High Power Pulsed Terahertz Radiation from Large Area Plasmonic Photoconductive Emitters

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***Abstract*—We experimentally demonstrate a novel large area photoconductive emitter based on a two dimensional array of plasmonic contact electrode gratings to achieve better optical-to-terahertz conversion efficiencies compared to conventional designs. The use of plasmonic contact electrodes enhances the time-varying dipole moment induced within the device active area by offering a more efficient separation and acceleration of optically-generated carriers. Pulsed terahertz radiation powers as high as 3.8 mW over 0.1-5 THz frequency range are achieved at 240 mW optical pump power.**

I. INTRODUCTION

PHOTOCONDUCTIVE terahertz emitters have been widely used to generate pulsed terahertz radiation in many different applications [1-8]. Especially, large area photoconductive emitters are very promising candidates for generating high power and broadband pulsed terahertz radiation [9-13]. The pulsed terahertz radiation is generated when a femtosecond optical pump is incident on the device, generating electron-hole pairs inside the photo-absorbing semiconductor substrate. The photo-generated electron-hole pairs are then accelerated and drifted by a bias electric field applied through a set of interdigitated bias electrodes. The acceleration and separation of the electron-hole pairs induce a time-varying dipole moment inside the device active area, which generates terahertz radiation [13]. Due to their relatively large active areas, large area photoconductive emitters have the capacity of offering high power pulsed terahertz radiation at high optical pump powers without being limited by the carrier screening effect and thermal breakdown. In addition, they can provide broadband radiation since the length of the dipoles is much smaller than terahertz wavelengths. However, optical-to-terahertz conversion efficiency of conventional large area photoconductive emitters is limited by the weak dipole moments induced within the device active area.

To address this limitation, we present a novel large area photoconductive emitter with plasmonic contact electrode gratings. It has been shown that incorporating plasmonic contact electrodes inside active area of photoconductive emitters improves optical-to-terahertz conversion efficiencies by reducing photocarrier transport path lengths to the device contact electrodes [14-21]. The use of plasmonic contact electrode gratings in large area photoconductive emitters not only reduces the transport path length of the photocarriers, it also strengthens the time-varying dipole moment induced inside the device active area by offering a more efficient carrier separation and acceleration. This is due to the fact that most of the photo-generated carriers drift to the contact electrode gratings within a sub-picosecond time-scale and propagate through metallic gratings. Therefore, the large area plasmonic emitter offers significantly higher terahertz radiation power levels with higher optical-to-terahertz conversion efficiencies compared to conventional designs [22].

II. RESULTS

Figure 1a and 1b show the schematic diagram and scanning electron microscope (SEM) images of a proof-of-concept large area plasmonic photoconductive emitter with 1×1 mm^2 active area. The device is fabricated on a semi-insulating (SI) GaAs substrate and consists of an array of plasmonic contact electrode gratings connected to anode bias lines of the photoconductive emitter within every other gap between the anode and cathode bias lines. The other gaps between the anode and cathode bias lines are shadowed by another metal layer deposited on top of a Si_3N_4 antireflection coating to prevent destructive terahertz radiation interference by blocking light transmission into the SI-GaAs substrate. The plasmonic contact electrode gratings (Au gratings with a 200 nm pitch, 100 nm metal width, and 50 nm metal height) and the Si_3N_4 antireflection coating (340 nm height) are designed to transmit 79% of an incident TM-polarized optical pump beam at 800 nm wavelength through the plasmonic contact electrodes into the SI-GaAs substrate. The length of the metallic gratings is chosen as 5 µm in order to keep the length of the terahertz radiating dipoles much smaller than the terahertz radiation wavelengths [22].

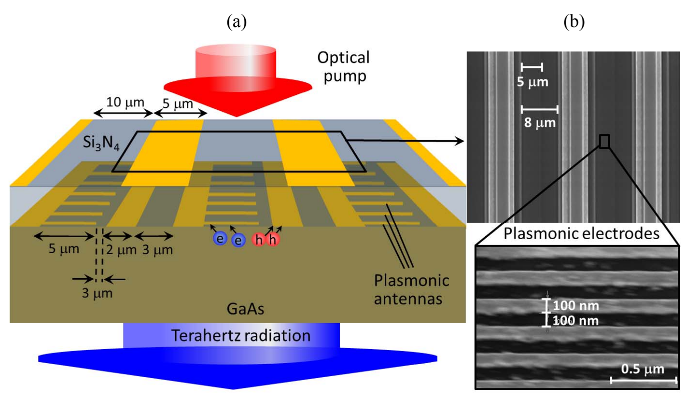

Fig. 1. (a) Schematic diagram and (b) SEM images of the presented large area plasmonic photoconductive emitter.

An 800 nm Ti:sapphire laser with 135 fs pulse width and 76 MHz repetition rate is used to characterize the proof-of-concept large area plasmonic emitter. The radiated terahertz power is measured by using a calibrated pyroelectric detector (Spectrum Detector, Inc. SPIA-65 THz) as a function of the optical pump power and bias voltage (Fig. 2a). 3.8 mW pulsed terahertz radiation power is achieved under 240 mW optical pump power. This is the highest-reported terahertz radiation power with more than an order of magnitude enhancement in the optical-to-terahertz conversion efficiency compared to the conventional designs [9-13]. The radiated electric field is characterized in a time-domain terahertz spectroscopy setup with electro-optic detection in a 1 mm thick ZnTe crystal. The time-domain radiated field and the corresponding radiation spectrum is shown in Fig. 2b and Fig. 2c, respectively [22].

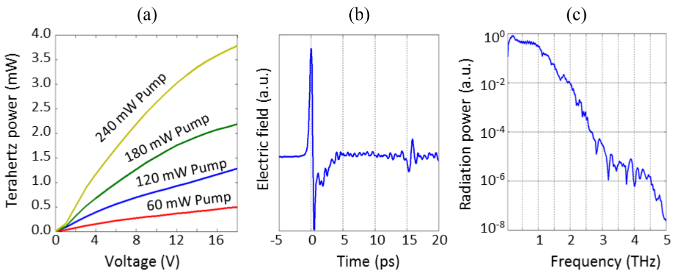

Fig. 2. (a) Terahertz radiation power as a function of the optical pump power, (b) terahertz electric field in the time domain, and (c) radiation spectrum of the presented large area plasmonic photoconductive emitter.

In summary, a novel large area photoconductive emitter based on plasmonic contact electrode gratings is presented. It is experimentally shown that by strengthening the induced dipole moment inside the device active area, optical to-terahertz conversion efficiency can be enhanced significantly. More than one order of magnitude enhancement in optical-to-terahertz conversion efficiency and record-high power pulsed terahertz radiation of 3.8 mW is achieved over 0.1-5 THz.

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