Monolithic Ultra-broadband Transimpedance Amplifiers using AlGaAs/GaAs HBTs

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ABSTRACT

Monolithic ultra-broadband transimpedance amplifiers have been developed using AlGaAs/GaAs HBTs. The amplifiers have exhibited DC to 13.4-GHz bandwidth, with an 18.1-dB gain, and a 49.8-dBΩ transimpedance. These results have been brought about by optimized circuit design considering large signal operation and an affordable HBT fabrication process using a self-aligned method.

INTRODUCTION

Key characteristics required for preamplifiers in optical transmission systems are a wide bandwidth, a wide dynamic range, and low input noise current performance. These requirements have presented a challenge to develop transimpedance amplifiers using ultra high-speed compound semiconductor devices. Among the devices, heterojunction bipolar transistors (HBTs) are especially suitable for this amplifier configuration[(1)-(3)], because of their large transconductance and high cut-off frequency, as well as uniform threshold voltage.

The present paper reports on the monolithic ultra-broadband transimpedance amplifiers, using AlGaAs/GaAs HBTs, for 10 Gb/s optical transmission systems. High performances of the amplifiers are mainly due to two factors, i.e., optimized circuit design for large signal operation and affordable fabrication process using a self-aligned method.

CIRCUIT DESIGN

Two categories of transimpedance amplifiers have been developed: basic-coupled and Darlington-coupled buffer amplifiers. Figures 1 and 2 show their equivalent circuits and chip photographs, respectively. The circuit design was carried out, using the harmonic balance method. Large signal device parameters were thereby extracted from both the DC characteristics and small signal S-parameters, measured under various collector bias current conditions. In designing transimpedance amplifiers, it is necessary to consider a trade-off relation between transimpedance and bandwidth, resulting from the transimpedance dependence on negative feedback quantity. In Fig. 1, bandwidths for the amplifiers were designed to be sufficient for 10-Gb/s optical data transmission, while still retaining gain as high as possible. In Fig. 2, the emitter size for the HBTs employed, is 2 μm x 10 μm. Level shift diodes utilized built-in voltage over base-emitter heterojunction. WSiN thin film resistors were employed to suppress impedance fluctuation at high frequencies. Chip size is 320μm x 320 μm for both the amplifiers.

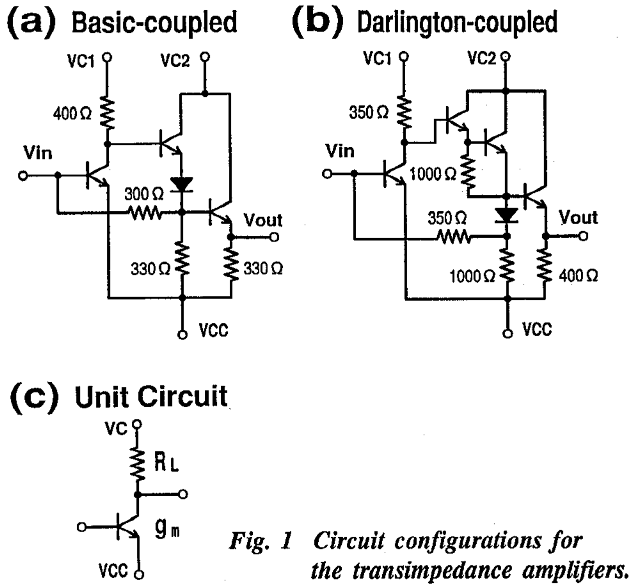
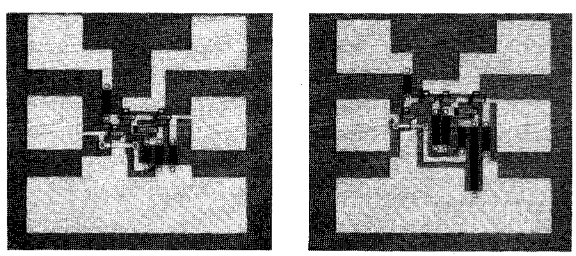


Fig. 1 Circuit configurations for the transimpedance amplifiers.



(a) *(b)*

Fig. 2 Chip photographs of the basic-coupled buffer amplifier (a) and the Darlington-coupled buffer amplifier (b).

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FABRICATION PROCESS AND HBT CHARACTERISTICS

Figure 3 shows the process flow for the proposed self-aligned HBT fabrication method. Layer structures, prepared by MBE on 2-inch semi-insulating GaAs substrates, include an InGaAs cap layer (100 nm, $2x10^{19}$ cm^{-3}), an AlGaAs emitter layer (200 nm, $3x10^{17}$ cm^{-3}), a GaAs base layer (80 nm, $4x10^{19}$ cm^{-3}), and a GaAs collector layer (500 nm, $5x10^{16}$ cm^{-3}). Emitter contact metal is composed of 200 nm-thick WSi and 500 nm-thick Au. This metal system was used as a mask on emitter mesa dry etching. The 200-nm thick SiO_2 side wall formation was followed by AuMn base metal evaporation, self-aligned to the emitter mesa.

The above-mentioned process has brought about low emitter contact resistances and their good uniformity. Figure 4 shows the standard deviation in base turn-on voltage, σV_{BE}, as a function of emitter current density, J_E. A σV_{BE} value of 7.5 mV has been achieved for the present HBTs, even at a large J_E of 4 x 10^4 A/cm^2. This value is 1/9 of the σV_{BE} value for the conventional HBTs[4]. Such a remarkable improvement is attributed to the thick emitter metal and the InGaAs cap layer in the present HBT structure, in contrast to AuGe-Ni alloyed emitter metal and a GaAs cap layer in the conventional HBT structure. Typical transconductance, g_m, is 3.6 mS/μm^2. Its standard deviation, σg_m, over the wafers has also been reduced to 0.10 mS/μm^2. Current gain, β, and its standard deviation, $\sigma\beta$, are 17 and 0.92, respectively. The cut-off frequency, f_T, and the maximum oscillation frequency, f_{max}, are 41 and 44 GHz, respectively.

The effects of the uniformity improvement, obtained for the HBT DC characteristics, on amplifier performances are roughly estimated using a unit amplifier circuit shown in Fig. 1(c). The voltage gain, G_V, of the unit amplifier is expressed as follows:

$$G_V = - g_m \cdot R_L \qquad (1)$$

where R_L is a load resistance (400 Ω). According to Eq. (1), the typical g_m value of 3.6 mS/μm^2 presents a G_V value of 28.8, while σg_m values of 0.1 mS/μm^2 for the present HBTs and 0.94 mS/μm^2 for the conventional HBTs lead to σG_V values of 0.8 and 7.5, respectively. These voltage gain deviations correspond to 0.25 and 2.3 dB, respectively. Therefore, the proposed HBT fabrication process is expected to attain excellent uniformity in the amplifier performances, as well as in discrete device characteristics.

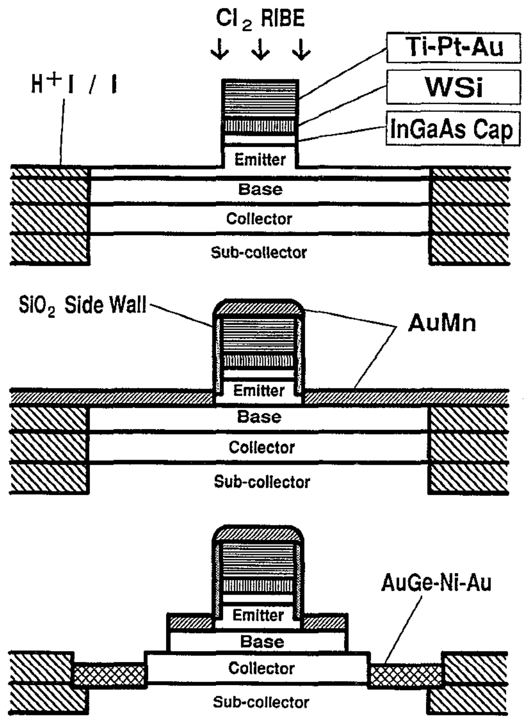

Fig. 3 Process flow for the self-aligned HBT fabrication.

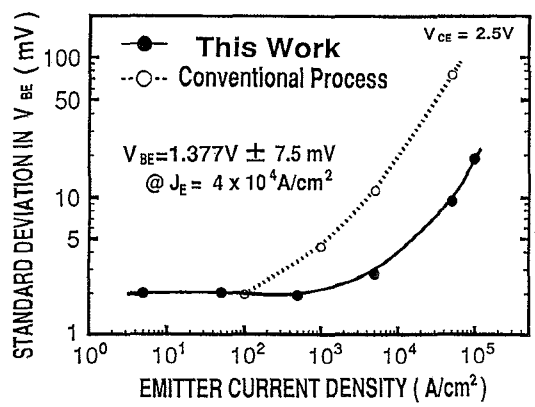

Fig. 4 σV_{BE} as a function of J_E.

AMPLIFIER PERFORMANCE

Small signal gain, input/output power response, 3rd-order intermodulation, and NRZ signals transmission characteristics for the amplifiers were measured on wafers using coplanar RF probes. Figure 5 shows the gain bandwidth characteristics for the two categories of amplifiers. The basic-coupled buffer amplifier exhibits DC to 13.4-GHz bandwidth, with an 18.1-dB gain when bias voltages are V_{C1} = 9V and V_{C2} = 5V. On the other hand, the Darlington-coupled buffer amplifier showed a little smaller bandwidth, for DC to 12.2 GHz with an 18.5-dB gain, when bias voltages are V_{C1} = 9V and V_{C2} = 7V. The transimpedance for the basic-coupled buffer amplifier, calculated from S-parameters, was 49.8 dBΩ, as shown in Fig. 6, while that for the Darlington-coupled buffer amplifier was 51.1 dBΩ.

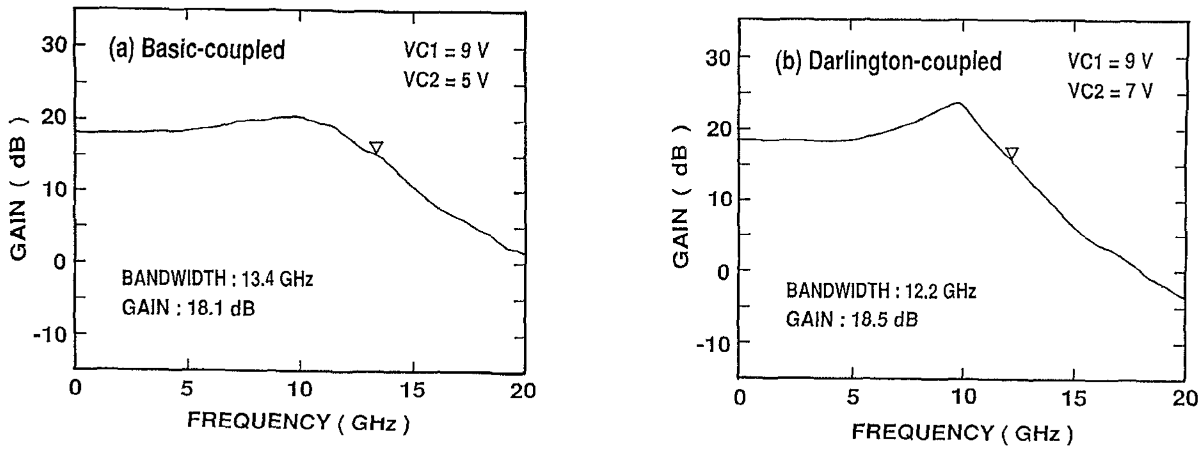

Fig. 5 Gain bandwidth characteristics of the HBT amplifiers.

Figure 7 summarizes direct-coupled HBT broadband amplifier performances that have ever been reported. In Fig. 7, the transimpedance amplifiers[1]-[3] are compared with the conventional direct-coupled ones[5],[6]. The author's transimpedance amplifiers show fairly good results, in regard to both bandwidth and gain. The standard deviations in gain and 3-dB gain roll-off frequency over the wafers were as small as 0.42 dB and 0.47 GHz, respectively, for the basic-coupled buffer ones when bias voltages are V_{C1} = 7V and V_{C2} = 5V. We believe that these excellent uniformity results from highly uniform characteristics of the HBTs, achieved by the reliable self-aligned fabrication process.

Figures 8 and 9 show input/output power response and the 3rd-order intermodulation distortion, respectively, measured at 8 GHz, for the basic-coupled buffer amplifier. As shown in Fig. 8, 1-dB gain compression output power is 5 dBm, corresponding to the maximum optical input power of -5 dBm when the amplifier receives signals from an avalanche photo diode with an avalanche gain of 5. This value is sufficient as an input power for 10 Gb/s optical transmission systems. The large signal simulation using the harmonic balance method presents fairly good agreements, both in the input/output power response and the 3-rd order intermodulation distortion. These agreements suggest that the extracted large signal HBT parameters are reasonable.

Figure 10 shows on-wafer pulse response to 10 Gb/s NRZ signals for the basic-coupled buffer amplifier. In this measurement, there is 4-dB cable loss at 8 GHz on each side of input and output. Nevertheless, clear opening eye pattern was obtained, as shown in Fig. 10. Similar pattern was obtained also for the Darlington-coupled buffer amplifier. These results indicate that both amplifiers are adapted to 10 Gb/s optical transmission systems.

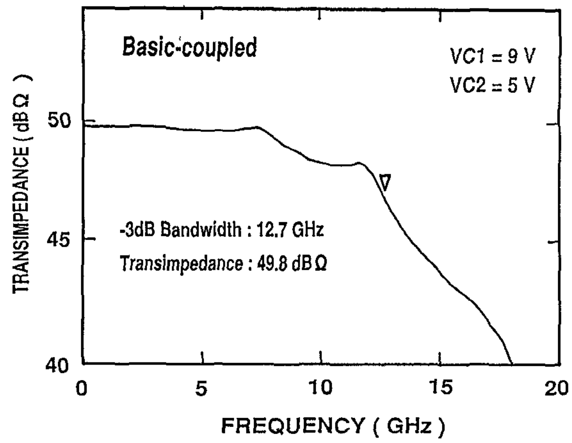

Fig. 6 Frequency dependence of the transimpedance of the HBT amplifier performances.

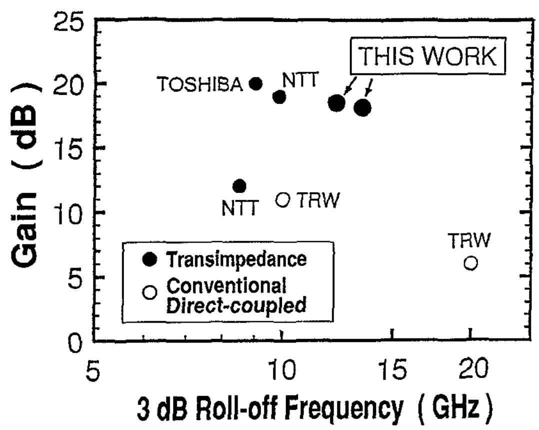

Fig. 7 Direct-coupled HBT amplifiers that have ever been reported.

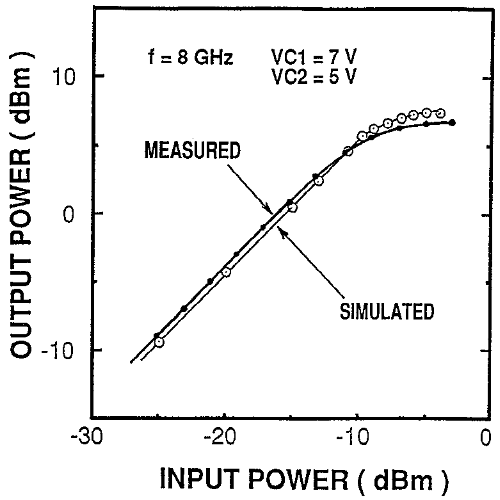

Fig. 8 Input/output power response of the basic -coupled buffer amplifier.

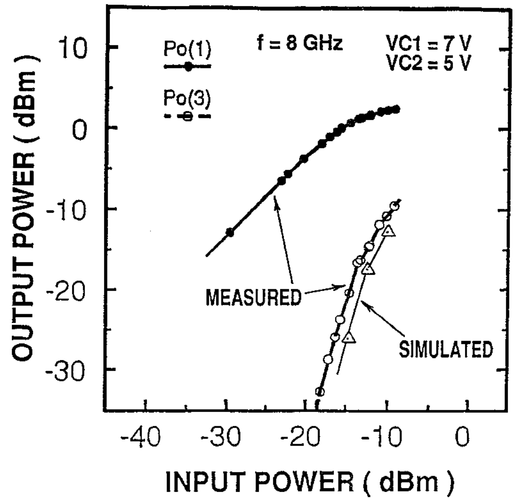

Fig. 9 The 3rd-order intermodulation distortion characteristics of the basic-coupled buffer amplifier.

CONCLUSIONS

We have developed monolithic ultra-broadband transimpedance amplifiers using AlGaAs/GaAs HBTs. The bandwidth and gain of the basic-coupled buffer amplifier were 13.4 GHz and 18.1 dB, respectively. The standard deviations in gain and 3-dB roll-off bandwidth over 2-inch wafers were as small as 0.42 dB and 0.47 GHz, respectively. These characteristics were achieved on the basis of the optimized circuit design considering large signal operation and the affordable HBT fabrication process. Excellent 10 Gb/s NRZ pulse response has confirmed that the amplifiers are adapted to 10 Gb/s optical transmission systems.

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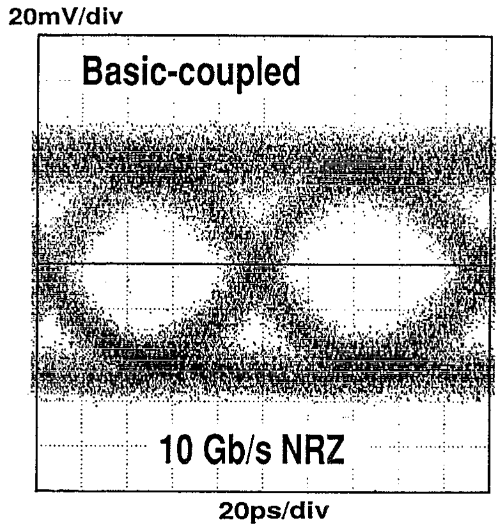

Fig. 10 Pulse response to 10 Gb/s NRZ signals, obtained for the basic-coupled buffer amplifier

REFERENCES

(1) Y.Yamauchi et al., " Direct-Coupled Amplifier using AlGaAs/GaAs Ballistic Collection Transistors (BCTs)," 1988 IEEE GaAs IC Symp. Dig., p.121
(2) J.Akagi et al., " GaAs/AlGaAs HBT Technology for 10 Gb/s Optical Communication," Proc. 16th Int. Symp. GaAs and Related Compounds 1989, p.695
(3) H.Nakajima et al., " Wideband Direct-Coupled Differential Amplifiers utilizing AlGaAs/GaAs HBTs," Electron. Lett. 24(18), p.1178, 1988
(4) N.Hayama et al., " Fully Self-Aligned AlGaAs/GaAs Heterojunction Bipolar Transistors for High-Speed Integrated-Circuits Application," IEEE Tran. Electron Devices, 35(11), p.1771, 1988
(5) K.W.Kobayashi et al.," GaAs Heterojunction Bipolar Transistor MMIC DC to 10 GHz Direct-Coupled Feedback Amplifier," 1989 IEEE GaAs IC Symp. Dig., p.87
(6) K.W.Kobayashi et al., " GaAs HBT MMIC Broadband Amplifiers from DC to 20 GHz," 1990 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symp. Dig., p.19