GaInP/GaAs HBT Broadband Monolithic Transimpedance Amplifiers and Their High Frequency Small and Large signal Characteristics

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Abstract - Monolithic broadband transimpedance amplifiers were developed using GaInP/GaAs single HBTs. The HBTs showed a cut off frequency (f_T) of 60GHz and maximum oscillation frequency (f_{max}) of 100GHz. The fabricated amplifiers had a maximum bandwidth of 19GHz and an associated transimpedance gain of 47dBΩ. The large signal characteristics of two transimpedance amplifier designs with similar gain were also investigated and showed that the cascode approach is much less sensitive to input power level.

1. Introduction

High speed and high capacity transmission systems are necessary for next generation optical communications. Considerations made in the development of such systems include process yield which is related to cost reduction, performance stability and device life time under actual circumstances.

AlGaAs/GaAs HBT preamplifiers based on advanced p+ regrown extrinsic technology have demonstrated excellent performance (34.6GHz) with a transimpedance gain of 41.6dBΩ [1]. GaInP/GaAs Heterojunction Bipolar Transistors (HBTs) are well known alternatives over AlGaAs/GaAs HBTs due to their attractive features such as excellent etching selectivity which contributes to process yield, device reliability [2] and improved carrier injection efficiency [3],[4] due to their large valence band discontinuity. GaInP/GaAs HBT monolithic transimpedance amplifiers can be used for short distance communication (0.8μm) such as board-to-board or chip-to-chip data links but also as an alternative solution to InP-based technology for long distance communication (1.3~1.5μm) by means of flip chip hybrid mounted InP photodiodes.

This paper describes the design, fabrication and high frequency characteristics of transimpedance amplifier OEICs using the GaInP/GaAs HBT approach. Their small but also large signal characteristics are reported since the latter can become an important issue when the front-end preamplifer receives large power signals as often occurs from a photodiode in optical receiver systems [5].

2. HBT Technology and Performance

The GaInP/GaAs HBTs were fabricated on layers which were grown by a specially developed hydride and hydrogen-free Chemical Beam Epitaxy (CBE) process which guaranteed a very high degree of reproducibility of growth parameters with small defect content and high output capability [6]. Self-aligned GaInP/GaAs single HBTs were fabricated on these layers using simple all wet chemical etching which minimized layer damage and device degradation. Ti/Pt/Au non-alloyed metal was deposited to emitter and collector layers while Pt/Ti/Pt/Au was used as the base metal. Laterally Etched undercut (LEU) was developed and applied between the base and collector region to reduce base-collector capacitance (C_{BC}) while avoiding base resistance degradation. More details about the fabrication process have been presented elsewhere [7]. Fabricated devices were measured using a network analyzer from 0.5 to 25.5 GHz. A

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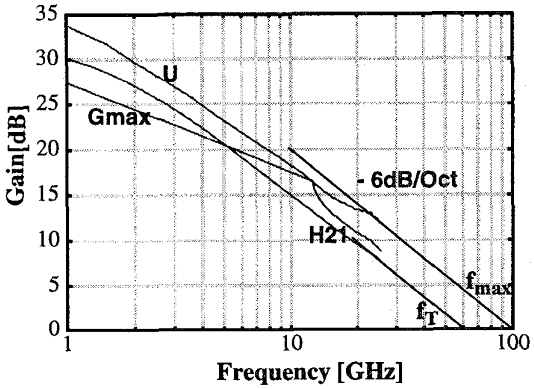


Fig. 1 Microwave performance of 2 x 30µm^2 single emitter HBT at V_{CE}=3V, I_C=20mA.

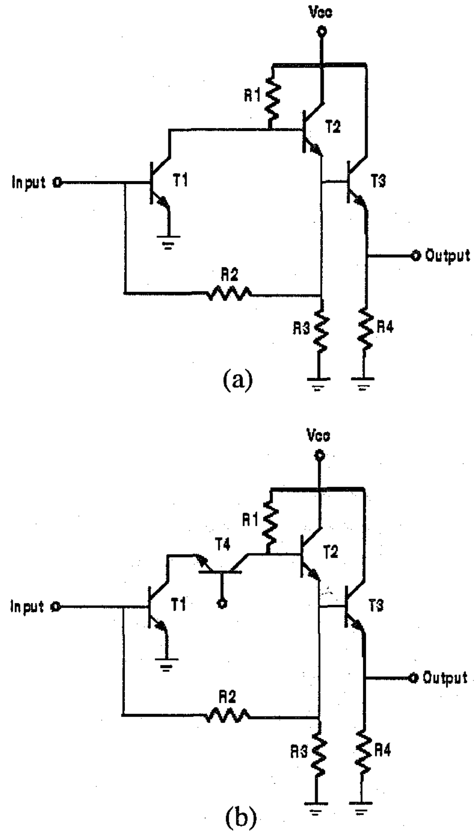


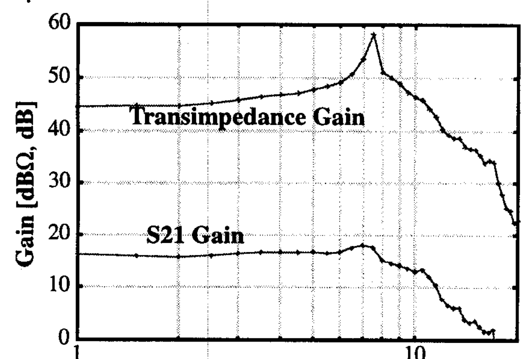
Fig. 2 Schematic of the GaInP/GaAs HBT transimpedance amplifiers (a)Design A, (b)Design B (cascode)

2 x 30µm^2 single emitter HBT has been employed in the OEIC designs. This HBT showed a cut-off frequency (f_T) of 60GHz and maximum oscillation frequency (f_{max}) of 100GHz based on current gain and unilateral gain measurements up to 25.5GHz and under V_{CE}=3V, I_C=20mA bias as shown in Fig. 1. The microwave performance of the investigated GaInP/GaAs HBTs shows only slight change with bias and permits therefore robust circuit design.

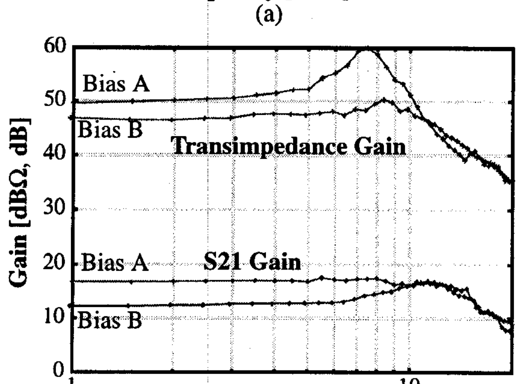
3. Design and Realization of Transimpedance amplifiers

Fig. 2(a) shows the schematic of the transimpedance amplifier (design A) employed in this work. The input signal current is amplified by the common emitter stage of transistor T_1 and resistor R_1. The feedback network which consists of resistors R_2 and R_3 stabilizes the transimpedance gain. Transistor T_2 serves as a buffer to isolate the feedback network from the gain stage. T_3 and R_4 behave as another buffer to isolate the feedback network and output. Fig. 2(b) shows the schematic of another transimpedance amplifier (design B) which was also explored and fabricated in the same lot. The schematic is identical to that of the simple transimpedance amplifier of Fig2(a) except that in this case, a cascode topology is used as the gain stage. As shown in the following, the cascode design not only improves the bandwidth, but also contributes to better large signal performance.

The design of the transimpedance amplifiers was carried out using the small and large signal equivalent circuits of HBTs. The small signal equivalent circuit parameters were directly extracted from measured S-parameters using an in-house analytical extraction technique [8]. The large signal model was then developed by combining the DC model with high frequency data. This model incorporated the self-heating effect to account for the negative slope observed in I_c-V_{ce} characteristics of the HBT at higher dissipated powers [9]. The simulations were carried out using HP-EESOF LIBRA. The technology used to fabricate these circuits is identical to that described for discrete devices in the previous section and employs Ni-Cr thin metal film for monolithic resistors and Al_2O_3 film as the insulator for high-Q MIM monolithic capacitors. Fig. 3(a) shows the measured transmission coefficient (S_{21}) and transimpedance gain of the simple transimpedance amplifier of the circuit of Fig. 2(a) measured with an HP 8722D network analyzer. A S_{21} gain of 17 dB with a bandwidth of 10GHz has been measured using on-wafer probe measurement. Fig. 3(b) shows S_{21} and transimpedance gain of the cascode transimpedance amplifier of the circuit of Fig. 2(b). A similar S_{21} gain of 17 dB with a bandwidth of 15GHz has been achieved for bias condition A ($V_{c,\ cas.}$=5V). The transimpedance gain was 47dBΩ and 50dBΩ for design A and design B respectively. By increasing the collector voltage of the cascode stage (Bias condition B), the bandwidth could be increased to 19GHz while the associated S_{21} and transimpedance gain were 12dB and 47dBΩ, respectively. Fig. 4 shows a photograph of the fabricated transimpedance circuit (design A). Coplanar waveguide transmission lines were employed to connect the amplifier to 50Ω terminations. The chip size for the circuits was 1125 x 800μm^2.



(a)



(b)

Fig3. Transmission coefficient S_{21} and transimpedance gain of the transimpedance amplifier [design A](a) and the cascode transimpedance amplifier [design B](b) measured by on-wafer probing.

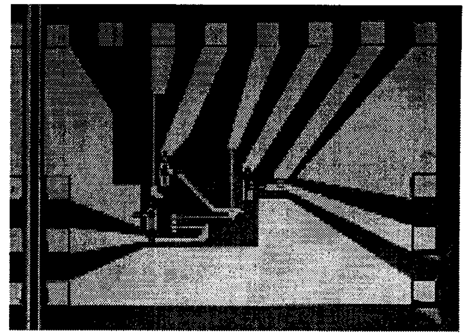


Fig. 4 Photograph of the fabricated transimpedance amplifier. (Design A)

4. Large Signal Performance

The large signal performance of the two transimpedance designs was evaluated using an HP 8722D network analyzer and the output power was monitored with a power meter for higher accuracy.

Figs. 5(a) and 5(b) show the P_{out}-P_{in} characteristics for different frequencies for design A and cascode transimpedance amplifiers respectively. The chips compared showed similar gain-frequency characteristics under small-signal conditions. The transimpedance amplifier (design A) shows a more pronounced gain compression especially at lower frequencies. The cascode transimpedance circuit, however, shows very small gain compression at high input power. This is mainly due to the fact that self-biasing effects resulting from the presence of large signal input conditions are reduced in this design.

A comparison between the collector currents of transistor T_3 (output stage) of these two designs revealed that in the case of design A, the collector current increases from the nominal value of 18 mA to 48 mA as the input power increases from 15 dBm to -3 dBm. The cascode design however shows a negligible current increase. Overall, the cascode design appears to be less sensitive to increased input power levels. This feature, in addition to a higher bandwidth, make the cascode design a better choice for optoelectronic applications.

Frequency dependence tests of the large-signal gain proved again the superiority of the cascode design in terms of immunity to increased input power level conditions.

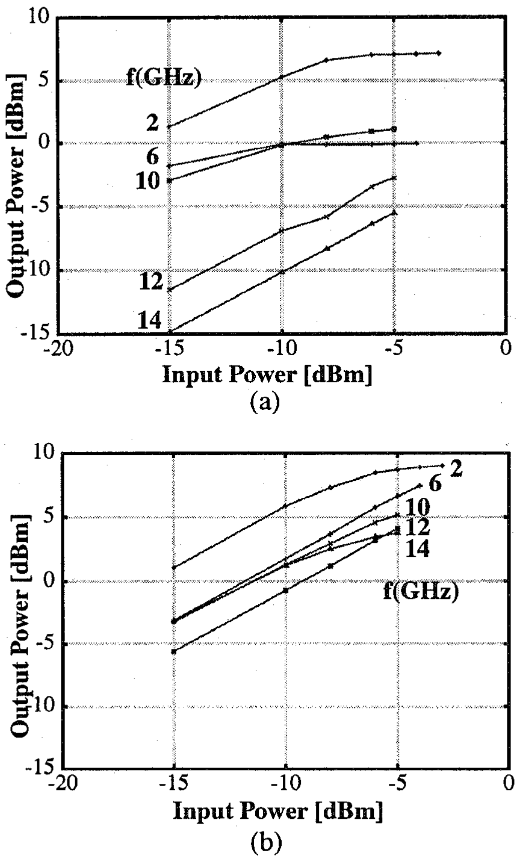


Fig. 5 P_{out}-P_{in} characteristics of design A (a) and design B [cascode] (b).

5. Conclusions

Broadband transimpedance amplifiers were designed, fabricated and tested using GaInP/GaAs HBT technology which is promising due to the combination of good electrical performance with process simplicity as necessary for production of high-speed and high capacity transmission systems. A maximum bandwidth of 19GHz and associated transimpedance gain of 47dBΩ were achieved using a cascode design approach. Two transimpedance designs were compared and the design based on the cascode approach showed larger bandwidth and a much smaller input power dependence due to reduced self-biasing effects.

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