InP Double Heterojunction Bipolar Transistor for detection above 1 THz

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*Abstract***— We evaluate the optical performance of the InP heterojunction bipolar transistors (DHBTs) designed for 100 Gbit/s circuit applications as a room temperature detector operating above 1 THz. They can operate far above the frequencies at which they have gain and can still rectify THz current and voltage.**

I. INTRODUCTION

TERAHERTZ (THz) electromagnetic waves (0.1-10 THz), with the frequencies between microwaves and infrared, have found many applications including THz imaging [1],which has a potential to enable contact-free non-destructive testing of numerous materials, devices, and systems. The THz images taken above 1 THz provide a higher spatial resolution than the images at sub-THz frequencies.

Several groups have also considered the prospect of using a THz carrier frequency for wireless communication to increase the transmitted data rate well above 40 Gbit/s for a single channel [2]. High-data-rate communication was demonstrated very recently using a commercial plasma-wave detector [3]. Error-free communications at data-rates up to 8.2 Gbps were reported at 310 GHz, thus demonstrating that such detectors are competitive for communication applications. However, communications at higher data rates were restricted by the relatively low sensitivities of these detectors. One of the main limitations was their cut-off frequency below 20 GHz.

The THz detectors based on the InP heterojunction bipolar transistors (DHBTs) with high cut-off frequencies are very promising for THz imaging and high-data-rate wireless communication applications. They are favorably compared with the existing detectors based on the Schottky diodes, field effect transistors, or Si heterojunction bipolar transistors [4, 5]. InP DHBTs already serve as a key component of the trans-impedance amplifiers for 100 Gb/s transmission [6].

In this work, we show new results related to the THz detection at room temperature with InP DHBTs in a frequency range above 1 THz.

II. TECHNOLOGY AND EXPERIMENTAL SET UP

The 0.7x5 μm² emitter size InP DHBTs were designed for 100 Gbit/s applications. They demonstrated f_T and f_{max} above 320 and 280 GHz respectively. The static current gain was around 40 and the common-emitter breakdown voltage was above 5V. They operated without any spatial coupling antennas. The radiation was coupled to the device only via the contact pads and/or the coupling wires to the device. The photoresponse Δu was measured with a continuous-wave CO_2 –pumped molecular gas laser emitting at 1.40 THz, 1.63 THz, 2.52 THz, and 3.11 THz with maximum output power of ~ 100 mW, 150 mW, 150 mW, and 90 mW, respectively. The radiation was focused on the transistor surface using parabolic mirrors and the radiation intensity was modulated by a chopper at 133 Hz. The focused spot size was close to the diffraction limit. A wire grid polarizer controlled the polarization of the incident THz radiation. The azimuthal angle φ (Fig. 1) is the angle between the electric field of the electromagnetic wave and the orientation of the emitter-to-collector direction. The emitter terminal of the device was grounded and the base-emitter bias V_{BE} was controlled by a Keithley Source Meter. The base-emitter bias and radiation frequency dependence was measured using a lock-in amplifier.

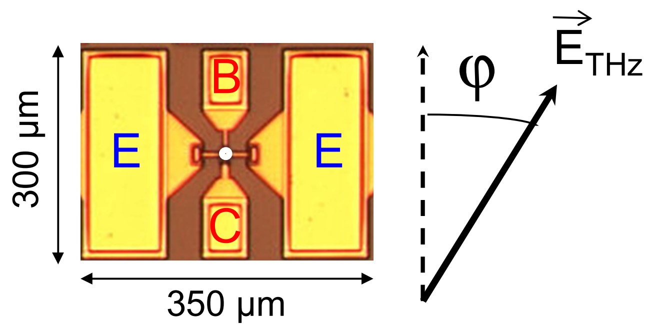

Fig. 1. Image of tested InP DHBT device. φ is the polarization angle of incident terahertz radiation.

III. RESULTS AND DISCUSSION

In Fig. 2 we have plotted the area-normalized responsivity R_V induced between the collector-emitter electrodes of the 0.7-μm DHBT as a function of base-emitter bias V_{BE}, for the four different frequencies. The responsivity R_V is normalized with regard to the area of the device taken equal to diffraction limited area [7]. In this case, R_V, is defined as the ratio between the voltage Δu induced by the radiation on the detector and the incident power, P_t. $R_V = (\Delta u S_t)/(P_t S_a)$, where P_t is the total power of the source, $S_t = \pi d^2/4$ is the radiation beam spot area, and S_a is the active area. Since the area of the DHBT with the contact pads was smaller than the diffraction limited area $S_\lambda = \lambda^2/4$ even for the larger frequency investigated (3.11 THz), the active area was taken equal to S_λ. The values of R_V used direct reference to laser emitted power without adjustments associated with the factor of coupling efficiency.

The device responsivity rolls off non-linearly with increasing frequency. This observed roll-off can be explained by the combined effects of the capacitance, *C*, shunting the active nonlinear device resistance, *R*, and parasitic series inductance, *L*. At high frequencies the voltage drop V_R across *R* becomes independent of *R* and proportional to $1/(\omega^2 LC)$. The detector response is proportional to V_R^2, and, therefore inversely proportional to $1/(\omega^4 L^2 C^2)$.

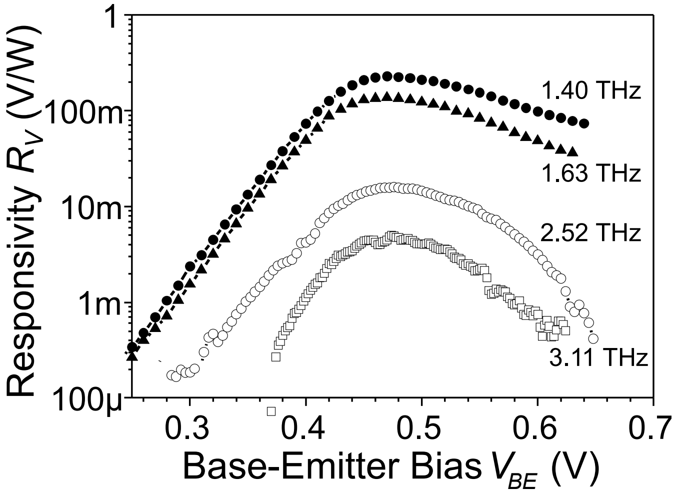

Fig. 2. Area-normalized responsivity R_V as a function of the base-emitter bias V_{BE} for frequency of the incident THz radiation of 1.40 THz (●●●), 1.63 THz (▲▲▲), 2.52 THz (○○○), and 3.10 THz (□□□). The polarization of the electric field of the incident THz radiation is perpendicular to the base-to-collector direction.

Moreover, for the polarization of the electric field of the radiation perpendicular to the emitter-to-collector direction, the optimal THz detection bias conditions were achieved for $V_{BE} \sim 0.48$ V. This value is smaller than the bias voltage that gives the maximum gain in the current voltage characteristic. Above 0.48 V, the responsivity was a decreasing function of V_{BE}.

IV. CONCLUSION

We have demonstrated broadband terahertz photoresponse of InP DHBT and estimated responsivity values. The increase of the responsivity with the *dc* base-emitter bias shows that the detection mechanism is the rectification of the THz radiation coupled to the device due to the nonlinearly of the device characteristics. The roll-off observed with increasing frequency can be explained by the combined effects of the capacitance shunting the active nonlinear device resistance, and parasitic series inductance.

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