Tunable Antenna-Coupled Intersubband Terahertz (TACIT) Mixer Integrated with Self-complementary Antenna

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***Abstract*—We are developing a novel THz hot-electron bolometer (HEB) mixer based on a high-mobility 2-dimensional electron gas (2DEG) confined in a single GaAs/AlGaAs quantum well. Named as Tunable Antenna-Coupled Intersubband Terahertz (TACIT) mixer, the device takes advantages of intersubband transitions of the confined 2DEG for efficient, tunable absorption of THz radiation. Here we demonstrate a TACIT mixer integrated with a self-complementary antenna suitable for the broadband operation of the device. We study the tunability in both direct detection and heterodyne detection responses and show that the observed tunability behavior is consistent with our device model based on intersubband transitions. In addition, we study the DC-bias dependence of the noise at 1.4 GHz and show that the noise behavior follows that of a HEB device.**

Keywords— THz heterodyne detector; high-mobility 2-dimensional electron gas; intersubband transitions

I. Introduction

Heterodyne detection is an important technique for high-resolution spectroscopy at THz frequencies for astrophysics and planetary applications. Above 1 THz, superconducting hot-electron bolometers (HEBs) are the heterodyne detectors of choice for most astrophysics applications because of their excellent sensitivity. For applications that cannot afford active cryogenic cooling (i.e., deep-space planetary applications), Schottky-diode mixers are the only option so far because of their higher operating temperature. However, compared with superconducting HEBs, Schottky-diode mixers suffer from much less sensitivity and much higher required local-oscillator (LO) power (~1 mW), the latter of which especially limits the use of the technology for multi-pixel heterodyne array applications.

We are developing a novel THz heterodyne detector based on intersubband transitions of a high-mobility 2-dimensional electron gas (2DEG) that may offer the best of both worlds [1]. Named as Tunable Antenna-Coupled Intersubband Terahertz (TACIT) mixers, our devices can be as sensitive as superconducting HEBs (with predicted single-sideband noise temperature T_{SSB} ~ 1,000 K) at higher operating temperature (40-60 K) with moderate LO power requirement (~1 μW) and with a useful intermediate frequency (IF) bandwidth (~10 GHz). In addition, TACIT mixers can offer wide in-situ tunability in the detection frequency (2-5 THz) with small (<1 V) DC voltage biases. These impressive mixer characteristics along with the tunability makes TACIT mixers an attractive THz mixer technology for low-noise, multi-pixel THz heterodyne spectrometers, especially for applications in which either active cryogenic cooling or available THz LO power is limited.

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II. Results

In our previous work, we demonstrated a proof-of-concept TACIT device integrated with a single-slot antenna and confirmed the tunability in the detection frequency (2.5-3.1 THz) as well as THz mixing capability at 60 K with an IF bandwidth exceeding 6 GHz [2]. Here we report on another version of a TACIT mixer integrated with a self-complementary Maltese-cross antenna (Fig.1. (a)). In this version of the TACIT mixer, the source and the drain of the device contain additional metal contacts that capacitively couple out the IF response from the 2DEG (Fig.1. (a) inset and Fig.1. (b)). With the top and the bottom gate metals, these capacitive contacts also form the self-complementary Maltese-cross antenna structure suitable for the broad tunability of the device (Fig.1. (a) inset).

Direct detection measurements in response to a monochromatic radiation at 2.52 THz and 3.11 THz at 10 K show that the tunability behavior of the device is consistent with the previous results and in good agreement with the device model presented in [1] (Fig.1. (a)). Heterodyne measurements in response to two monochromatic sources near 2.52 THz at 10 K also resulted in the tunability behavior consistent with the direct detection result at 2.52 THz. In addition, noise power measurements at 1.4 GHz show that the noise power peaks at the source-drain DC biases near the knee of the current-voltage (IV) curve in which the contribution of the thermal fluctuation noise is expected to be maximum. By measuring the noise power at zero source-drain DC bias with and without 2.52 THz, we observed the change in the noise power that corresponds to ~ 20 K of heating of the 2DEG with THz.

Heterodyne measurements at higher temperatures (40-60 K) and noise temperature characterizations are currently underway.

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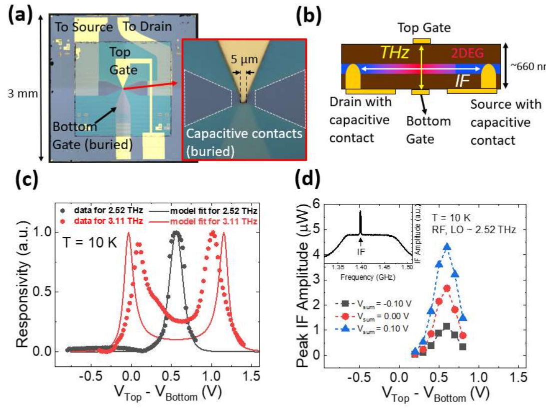

Fig. 1. (a) TACIT mixer integrated with a Maltese-cross antenna on a high-resistivity Si substrate. The inset shows the four-terminals of the device near the active region (5 µm × 5 µm patch) that form the self-complementary antenna for broadband THz absorption. (b) schematic showing the vertical profile and the four-terminals of the device. The two Schottky contacts (top and bottom gates) sandwiching the active region orient the THz electric fields perpendicular to the 2DEG plane (required to satisfy the selection rule for the intersubband transition) for efficient THz absorption. The two Ohmic contacts with capacitive contacts (source and drain) couple out the IF response in the in-plane resistance of the 2DEG. (c) direct detection response at 10 K with theoretical model curves (d) gate-voltage dependence of the IF peak amplitude for the heterodyne detection of ~ 2.52 THz at 10 K. The inset shows the IF signal near 1.4 GHz for the heterodyne detection.

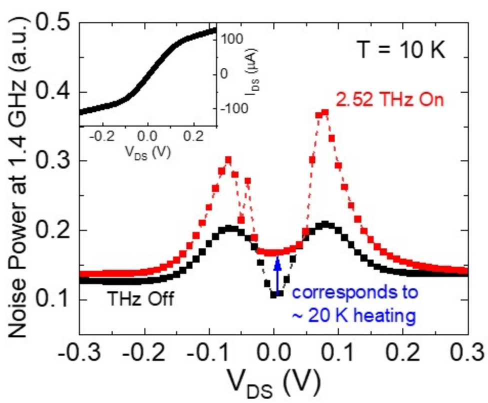

Fig. 2. DC-bias dependence of the noise power at 1.4 GHz with and without 2.52 THz at 10 K. The inset shows the device current-voltage (IV) curve without THz illumination at 10 K.

References

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