# Broadband-response and Frequency-tunable Terahertz Photonic Transmitters with High Efficiency

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**Abstract:** We demonstrate broadband-response terahertz photonic transmitters with an ultrawide frequency tuning range. Combining with coherently controlled quasi-continuous-wave optical excitation, these devices exhibit record-high light-terahertz external quantum efficiency (> 290%).

**OCIS codes:** (260.5150) Photoconductivity; (320.7080) Ultrafast devices

With increasing applications of the terahertz waves, such as molecule image and warfare inspection, a compact high-efficiency reliable terahertz CW radiation source becomes highly desirable. Compared with other CW THz emission techniques such as Gunn diodes, p-type Ge based or quantum cascade THz lasers, and resonant tunneling diodes, photomixing in low-temperature-grown GaAs (LTG-GaAs) photoconductors [1,2] has the advantages of simplicity, room-temperature operation, tunable THz wavelength, and integratability with other semiconductor devices to become compact THz sources. Low-temperature-grown GaAs (LTG-GaAs) has been utilized to fabricate photonic transmitters due to its ability to operate in the THz frequency regime (corresponding to 100μm~1000μm optical wavelength), which lies beyond the capabilities of both solid-state laser on the short-wavelength side and of electronic sources such as Gunn or IMPATT diodes on the long-wavelength side. Recently we have demonstrated a novel edge-coupled membrane photonic transmitter based on LTG-GaAs MSM TWPDs. With a slot antenna, our previous device exhibited an strong resonance with the antenna frequency and an external light-THz power-conversion efficiency of 0.11% at the resonance frequency (645GHz) was achieved [4], corresponding to an external quantum efficiency as high as 64% not to mention that the correction of un-efficient collection of THz radiation and optical coupling loss have not yet been considered. Even though our previous devices showed promising performance, the frequency tunability of a single device is strongly restricted by our previous antenna design, thus prevent them from spectral applications with a single device.

By improving the antenna and device design, here we demonstrate broadband-response terahertz photonic transmitters with an ultrawide frequency tuning range (from <100GHz up to 1.1THz) under optical excitation. Combining with coherently controlled quasi-continuous-wave optical excitation, these devices exhibit record-high light-THz power-conversion efficiency of 0.33%, corresponding to an external quantum efficiency over 100% (291%). These demonstrated photonic transmitters were fabricated with LTG-GaAs active region composed of an edge-coupled metal-semiconductor-metal traveling-wave photodetector (MSM-TWPD) [3], a coplanar waveguide (CPW) fed slot antenna, a low pass filter, and a dc probe pad. Two antenna designs were adopted in our photonic transmitters: one is with a conventional slot dipole antenna (called type A); the other is with a bow-tie antenna (called type B), as show in Fig. 1.

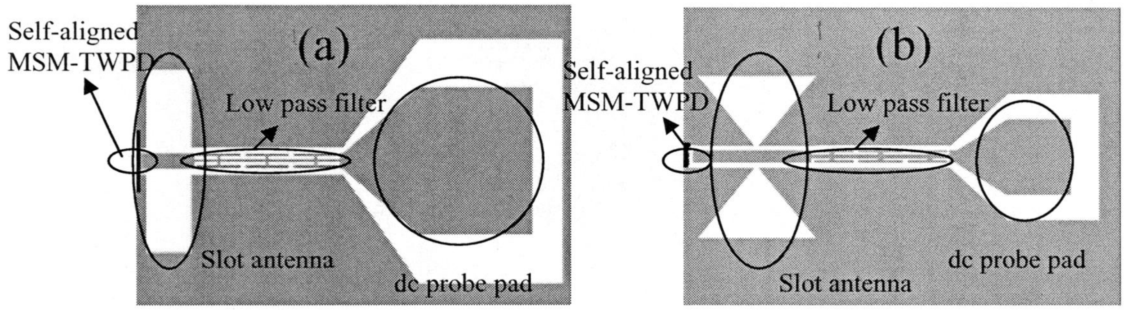


Fig. 1 Two types of broadband photonic transmitters: (a) Type A with a slot dipole antenna; (b) Type B with a bow-tie antenna.

After taking the frequency response of the MSM-PWPD into consideration, we particularly designed the patterns of the photonic transmitters so that our antenna can provide a broadband and frequency-tunable terahertz radiation. Figure 2 shows the designed frequency responses of the photonic transmitters, after considering the photodetetor response. The antenna resonance frequency of the Type A device was designed to be 800 GHz with a shifted 2λ resonance frequency around 360GHz and a 4λ resonance frequency around 200GHz. The enhanced radiation around 400-500GHz is contributed from the device structure resonance. In order to compensate the low radiation efficiency at around 600GHz, a broad-resonance frequency bow-tie antenna was adopted for type B devices with a shifted 2λ resonance frequency around 430GHz.

For optical excitation, we adopted a coherent control method [5] to create THz beating frequency based on a broadband femtosecond pulse to mimic the quasi-continuous-wave excitation. The measured excitation-frequency dependent THz power is shown in Fig. 3(a) and (b). A broadband response with an ultrawide tuning range can be found, confirming our device design.

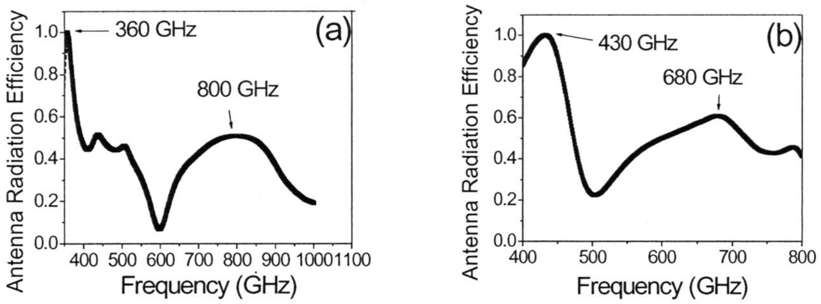


Fig. 2 Designed frequency responses for (a) type-A photonic transmitter and (b) type-B photonic transmitter.

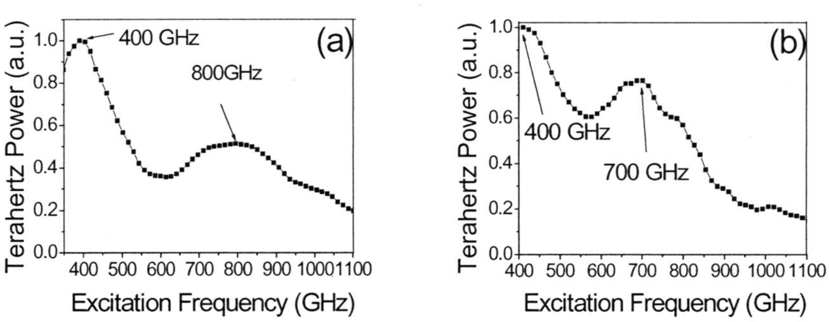


Fig. 3 Measured frequency responses for (a) type-A photonic transmitter and (b) type-B photonic transmitter.

Fig. 4 shows the measured bias dependent output power (solid squares) at 400GHz under a fixed optical excitation (1.87mW). Best measured external light–terahertz power conversion efficiency of 0.33% (including optical coupling loss and THz collection loss), corresponding to an external quantum efficiency of 291%, can be achieved at a 20V dc bias voltage, where the collected terahertz power was 6.11μW. It is at least 3 times higher than our previously reported record value [5]. We squared the measured bias dependent photocurrents (open circles) and compared them to the bias dependent THz output power. These two curves overlap very well as the bias voltage is below 15V. When the bias exceeds 15V, these two curves begin to separate. We attribute this power saturation phenomenon to the increased carrier lifetime of LTG-GaAs under high bias voltages. More characterization data of the photonic transmitters, such as the excitation power dependency of the terahertz power, will be discussed at the conference.

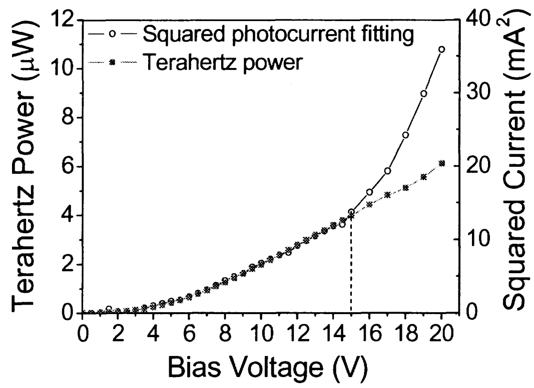


Fig. 4 THz power (solid squares) and squared photocurrent (open circles) vs. bias voltage for input optical power of 1.87mW.

In summary, we demonstrate an edge-coupled membrane terahertz photonic transmitter with an ultrawide frequency tuning range under optical excitation. Record-high light-terahertz external quantum efficiency (>290%) is achieved under coherently controlled quasi-continuous-wave optical excitation. This efficient broadband THz emitter will play central roles in the future THz-based applications including molecule spectral image and warfare inspection.

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