A Comparison of Noise Performance between a PIN Diode and MMIC HEMT and HBT Optical Receivers

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Abstract

The noise performance of MMIC HEMTs and HBTs are experimentally compared with conventional PIN photodiodes. HEMT and HBT are fabricated using a conventional MMIC process. These devices are characterized using a modified electrooptic on-wafer probe station and a LiNbO3 optical external modulator. The attained signal-to-noise ratio of HEMT, HBT and PIN detectors at a signal frequency of 1GHz, an optical carrier of 0.83μm and a frequency bandwidth of 1MHz are 52.3dB, 55.9dB and 54.1dB, respectively.

INTRODUCTION

Fiber optic subcarrier transmission links are intensively investigated for use in phased array antenna, microcellular radio and CATV distribution networks [1]-[3]. In these systems, a large number of optical/RF transducers are required for signal radiation or distributions. MMIC compatible devices, e.g. MESFET, HEMT and HBT have been studied as high-speed optical detectors [4]-[6], in order to realize compact and cost-effective optical/RF transducers. However, most of three terminal devices investigated so far are not MMICs, but discrete transistors. The characteristics of these devices under illumination are mainly examined on the frequency amplitude response. MSM photodetectors which are two terminal devices have been used for OEIC receivers due to its simple planar geometry [7]-[9], however, the responsivity of the devices is lower than that of three terminal devices.

In this paper, the noise performance of HEMT and HBT photodetectors, which are respectively fabricated by HEMT and HBT MMIC processes, has been studied and compared with that of a PIN photodetector [10]-[12]. The higher responsivity of the HEMT is expected due to photovoltaic and photoconductive effects [13]. HBT can have large current gain because of a phototransistor operation [14]. However, the noise performance of these MMIC devices under illumination has not been well evaluated, particularly at microwave frequency bands. This paper first describes the basic frequency response of HEMT, HBT and PIN devices. Second, the noise characteristics are experimentally studied in terms of signal-to-noise ratio.

FREQUENCY RESPONSE

MMIC HEMT and HBT photodetectors are characterized using a modified electrooptic on-wafer probe station [12]. Fig.1 shows the frequency response of these devices as well as a PIN photodiode. The PIN photodiode used in the experiment has a responsivity of 0.3mA/mW and a 3-dB bandwidth of 10GHz. An external optical modulator fabricated on a LiNbO3 substrate was used for microwave subcarrier signal generation. Since the performance of the EOM is subtracted from the frequency response, Fig.1 shows the intrinsic response of each photodetector. The HEMT, whose cutoff frequency is 40GHz, has a gate length of 0.25μm and a gate width of 50μm. The HBT, with a cutoff frequency of 20GHz, has an emitter length of 1.5μm and an emitter width of 10μm. The HBT is configured in a three finger structure which improves optical coupling efficiency. Optical power is coupled to each detector via a single mode fiber and optical lenses, as shown in Fig.2(a). The spot diameter is less than 20μm and the illuminated dc power is 0.4mW. The 0-dB response

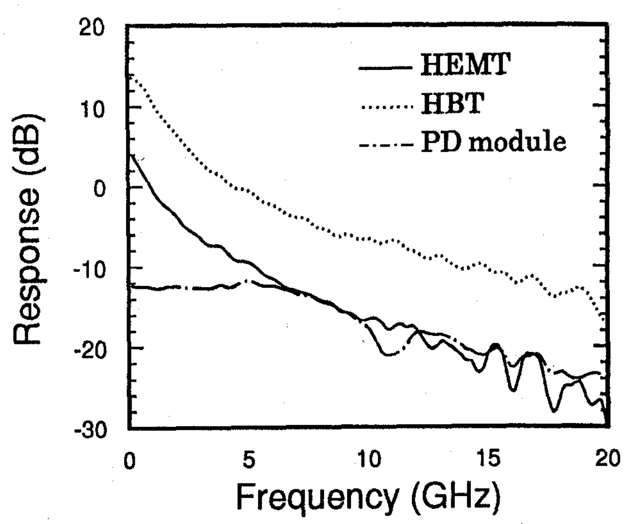

Fig.1. Frequency response of HEMT, HBT and PIN detectors. 0-dB response value corresponds to a responsivity of 1mA/mW.

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value on the vertical axis of Fig.1 corresponds to the responsivity of 1mA/mW. Thus, HEMT as well as HBT devices can achieve higher responsivity than a PIN device, particularly at lower frequency bands. The similar performance was obtained by discrete MESFETs [15].

NOISE PERFORMANCE

In order to evaluate the influence of high responsivity on the noise performance, the signal-to-noise ratio (SNR) was measured at a signal frequency of 1GHz. Fig.2 shows the experimental setup which is composed of a 0.83-μm laser diode, a LiNbO3 optical external modulator, a single mode fiber, a spectrum analyzer, microwave amplifiers, and a modified electrooptic on-wafer probe station for the MMIC HEMT and HBT. Fig.2(b) shows the experimental setup for a PIN photodiode. The noise figure and input impedance of the amplifier are 5.9dB and 50ohm, respectively, at a frequency of 1GHz.

The noise performance was evaluated using the following process:

(1) First, the collector voltage of the HBT is optimized at an optical input power of 0.6μW where the noise is dominated by the thermal. Fig.3(a) shows the collector current dependence of the detected signal and noise level. The measured frequency bandwidth is 1MHz. The maximum SNR of 17.9dB was obtained at a collector current of 1.8mA which corresponds to a base current of 50μA.

(2) Second, the detected signal level at P_1 of the HBT is equalized to that at P_2 of the PIN using a microwave amplifier at an optical input power of -7.8dBm where the noise is dominated by the laser intensity noise. The gain of the amplifier is fixed at 20dB because of the amplitude difference between HBT and PIN at 1 GHz, as shown in Fig.1. Figs.3(b) and 3(c) show the detected signal and noise level of the HBT and PIN detectors, and the SNR of these devices, respectively. Despite high responsivity of HBT detector, the SNR of 55.9dB at an optical input power of -4.6dBm was obtained, whose value is larger than that of PIN detector (54.1dB at an optical input power of -2.4dBm).

The bias condition of HEMT is also optimized under illumination of 0.6μW optical power. Fig.4(a) shows the drain current dependence of the detected signal and noise level. The maximum SNR of 16.2dB was obtained at a drain current of 1.4mA. Figs.4(b) and 4(c) show the comparison of HEMT and PIN detectors. The detected signal level of HEMT is lower than that of PIN detector due to a fixed amplifier gain of 20dB. The attained SNR of HEMT at an optical input power of -6.9dBm is 52.3dB which is smaller than that of PIN detector.

DISCUSSION

Although our experiment is not yet complete to evaluate the noise performance of MMIC HBT and HEMT devices, the following results are obtained. The equivalent circuits of these devices consist of two functions, i.e. photodetection and amplification. Because of the amplification of signals, the three terminal devices have higher responsivity than PIN devices. The amplifier connected to the output of PIN diode corresponds to the amplification function of HBT or HEMT devices. The measured minimum noise level is determined from the noise figure of amplifiers which amplify the detected signals. The noise figure of the amplifier used in the experiment for the PIN device is 5.9dB and the measured minimum noise level is -92dBm. As for the HBT

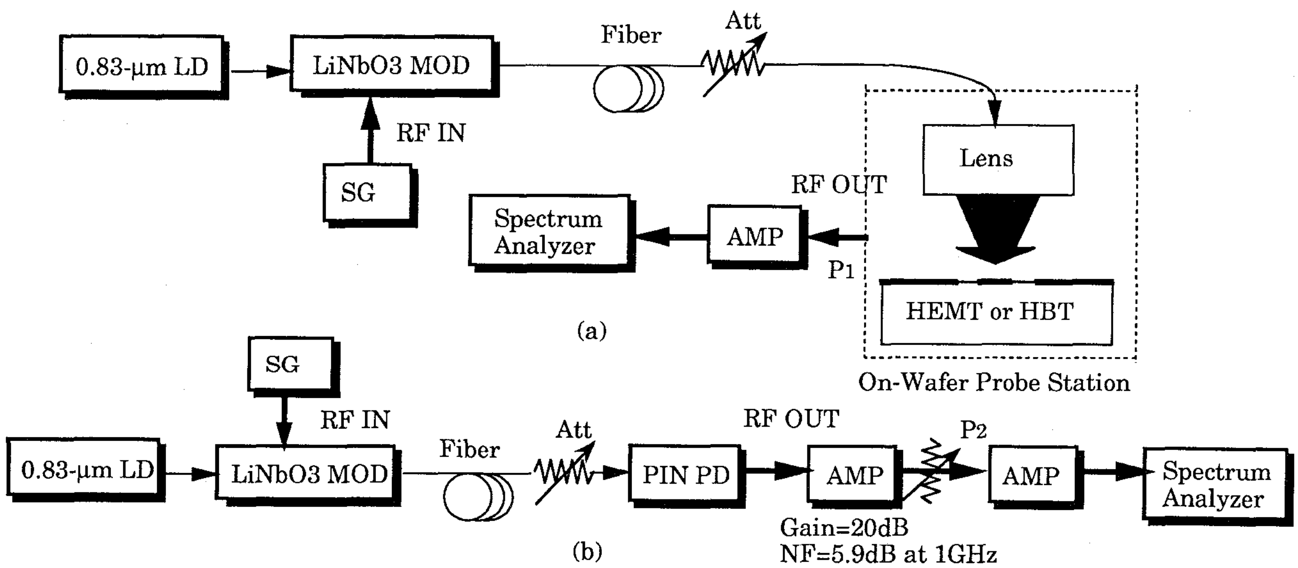

Fig.2. Experimental Setup for noise characterization of HEMT, HBT and PIN devices. (a) Amplitude response for HEMT and HBT. (b) Amplitude response for PIN.

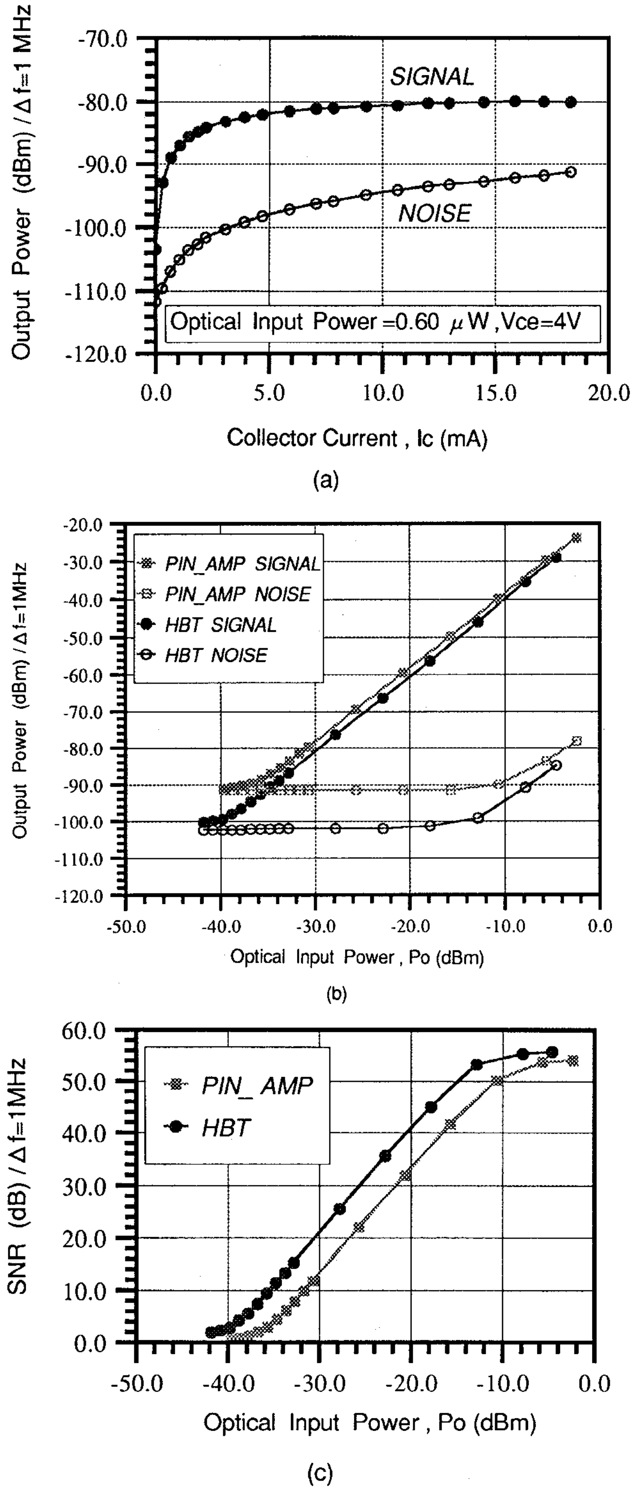

Fig.3. Noise characteristics of HBT detector. Measured noise bandwidth and signal frequency are 1MHz and 1GHz, respectively. (a) Detected signal and noise power versus collector current. (b) Detected signal and noise power versus optical input power. (c) Signal-to-noise ratio versus optical input power.

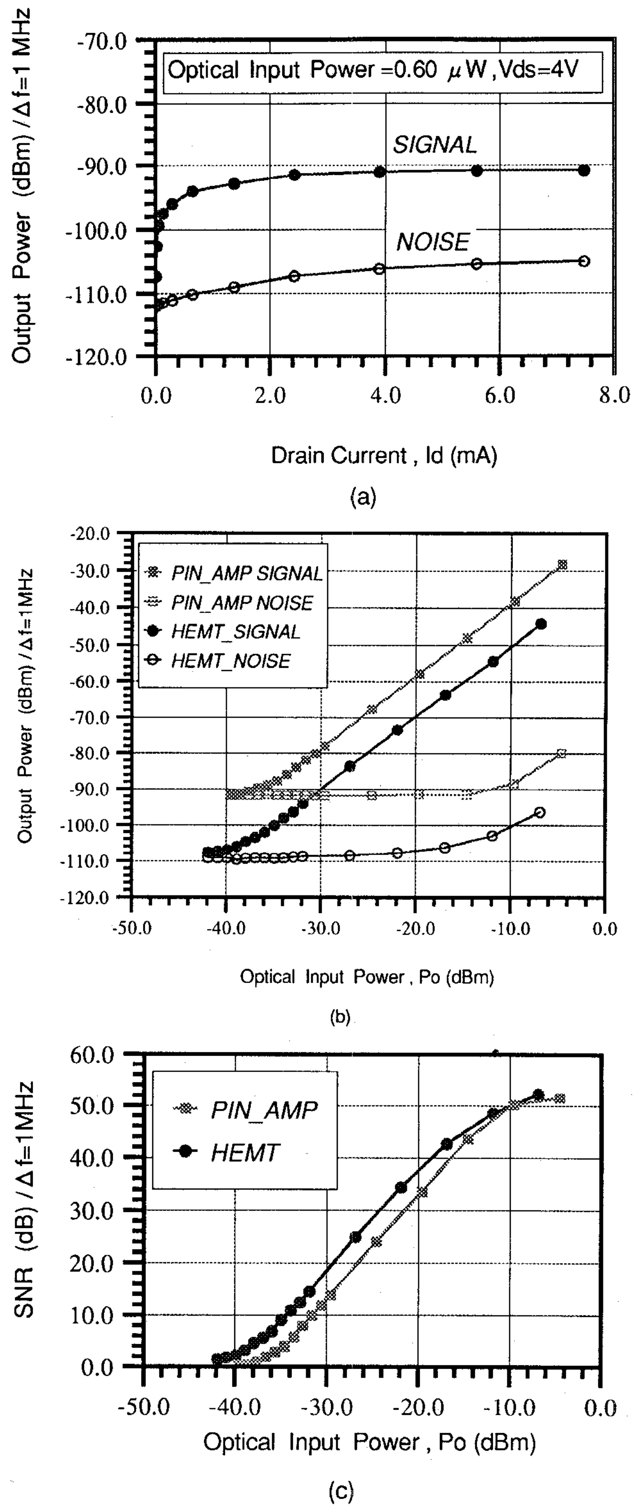

Fig.4. Noise characteristics of HEMT detector. Measured noise bandwidth and signal frequency are 1MHz and 1GHz, respectively. (a) Detected signal and noise power versus drain current. (b) Detected signal and noise power versus optical input power. (c) Signal-to-noise ratio versus optical input power.

device, the minimum noise level is -102dBm. The 10-dB improvement of the HBT device is caused from the low noise characteristics of the internal amplification of the HBT. The SNR of the HEMT is lower than that of the HBT because the coupling efficiency of the one-finger type of the HEMT is lower than that of the three-finger type of the HBT.

CONCLUSION

The noise performance of MMIC HEMT and HBT photodetector are evaluated using 0.83μm optical carrier and 1-GHz signal frequency. Due to the MMIC structure, electrooptic on-wafer probe station was used for characterization of these devices. The attained SNR of HEMT, HBT and PIN detectors in our experiment are 52.3dB, 54.1dB and 55.9dB, respectively. MMIC HEMT and HBT can be expected to realize low noise and cost-effective optical/RF transducers.

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