High-Gain GaInP/GaAs HBT Monolithic Transimpedance Amplifier for High-Speed Optoelectronic Receivers

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Abstract

A self-aligned GaInP/GaAs HBT technology was used to develop a monolithic high-gain transimpedance amplifier suitable for optical communication receivers. On-wafer probe measurements revealed a gain (S_{21}) of 18.8 dB with a bandwidth of 13.5 GHz and input, output matching better than –8 dB. The amplifier showed a sensitivity of –15 dBm for 10 Gb/s NRZ 2^7-1 pseudo-random bit sequence with a BER of 10^{-9}. The noise figure of the amplifier was better than 7.5 dB over the bandwidth of operation.

Introduction

High-speed optical communication receivers often use a high-gain transimpedance preamplifier in conjunction with a photodiode to transform the optical signal into electrical signal. These transimpedance amplifiers are utilized with various technologies such as hybrid and monolithic HEMT and HBT based integrated circuits. Very high bandwidths have been reported for receivers fabricated by various technology approaches, such as 23 GHz for a monolithic InP/InGaAs HBT transimpedance amplifier [1] and 20 Gb/s operation speed with a sensitivity of –17.6 dBm at a bit error rate of 10^{-9} has been achieved using InP HBT OEICs [2]. A bandwidth of 18.5 GHz has been demonstrated for a monolithic InAlAs/InGaAs HEMT photoreceiver [3] while AlGaAs/InGaAs preamplifiers showed 40 Gb/s transmission capability with a bandwidth of 34.6 GHz and a transimpedance gain of 41.6 dBΩ [4]. The use of InP based technology offers the advantage of integration possibility with PIN photodiodes and thus operation at 1.55 μm wavelength.

Employment of GaAs based technology allows realization of integrated optical receivers for short wavelength (~0.8 μm) communication. It can also be used in conjunction with InGaAs PIN photodiodes in hybrid form for long wavelength systems. GaAs technology offers the advantages of high throughput, high yield and process maturity over its InP based counterpart. Moreover, the lack of integration capability with 1.55 μm photodiodes can be compensated by the significant progress made recently in flip-chip mounting technology [5]. An additional advantage of this approach is the possibility of selecting optimum PIN photodiode characteristics so that small input power levels and good overall quantum efficiency can be achieved.

In this work, we present a high-gain transimpedance amplifier with a transimpedance gain of 52 dBΩ and a bandwidth of 13.5 GHz. GaInP/GaAs HBT technology has been employed for amplifier realization since it offers several advantages over AlGaAs/GaAs, such as high injection efficiency and excellent etching selectivity between GaInP and GaAs. Moreover, the reduced toxicity TBA, TBP precursors employed in this work proved to result in excellent discrete device and IC chip performance as previously reported by the authors [6][7].

Design of the Transimpedance Amplifier

On-wafer probe measurement of discrete 2×30 μm^2 emitter finger HBTs was used to model the devices in HP-EESOF LIBRA environment. A physical small signal model was extracted from cold and hot S-parameter measurements [8]. Moreover DC and multi-bias S-parameter data were used to model the transistor under large-signal operation [9].

The developed small and large signal models were used to design the transimpedance amplifier. The design employed two cascaded common-emitter stages (transistors T_1 and T_3) with dual-feedback network (R_{f1}, R_{f2} and R_{f3}) for improved bandwidth and gain stability [10][11] (see Fig. 1). A common-base output stage (transistor T_6) was used for improved output matching to 50Ω. The design was optimized for high-gain yet large-bandwidth operation.

GaInP/GaAs HBT MMIC Technology

The HBT MMIC technology employed in this work takes advantage of several advanced techniques that proved to permit realization of high-performance high-reliability discrete and integrated HBT circuits [6][7].

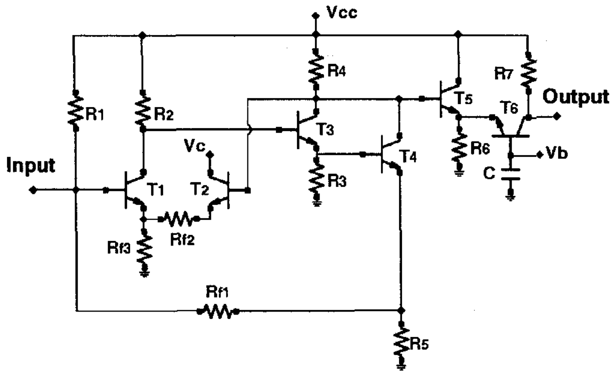

Fig. 1: Schematic of the HBT transimpedance amplifier employed in this work.

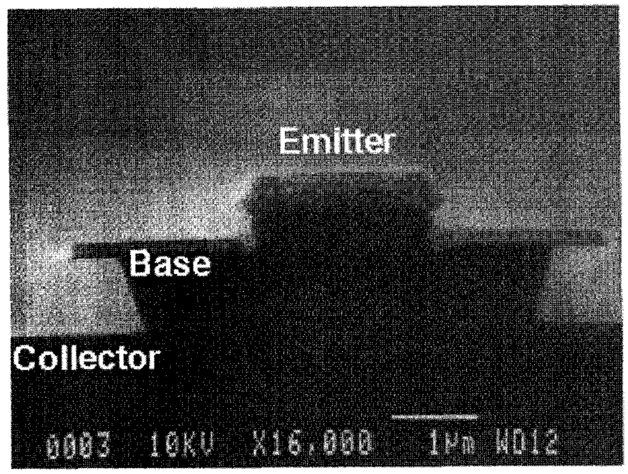

Fig. 2: Cross-section of the fabricated self-aligned GaInP/GaAs HBT.

The HBT layers were grown using a specially developed for this purpose hydride and hydrogen-free chemical beam epitaxy (CBE) process with very low defect density (<10 def/cm^2). Details of the process have been previously reported by the authors [7]. Self-aligned GaInP/GaAs single HBTs were fabricated on these layers using simple, all wet chemical etching which minimizes layer damage and allows excellent selectivity. Non-alloyed metals were deposited for emitter, base and collector contacts. A laterally etched undercut (LEU) technology was developed and applied in the base-collector region to reduce the base-collector capacitance (C_{BC}) while avoiding base resistance degradation. Silicon dioxide was used for passivation. Fig. 2 shows the cross-section of a 2μm emitter finger HBT fabricated with this technique.

Fabricated 2×30 μm^2 HBTs showed a DC gain of 35 and cut-off frequency (f_T) and maximum oscillation frequency (f_{max}) of 55 and 80GHz, respectively. Reliability tests performed on the devices revealed only 3% degradation in the current gain after 1000 hours of bias and temperature stress (J_c=40kA/cm^2 and T_j=150 °C).

Integrated resistors were realized using 700Å Ni/Cr thin metal film deposition. MIM monolithic capacitors for high-frequency grounding were fabricated using Al_2O_3. The amplifier chip was connected to the high-frequency test ports via 50Ω CPW lines. Fig. 3 shows a photomicrograph of fabricated transimpedance amplifier in GaInP/GaAs HBT technology.

Transimpedance Amplifier Characterization

On-wafer small-signal S-parameter measurements were performed to assess the amplifier performance. A forward transmission gain (S_{21}) of 18.8 dB with a 13.5 GHz bandwidth was measured. Input and output reflection coefficients were better than -8 dB over the bandwidth of operation (see Fig. 4).

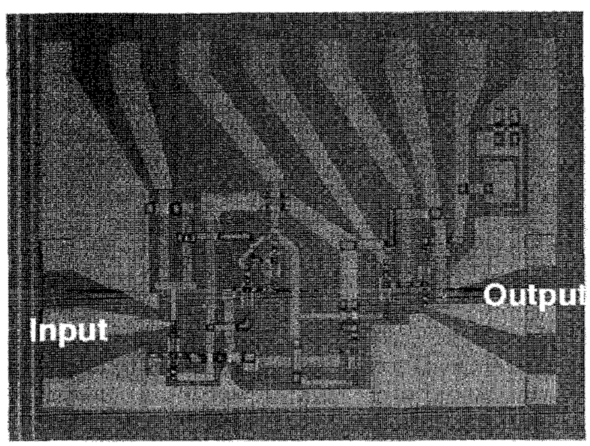

Fig. 3: Photomicrograph of the fabricated transimpedance amplifier. The chip size is 800 × 1125 μm^2.

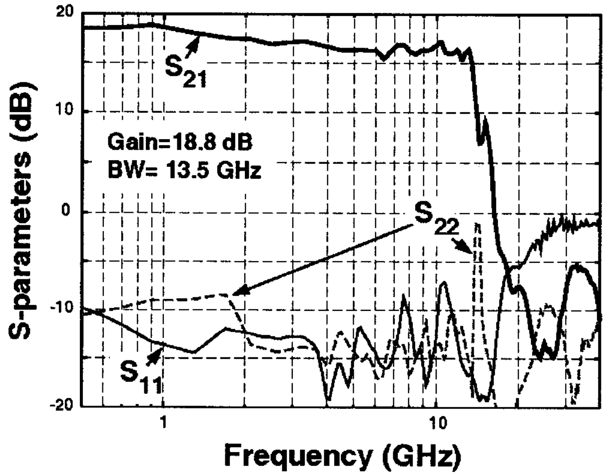

Fig. 4: Measured S-parameters of the transimpedance amplifier.

Moreover, the effective transimpedance gain was calculated from measured small-signal S-parameters and showed a flat gain of 52 dBΩ over a bandwidth of 13.5 GHz (see Fig. 5).

The gain-bandwidth product of the amplifier calculated to be 118 GHz and is the highest reported figure for GaInP/GaAs HBT technology.

Eye-diagram tests were performed for the amplifier at 10 Gb/s with a 2^{15}-1 NRZ pseudo-random bit sequence (prbs) using an Anritsu MP1701B pattern generator and a Tektronix 11801B sampling oscilloscope. Fig. 6 shows the measured results indicating very open eye characteristics, thus, proper operation of the amplifier at 10 Gb/s input data.

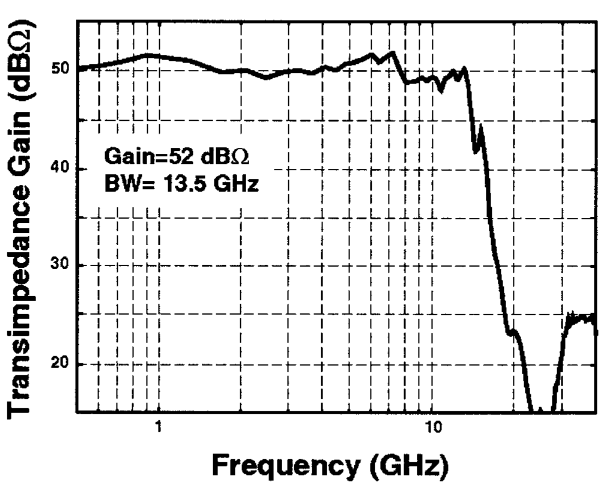

Fig. 5: Effective transimpedance gain of the amplifier calculated from small-signal S-parameter measurement.

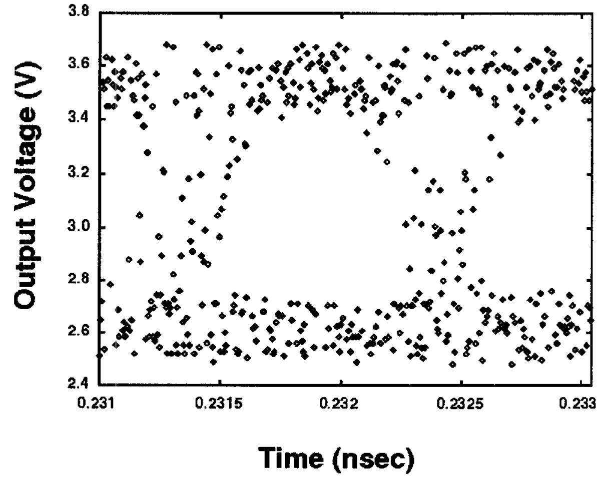

Fig. 6: Measured eye-diagram of the transimpedance amplifier at 10 Gb/s 2^{15}-1 NRZ prbs.

The electrical sensitivity of the amplifier was measured using an Anritsu MP1702A bit-error rate detector. Fig. 7 shows the bit-error-rate measured at 10 Gb/s NRZ pseudo-random bit sequence with different word lengths. The 2^7-1 word length showed a sensitivity of -15 dBm at 10^{-9} bit-error rate while the 2^{15}-1 word length had a lower sensitivity of -12 dBm.

The error probability (bit-error rate) of any system is inversely proportional to the exponential of the signal to noise ratio at the output of that system. Therefore, to improve the bit-error rate performance of the amplifier, one has to design for very low-noise performance. The electrical sensitivity data of -15 to -12 dBm reveals that the noise performance of the amplifier could be further optimized. By way of comparison, InP-based HBT photoreceivers showed a sensitivity of –20 dBm for data rates of 10 Gb/s at a bit-error rate of 10^{-9} [2]. Photoreceivers developed by the authors using distributed amplifier also show sensitivity of better than –30 dBm at 10 Gb/sec input signal [12].

The overall noise performance of the receiver chip is determined by the transimpedance amplifier and photodiode noise. To evaluate the dominant photoreceiver noise, we have, therefore, measured the noise figure of the amplifier from 250 MHz to 18 GHz under nearly 50 Ω source termination. The amplifier showed a noise figure of 4 to 7.5 dB over the bandwidth of operation. This high value of noise figure is attributed to the non-optimized HBT layer structure, geometry and biasing, and also to non-optimized circuit design for low-noise operation.

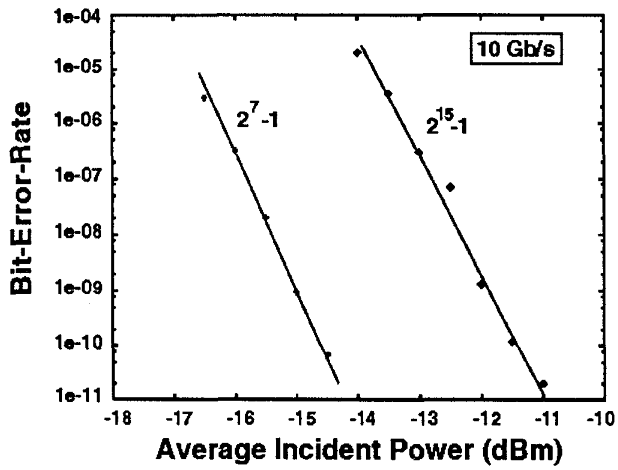

Fig. 7: Bit-error rate of the transimpedance amplifier as a function of average incident power measured at 10 Gb/s NRZ prbs.

Conclusions

Overall, a high-gain, high-bandwidth transimpedance amplifier was designed, fabricated and tested in this work. To our knowledge, the gain-bandwidth product of this amplifier is the highest reported figure for GaInP/GaAs HBT technology. This amplifier can be employed in high-speed, low-noise, medium to long-haul optoelectronic receivers. Simplicity in fabrication, high yield, high reliability and high performance are some of the advantages of the technology employed for its fabrication.

Acknowledgment

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