A 63-Pixel Terahertz Focal-Plane Array for Terahertz Time-Domain Spectroscopy and Imaging

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***Abstract*—We present a high-sensitivity and broadband photoconductive terahertz focal-plane array with 63 pixels. We utilize a plasmonic nanoantenna array and an optical diffuser to provide a high spatial overlap between the received terahertz field and the optical pump beam to offer an efficient terahertz detection performance. We experimentally demonstrate more than a 60 dB signal-to-noise ratio and a 2 THz detection bandwidth for all of the pixels of the focal-plane array.**

I. INTRODUCTION

TERAHERTZ time-domain spectroscopy and imaging systems have many unique applications in security screening, medical diagnosis, and non-destructive industrial inspection [1]-[8]. However, unlike the visible and near-infrared domains, it is very challenging to develop focal-plane arrays for terahertz time-domain spectroscopy and imaging systems. Conventional terahertz time-domain spectroscopy and imaging systems are often based on a single-pixel detector and require two-dimensional scanning of the imaged object, which increases scanning time, complexity, reliability, size, and weight of the system [9]-[11]. In order to address these limitations, we present a photoconductive terahertz focal-plane array (FPA) based on a plasmonic nanoantenna array. To improve the overall optical pumping efficiency, an optical diffuser and an objective lens are used to focus the optical pump beam only on the active area of each pixel. The wire routing for the FPA output signals is placed in the dark regions between the adjacent pixels, providing a highly scalable structure for expanding the number of pixels. Under a 200-mW optical pump power, we experimentally demonstrate more than a 60 dB signal-to-noise ratio (SNR) and a 2 THz bandwidth for all 63 pixels of the FPA.

II. DEVICE DESIGN AND EXPERIMENTAL RESULTS

Schematic diagram of the photoconductive terahertz FPA is shown in Fig. 1(a). The plasmonic nanoantenna array is fabricated on a low-temperature grown GaAs (LT-GaAs) substrate with a carrier lifetime of 0.3 ps. The nanoantenna array and the optical pump lines have the same periodicity to efficiently excite surface plasmon waves at the center of each array [12]-[21]. The geometry of the nanoantennas is chosen to maximize both the optical pump intensity and the terahertz electric field at the tip-to-tip gaps of the nanoantennas for an optical pump polarization orthogonal to the nanoantennas and a terahertz polarization in parallel with the nanoantennas. By increasing the spatial overlap between the terahertz electric field and photocarrier concentration, the output photocurrent of each FPA pixel is maximized. The microscopy image of a fabricated 9×7-pixel terahertz FPA is shown in Fig. 1(b). The active areas of the entire FPA and each pixel are 2.43×1.68 mm^2 and 270×240 μm^2, respectively. The fabricated photoconductive terahertz FPA is characterized in a terahertz time-domain spectroscopy setup. A Ti:sapphire laser that generates optical pulses with an 800 nm central wavelength, 135 fs pulse width, and 76 MHz repetition rate is used to provide the pump beam. A large-area plasmonic photoconductive terahertz source is used to provide sub-picosecond terahertz pulses [22]. An FPGA-based readout circuit is used to extract the output signals of the FPA pixels. A total optical pump power of 200 mW is used for characterizing the terahertz FPA. The time-domain electric field traces and the corresponding power spectra from one center pixel and one corner pixel are shown in Figs. 2(a) and 2(b), respectively. Noise power spectra for each pixel, which are dominated by the Johnson Nyquist noise [23], are measured by blocking the incident terahertz radiation and keeping other conditions the same. The center pixel provides more than an 80 dB SNR and a 3 THz bandwidth, while the corner pixel offers more than a 60 dB SNR and a 2 THz bandwidth. The differences in the SNR and bandwidth values are due to the non-uniform distribution of the optical pump lines generated by the diffuser and objective lens. Figure 2(c) shows the color-map profile of the normalized output of the FPA pixels. Normalization is performed by dividing the terahertz photocurrent of each pixel by the photocurrent in the absence of terahertz radiation. The terahertz FPA provides a uniform response with less than a 20% variation over all 63 pixels.

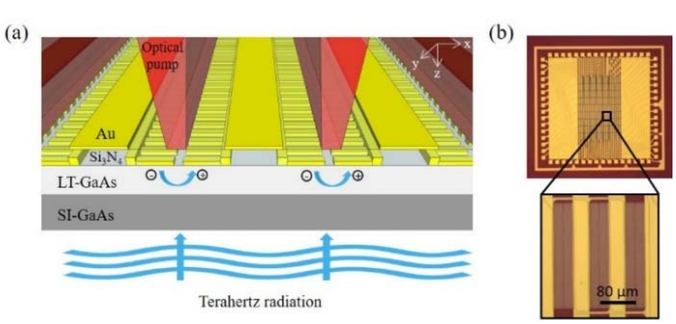

Fig. 1. (a) Schematic of the plasmonic photoconductive terahertz FPA. (b) Optical microscopy images of the fabricated 63-pixel terahertz FPA. The enlarged section is one pixel.

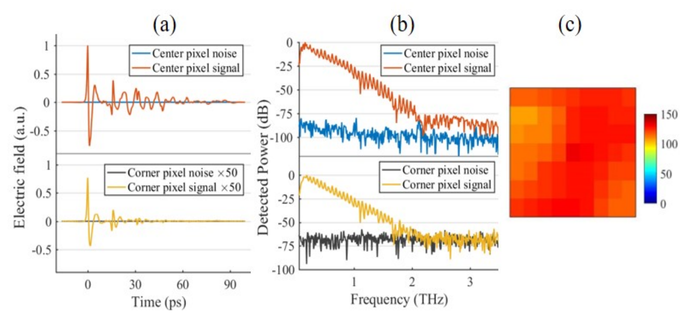

Fig. 2. The time-domain electric field traces (a) and the corresponding power spectra (b) detected by a center pixel and a corner pixel from the terahertz FPA. (c) The color plot of the FPA output. The color of each pixel shows the detected photocurrent pulse level after normalization.

III. CONCLUSION

In conclusion, a 63-pixel plasmonic photoconductive terahertz FPA is demonstrated, which offers more than a 60 dB SNR and a 2 THz detection bandwidth for all of the pixels. The demonstrated FPA eliminates the need for mechanical scanning in pulsed terahertz imaging systems and, therefore, increases the image acquisition speed significantly.

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