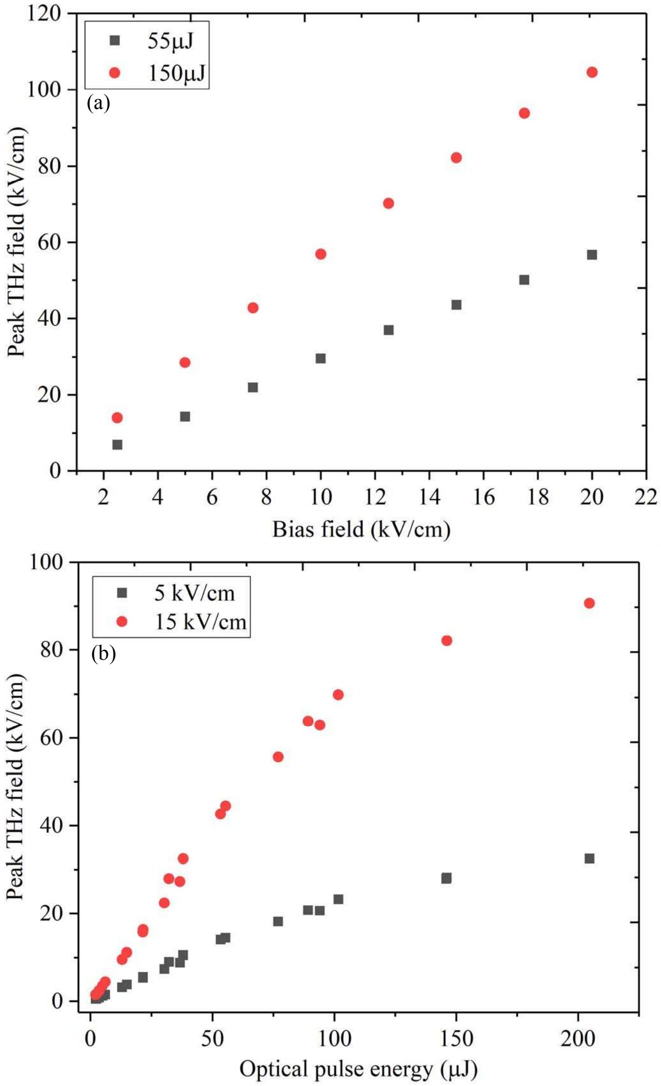

Fig. 3. Peak output THz field, extracted from time-domain traces, as a function of a) bias field and b) optical power, for two different excitation/bias conditions.

The excess NIR beam which does not interact with the LT-GaAs is completely absorbed using an expanded PTFE filter. Fig. 2 (inset) displays the time-domain trace of a THz pulse generated using the array structure within this setup. Taking the FFT of this data reveals a useable bandwidth of greater than 6 THz, a significant improvement over previously published large-area photoconductive structures[1], [2]. In Fig. 3 the peak THz field has been extracted from time-domain traces and plotted as a function of a) bias field and b) optical power. The linear relationship between peak THz field and applied bias resulted in a maximum output field of greater than 100 kV/cm. This is achieved by applying an optical fluence of 150 μJ/cm^2, onto the emitter which, from Fig. 3b), is shown to be close to the saturation point of the device. By scaling the device area and optical power by a factor of 10, an achievable prospect with this fabrication method, a 2 mJ pulse could be used to achieve an output THz of 1 MV/cm.

III. SUMMARY

In summary, our LoQ large-area interdigitated photoconductive arrays generate peak THz fields of at least 100 kV/cm with a bandwidth greater than 6 THz with the prospect of scaling this to 1MV/cm. These attributes, combined with the relatively simple fabrication procedure, make them perfect candidates for sources in non-linear spectroscopy experiments.

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