Frequency Response of HBT's as Photodetectors

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***Abstract*— Photodetection measurements of HBT's fabricated by the MMIC HBT process have been experimentally investigated for the first time. A 3-dB bandwidths of 2 GHz and more than 20 GHz have been achieved in a CE (common emitter) HBT and a CB (common base) HBT, respectively. The photoresponse of the CEHBT is approximately 25 dB higher than that of the CBHBT at 1 GHz. The CEHBT has a higher signal-to-noise ratio than a PIN/50-Ω FET-amplifier at 10 GHz.**

I. Introduction

Heterojunction phototransistors (HPT's) have been studied for several years because of their potential as high-performance photodetectors for lightwave communications and as a possible alternative to a PIN/FET combination in optoelectronic integrated circuits (OEIC's) [1], [2]. Recent work, however, has suggested that a frequency bandwidth of 100 MHz has been achieved in HPT's with a base terminal [2], while that of several GHz has been achieved with a PIN/FET combination in OEIC's [3]. Since the HPT's include a circular emitter whose diameter exceeds 10 μm [1], [2], the frequency bandwidth is less than that of the PIN/FET combination.

Heterojunction bipolar transistors (HBT's) with high cutoff frequencies, on the other hand, have been demonstrated in recent years; cutoff frequencies in excess of 160 GHz have been measured in discrete devices. HBT's have a structure similar to that of HPT's. Consequently, if the HBT's can operate as photodetectors, the frequency performance of the photodetectors can be improved.

The MESFET, HEMT, and HBT, i.e., the basic building blocks of MMIC's, can be used as photodetectors embedded on the monolithic chip itself. The photoresponsivity of the MESFET and HEMT have been investigated [4], but no work on HBT photodetection in the microwave and millimeter-wave frequency bands has been reported. This letter presents the basic performance of HBT's as photodetectors. The photoresponsivity of the CB (common base) HBT and CE (common emitter) HBT have been experimentally studied in the microwave frequency range.

II. Electrical Characterization and Experimental Setup

The basic performance of GaAs–AlGaAs HBT's as photodetectors is evaluated using a 0.83-μm wavelength carrier and an $LiNbO_3$ external optical modulator (EOM). Fig. 1 shows the experimental setup for the HBT devices. The frequency performance of the HBT's as photodectors is characterized by using a modified electrooptic on-wafer RF-probe station. The input optical beam is focused within a spot diameter of 20 μm by using a microscope objective lens.

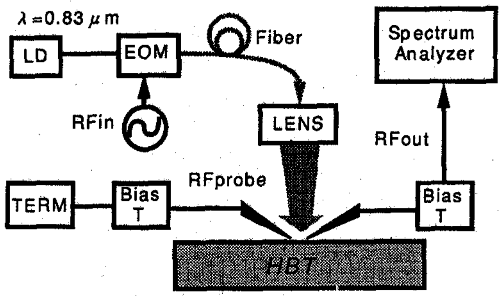

Fig. 1. Experimental setup for frequency response measurement of HBT photodetectors.

The MMIC-compatible fabrication and structure of the HBT's have been reported. HBT's with 3-terminals and interdigitated electrodes have 2 × 3 μm × 20 μm emitters for a CEHBT and 2 × 2 μm x 10 μm emitters for a CBHBT [5]. The areas of the HBT electrodes are roughly the same size as the optical beam-spot area.

The dc current gain of the CEHBT was about $h_{FE} \geq 70$ for a base current $I_B \geq 70$ μA. A unity current gain cutoff frequency f_t for the CEHBT is 30 GHz at $V_{CE} = 4$ V and $I_C = 12$ mA. The CBHBT has a 3-dB current gain bandwidth of 30 GHz at $V_{BC} = 3$ V and $I_E = 3$ mA; these values were derived from S-parameter measurements up to 40 GHz.

III. Frequency Response of HBT Photodetectors

Figs. 2 and 3 show the measured frequency response (RF response) and small-signal gain $|S_{21}|$ of the HBT's. The RF response of a wide-band PIN photodetector (PIN-PD) with a 3-dB bandwidth of 10 GHz and a dc responsivity of 0.30 A/W was also measured for comparison with the HBT photodetectors. The RF response is the intrinsic response of the photodetectors which subtracts the EOM response from the detected power; the modulated optical input power into the photodetectors is 0 dBm. In the measurement, the HBT dc-biased conditions were identical to those for the above-mentioned current gain measurement. The 3-dB bandwidths of 2 GHz and 8 GHz were obtained for the CEHBT and the PIN-PD, respectively. The 3-dB bandwidth of the CBHBT was over 20 GHz.

The RF response of the CEHBT is approximately 25 dB higher than that of the CBHBT at 1 GHz because of the higher internal gain and the higher optical coupling efficiency of the CE HBT. The internal gain roughly corresponds to a small-signal gain $|S_{21}|$ under the operating collector current because the photogenerated current swept into the base from

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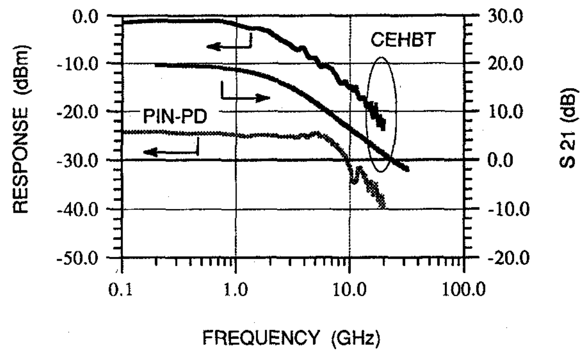

Fig. 2. Frequency dependence of measured photoresponsivity and small-signal gain $|S_{21}|$ for a CE (common emitter) HBT at $V_{CE} = 4$ V and $I_C = 12$ mA and that of measured photoresponsivity for a PIN-PD. The modulated optical input power into the CEHBT and PIN-PD is 0 dBm.

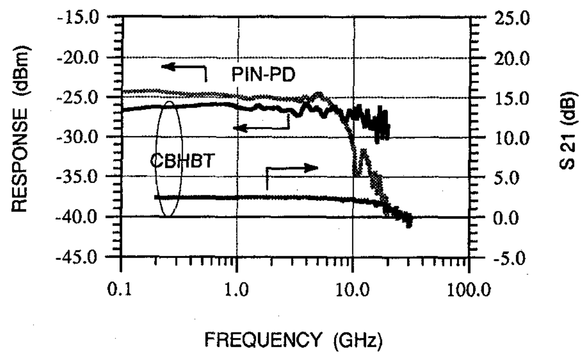

Fig. 3. Frequency dependence of measured photoresponsivity and small-signal gain $|S_{21}|$ for a CB (common base) HBT at $V_{BC} = 3$ V and $I_E = 3$ mA and that of measured photoresponsivity for a PIN-PD. The modulated optical input power into the CBHBT and PIN-PD is 0 dBm.

the base-collector junction can be considered to an input-signal and the input port (base terminal for the CEHBT or emitter terminal for the CBHBT) is terminated to 50 Ω (Fig. 1). The efficiency, i.e., the ratio of absorbed to incident photons is the quantum efficiency of the photodiode formed by the base-collector junction of the HBT photodetectors [1], [2]. The efficiency estimated from the RF responsivity of the CBHBT was about 15%, while that of the CEHBT was about 31%. The HBT's with different efficiencies were fabricated using different metal-contact-layouts and different processes to utilize for other microwave applications. The efficiency for the PIN-PD was 42%. The efficiencies of HEMT's and MESFET's are reported to be less than 10% [4].

In order to evaluate the influence of shot noise produced by collector and base currents, the signal-to-noise ratio (SNR) of the CEHBT was compared with the PIN/50-Ω FET-amplifier at 10 GHz and the EOM's modulation index of 0.34. The FET-amplifier had a noise figure of 5.4 dB with gain of 15.1 dB. Fig. 4 shows the detected signal and noise power. The CEHBT has a 10-dB higher SNR and a 12-dB lower noise floor than the PIN/50-Ω FET-amplifier at an optical power of −30 dBm. The CEHBT also has good linearity for the output versus the input power. The noise issues of HBT's as photodetectors will be quantitatively discussed in future work.

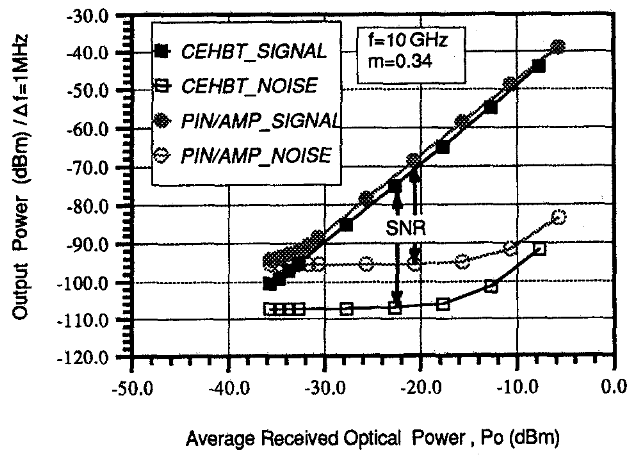

Fig. 4. Received average optical power dependence of detected signal and noise power for CE HBT and a PIN/FET amplifier at 10 GHz. The bias condition of the CEHBT is $V_{CE} = 4$ V and $I_B = 70$ μA. The noise figure of the FET amplifier is 5.4 dB with a gain of 15.1 dB at 10 GHz. The modulation index m of the EOM is 0.34 at 10 GHz.

IV. Conclusion

We have shown for the first time that HBT's can be used as high-speed photodetectors. A 3-dB bandwidth of 2 GHz and above 20 GHz are obtained in a CEHBT and a CB HBT, respectively. It was proved that the small-signal gain $|S_{21}|$ and optical coupling efficiency are strongly reflected in the RF responsivity. The use of a common-base configuration will allow for broadband operation up to the cutoff frequency of the HBT. HBT photodetectors have a higher optical coupling efficiency than HEMT's and MESFET's. The CEHBT has a higher signal-to-noise ratio than a PIN/50-Ω FET- amplifier at 10 GHz. The performance of the HBT photodetectors can be further improved by optimizing the electrode's shape and size.

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