LT-GaAs metasurfaces as continuous-wave THz detectors operating in the telecommunications band

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***Abstract*—We present a novel approach for efficient continuous-wave (CW) detection of terahertz (THz) radiation using low-temperature-grown gallium arsenide (LT-GaAs) metasurfaces. While typical THz CW detectors require complex material growth, annealing, and device architectures, our approach demonstrates that LT-GaAs, despite its low absorption at infrared wavelengths, can be used for low-noise THz detection by nanostructuring it into a metasurface.**

I. INTRODUCTION

LT-GaAs is a popular material for photoconductive THz receivers due to its electrical properties, which can be tailored post-growth through annealing the material for a specific time and temperature. The duration of annealing affects the material's dark resistivity, carrier mobility, and carrier lifetimes [1]. For THz detection, high dark resistivity, short carrier lifetime, and high mobility are desirable properties.

LT-GaAs PCAs are widely used in THz time-domain spectroscopy (TDS) systems and typically operated at a pump wavelength of 800 nm, which corresponds to photon energy above the GaAs bandgap (1.42 eV). TDS systems rely on expensive ultra-fast pulsed lasers and optical delay lines, and have spectral resolutions typically in the range of GHz. To make THz detection more cost-effective and versatile, it would be desirable to use LT-GaAs PCAs with mature laser technologies developed at telecommunications band wavelengths (1550 nm), enabling the development of portable continuous-wave (CW) THz spectrometers with higher spectral resolution.

At photon energies below the bandgap, LT-GaAs can absorb photons via mid-gap defect states. However, this process is weak and requires either very thick material films or high pump powers. Recently, photoconductive metasurfaces made from LT-GaAs have been developed to absorb light at 1550 nm using degenerate critical coupling and non-linear absorption. This enabled achieving good absorption at the infrared (IR) wavelength (100 fs excitation), while maintaining the beneficial LT-GaAs properties such as low dark current [2]. Here, we extend this concept to develop LT-GaAs detectors operating in a CW spectroscopy system. In 1550 nm CW THz spectroscopy systems the peak optical pump power is much lower than in TDS systems, requiring strong confinement of the optical field to enhance the optical absorption. In this work we modify the dimensions of the metasurface and the optoelectronic properties of the LT-GaAs to achieve low-noise THz detection. This technology holds promise for the development of more cost-effective THz systems based on versatile LT-GaAs PCA detectors which can be designed to operate in both pulsed and continuous wave modes.

II. RESULTS

Perfect absorption can be achieved in dielectric metasurfaces when two degenerate modes of the metasurface are critically coupled to the incident field. This is of particular interest for low-noise THz detection [3] and for integrated THz detectors (e.g. nanoscale THz detectors in THz near field probes [4]). Here we use the same approach to greatly enhance the mid gap absorption of LT-GaAs. We also examine the annealing conditions of LT-GaAs to affect the optical absorption at 1550 nm and it's influence of the noise floor of a CW THz spectrometer operating at 1550 nm shown schematically in Figure 1.

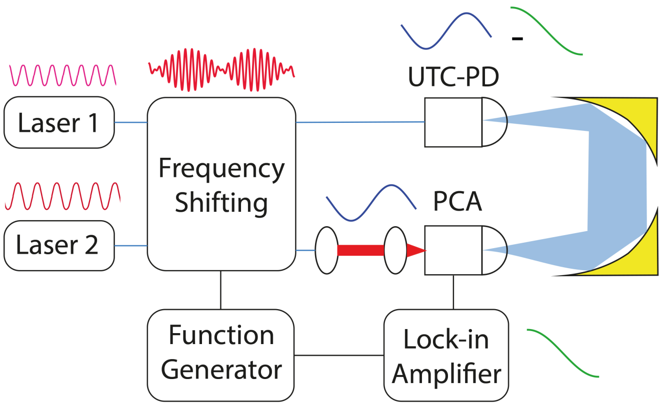

Fig. 1. Schematic diagram of the experimental arrangement. Two lasers are combined to create an optical heterodyne beat note. One pair of lasers is shifted in frequency by 2 kHz using Serrodyne optical frequency translation. The THz signal is detected at this offset frequency using a lock-in amplifier

Figure 2 shows the electrodes of a THz antenna deposited onto the metasurface. A 200 mV bias was applied to the antenna and photocurrent was recorded using a source meter while the laser wavelength was tuned. Two samples were measured with different annealing times, the measured responsivity of the detectors is shown in Figure 3. The shorter annealing time produces a higher responsivity. The peak absorption in both cases was shifted to the shorter wavelelength region of the telecommunications band, however the peak wavelength is defined the metasurface design can be adjusted. We also carried out numerical simulations which demonstrate that the metasurface absorption is also sensitive to the influence of the

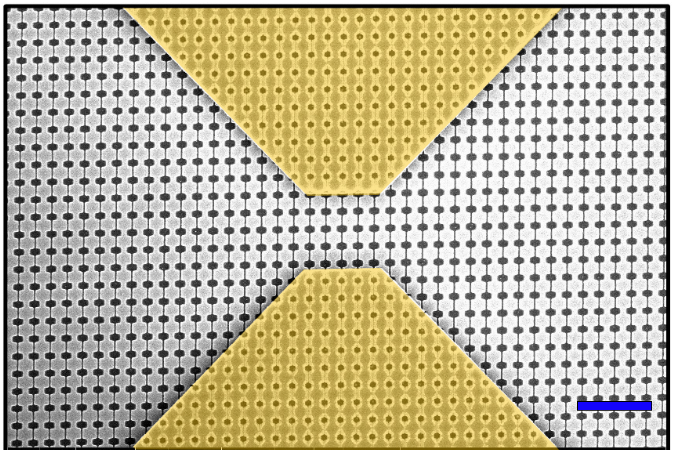

Fig. 2. A false-color scanning electron microscope (SEM) image of a THz PCA with a metasurface integrated between the antenna electrodes. The blue scale bar on the image corresponds to a length of 2μm

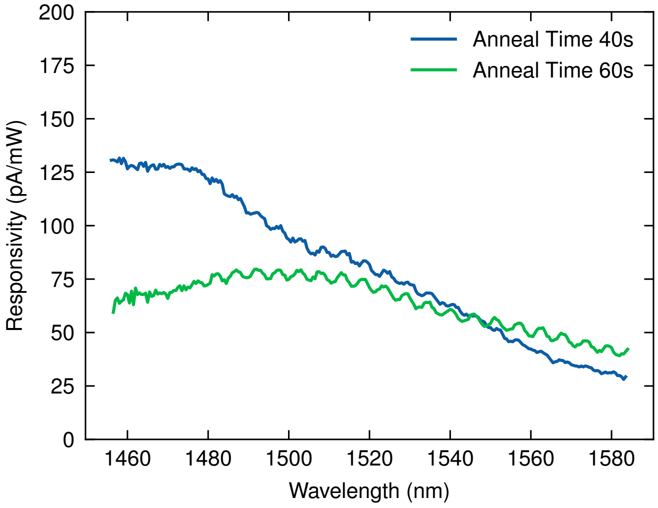

Fig. 3. Optical responsivity of two LT-GaAs metasurfaces in the telecommunications band with different annealing times

metallic antenna and the spatial profile of the excitation source. The detectors were evaluated in a THz CW spectrometer for comparison to commercial InGaAs photoconductive receivers. THz radiation was detected at 0.2 THz while the optical pump power at 1550 nm to the detector was increased using an Erbium doped fibre amplifier. The dynmaic range of the detector at 0.2 THz is shown in Figure 4. The dynamic range seems to saturate at optical pump powers around 35 mW and failure of the devices occurs at powers beyond 40 mW.

III. Summary

We have successfully demonstrated enhancement of absorption of 1550 nm continuous-wave light using an LT-GaAs metasurface. By tuning the annealing time and metasurface dimensions we were able to increase the material absorption in the short wavelength region of the telecommunications band. Further study on the tolerances of the metasurface could provide a pathway to further enhancement in the absorption of the metasurface, centred on 1550 nm to make better use of off the shelf components operating in the telecommunications band. The device was used to detect THz radiation between 0.1-1.0 THz from a UTC-PD CW THz source, demonstrating LT-GaAs metasurface THz detectors operating in CW mode.

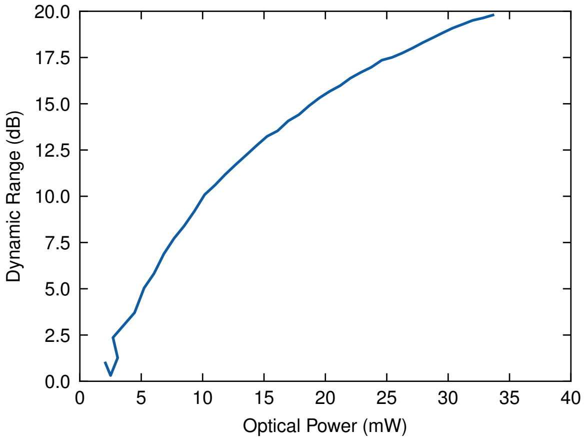

Fig. 4. Dynamic range of THz detector at 0.2 THz with increasing ramp of optical pump power.

IV. Acknowledgements

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