High-Power Terahertz Generation from Telecommunication-Compatible, Bias-Free Photoconductive Nano-Antennas

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***Abstract*— We present a telecommunication-compatible, bias-free photoconductive terahertz source with arrays of plasmonic nano-antennas. We demonstrate pulsed terahertz radiation with powers up to 72 μW, enabling time-domain terahertz spectroscopy over a 3 THz bandwidth with a 100 dB dynamic range.**

I. INTRODUCTION

PHOTOCONDUCTIVE terahertz sources are extensively used in time-domain terahertz spectroscopy (THz-TDS) systems for various imaging and sensing applications [1]–[5]. To generate terahertz pulses, a bias voltage is applied to a photoconductor illuminated by a femtosecond optical pump beam and the generated photocurrent is routed to a terahertz radiating element[6], [7]. It is highly desirable to develop photoconductive terahertz sources that can operate at telecommunication optical wavelengths (~1550 nm), where low-cost, compact lasers are available[8]–[10]. However, photo-absorbing substrates at these optical wavelengths have low resistivity, which results in high dark currents and thermal breakdown before reaching high radiation powers.

To address this limitation and realize high-reliability, high-performance, telecommunication-compatible photoconductive terahertz source, we introduce a new type of photoconductive source, which can generate high terahertz radiation powers without a need for a bias voltage. The photoconductor is designed such that a built-in electric field induced inside the photo-absorbing substrate drifts the photo-generated carriers. As a result, relatively high photocurrent values feed the terahertz radiating elements at a zero dark current. We use arrays of plasmonic nano-antennas as the terahertz radiating elements, which provide broadband, high-power terahertz radiation [11]–[14].

II. SOURCE DESIGN AND EXPERIMENTAL RESULTS

The designed bias-free photoconductive terahertz source consists of a 1×1 mm^2 array of plasmonic nano-antennas fabricated on an InAs layer grown on a semi-insulating GaAs substrate. InAs is chosen as the photo-absorbing semiconductor because of its high carrier mobility. The InAs layer is highly p-doped (1.4×10^{19} cm^{-3}) to introduce a strong built-in electric field at the interface between InAs and the Ti/Au plasmonic-nano-antennas (Fig. 1a). When the terahertz source is illuminated with a femtosecond optical excitation, the photo-generated electrons drift to the plasmonic nano-antennas by the built-in electric field and feed the nano-antennas with the ultrafast current required for generating terahertz pulses.

Geometry of the plasmonic nano-antennas (Ti/Au gratings with a 450 nm periodicity, 370 nm metal width, and 80 nm metal height, coated with a 240 nm-thick Si_3N_4 anti-reflection coating) is chosen to maximize optical absorption at the InAs-Ti/Au interface. Length of the nano-antennas (5 μm) is chosen to be much smaller than terahertz wavelengths to maintain a broadband radiation. Optical and scanning electron microscope images of a fabricated terahertz source are shown in Fig. 1b.

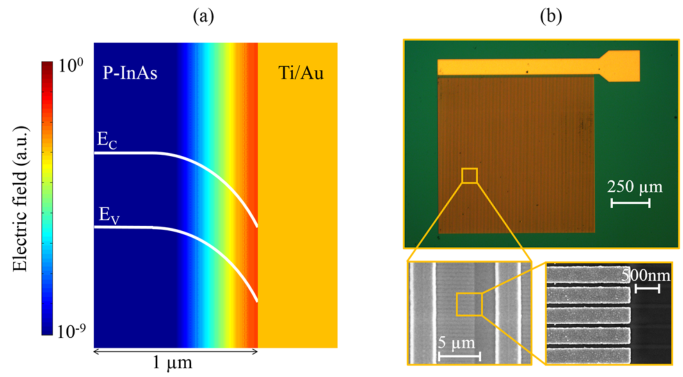

Fig. 1 (a) Band diagram (white lines) and built-in electric field (color plot) at the interface between the InAs substrate and the plasmonic nano-antennas. (b) Optical and scanning electron microscope images of the fabricated photoconductive terahertz source.

Performance of the fabricated terahertz source is characterized using an optical parametric oscillator that generates optical pulses with a 1550 nm center wavelength, 76 MHz repetition rate, and 100 fs pulse width. The generated terahertz power is measured using a pyroelectric detector calibrated by Physikalisch-Technische Bundesanstalt (PTB), Germany. Power measurement results (Fig. 2a) show up to 72 μW radiated terahertz power from the fabricated terahertz source. Radiation spectrum of the terahertz source is analyzed using a THz-TDS system. The measured time-domain electric field (Fig. 2b) and the corresponding power spectrum (Fig. 2c) for the terahertz source indicate radiation bandwidths exceeding 3 THz with a 100 dB dynamic range.

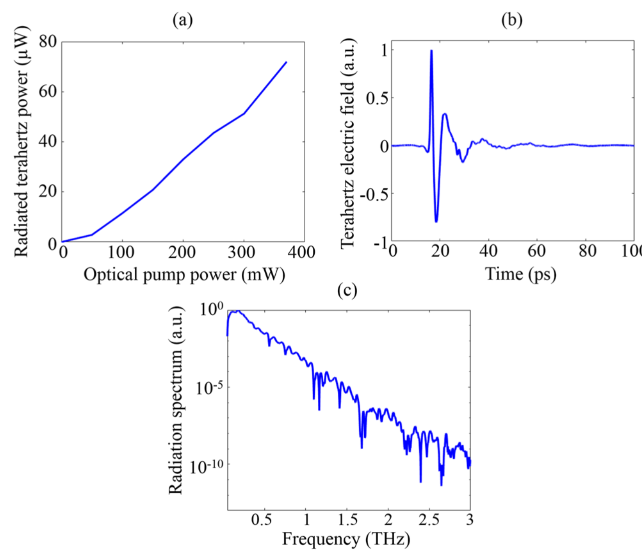

Fig. 2: The measured terahertz power, time-domain electric field, and radiation spectrum of the fabricated photoconductive terahertz source are shown in a, b, and c, respectively.

III. CONCLUSION

To summarize, a bias-free and telecommunication-compatible photoconductive terahertz source, which offers radiation powers exceeding 72 μW over a 3 THz bandwidth, is introduced. The presented terahertz source would significantly improve the performance, reliability, and practicality of THz-TDS systems for various imaging and sensing applications.

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