InP/GaAsSb/InP DHBT Monolithic Transimpedance Amplifier with Large Dynamic Range

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***Abstract* — InP/GaAs$_{0.51}$Sb$_{0.49}$/InP DHBT (Double Heterojunction Bipolar Transistor) technology is investigated and presented for low power consumption and high power microwave amplification. A low power monolithic transimpedance circuit using InP/GaAsSb/ InP DHBTs presented a 11.0dB gain, 9.5GHz bandwidth, 46dBΩ transimpedance, and a corresponding gain-bandwidth of 1.88THz-Ω. The power characteristics of the DHBT devices have not been discussed extensively in the past and are shown here to present large 1dB-compressed output power corresponding to 0.76mW/μm^2 at 5GHz and high efficiency due to the use of an InP collector. This opens the possibility for transimpedance amplifier use in applications where an input signal with large dynamic range may be present.**

I. INTRODUCTION

High speed, large dynamic range demanding transmission systems are necessary for next generation optical and wireless communications. InP/GaAs$_{0.51}$Sb$_{0.49}$ /InP DHBT (Double Heterojunction Bipolar Transistor) technology is attractive for low dc power and high speed ICs due to its inherently low bandgap base GaAsSb material and higher electron mobility compared to GaAs and or silicon based HBT/BJT technologies. The low bandgap material (E_g =0.72eV for GaAsSb) results in low V_{BE} turn-on voltage of 0.6-0.8V while the device emitter-collector symmetry results in almost zero offset voltage. This reduces the required dc supply of IC's making this technology competitive with SiGe HBTs and BJTs, but with greater speed capability.

Compared with conventional InP-based DHBTs using InGaAs as base material, the conduction band edge of the GaAsSb base lies above the conduction band edge of the InP collector (type-II lineup), permitting the implementation of uniform InP collectors without collector current blocking found in conventional InGaAs base DHBTs with InP collector. Therefore, excellent high-speed/low-power consumption, and high-speed/high-power capability may be obtained on the same chip simultaneously using InP/GaAsSb/InP DHBTs without the need for complex device or circuit optimization. GaAsSb DHBTs have shown record high-frequency performance with f_T and f_{max} surpassing 300GHz [1-2]. The microwave power performance of InP/GaAsSb/InP DHBTs has been reported by the authors [3], who reported a large power density of 1.6mW/μm^2 per emitter area at 5GHz. First monolithic circuits have also recently been successfully demonstrated by the authors [4]. This work presents the small signal characteristics of a transimpedance amplifier based on novel InP/GaAsSb /InP DHBT technology and discusses at the same time for the first time the power characteristics of the devices used in the monolithic implementation. Due to the large power capability possible through the use of the InP collector, transimpedance amplifiers of this type are promising for applications where input signals with a large dynamic range of power levels may be present.

II. DEVICE TECHNOLOGIES AND HIGH-FREQUENCY PERFORMANCE

The InP/GaAs$_{0.51}$Sb$_{0.49}$/InP DHBT structure was grown on nominal (001) InP substrate using MOCVD. The DHBT layers consisted, starting from the bottom, of an n$^+$ 5200Å thick InP doped at 7×10^{18}cm^{-3} followed by a 200Å thick n$^+$ InGaAs and 900Å thick InP subcollector, and a 2500Å thick n- InP collector doped at 3×10^{16}cm^{-3}. The 400Å thick p$^+$-doped GaAs$_{0.51}$Sb$_{0.49}$ base had a sheet resistance of 1150Ω/□. The base was followed by a 750Å thick InP emitter doped at 3×10^{17}cm^{-3}, an n$^+$ 1300Å thick InP and an n$^+$ 600Å thick InGaAs emitter cap. InP/GaAsSb/InP DHBT devices with different emitter geometries were fabricated and characterized. The fabrication utilized an emitter-up triple mesa structure using wet chemical etching and self-aligned base metalization. Due to the InP etch selectivity over GaAsSb, the InP emitter can be completely removed using over etch without affecting the GaAsSb base layer, resulting in good device uniformity across wafers. Ti/Pt/Au was used for both emitter and collector contacts while Pt/Ti/Pt/Au was used as base contact. Following the formation of emitter, base and collector metal contacts, isolation of devices was achieved by undercutting of the parasitic connections under the emitter and base metal pads. Finally, airbridges were used to connect the emitter, base and collector to microwave pads, as necessary for high-speed/high-frequency IC applications.

Fig. 1 shows the microwave performance f_T and f_{max} as a function of collector current I_C of two GaAsSb DHBT devices with emitter sizes of 1×10μm^2 and 2×10μm^2 respectively. The best f_T values obtained for 1μm and 2 μm devices are comparable (~120GHz; at similar collector current densities of 1.6mA/ μm^2). The best f_{max} value of 2μm devices (62GHz) is, however, 40% less than that of 1μm devices (99GHz) due to the increased base-collector capacitance. Further improvement on f_{max} is expected by optimizing the base contact resistance.

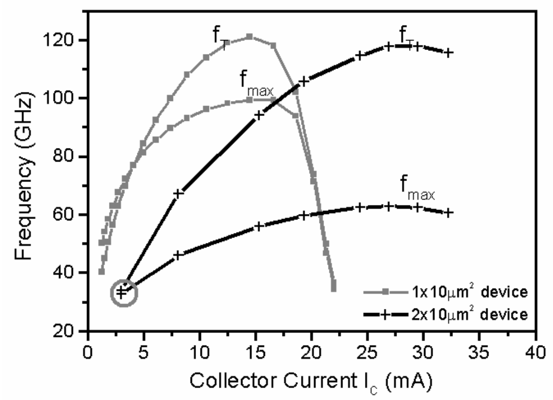

Fig. 1. High frequency performance of 1×10μm^2 and 2×10μm^2 devices with V_{CE} =2.0V. 2×10μm^2 devices biased at low I_C (marked by the circle) were chosen for the low-power transimpedance amplifier design.

III. Device Power Characteristics

Load-pull and power sweep measurements were conducted at 5GHz on the GaAsSb DHBT devices used for monolithic. Fig. 2 shows the load-pull contours for a 5×10μm^2 device biased at V_{CE} =2.8V and I_C =20mA with 1dBm input power.

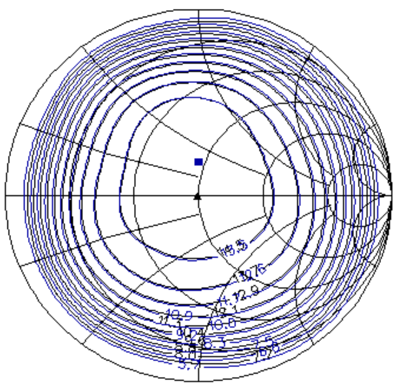

Fig. 2 Constant power gain contours from load-pull measurement of a 5×10μm^2 device biased at V_{CE} =2.8V and I_C =20mA. The source impedance was 50Ω. Maximum gain =14.3dB when load impedance was 47+j18Ω.

The source impedance was kept constant at 50Ω. Maximum output power of 15.3dBm (with associated gain of 14.3dB and PAE of 36%) was achieved at a load impedance of 47+j18Ω. It can be seen that the area corresponding to the 1dB-gain compression contour encloses a quite large region which is located almost at the center of Smith Chart, indicating the possibility of relaxed matching circuit design for devices of this size. The 5×10μm^2 GaAsSb DHBT devices may therefore be used in developing ultra high-power microwave sources with low-loss, high-efficiency, and small chip area. Devices with other emitter sizes also showed fairly large areas enclosed by the 1dB-gain compression contours on the Smith Chart, an ideal feature for relaxed load matching. Source-pull measurements were also performed for these devices and showed that the power gain was almost independent of source impedance (only 1-2dB gain variations across the Smith Chart).

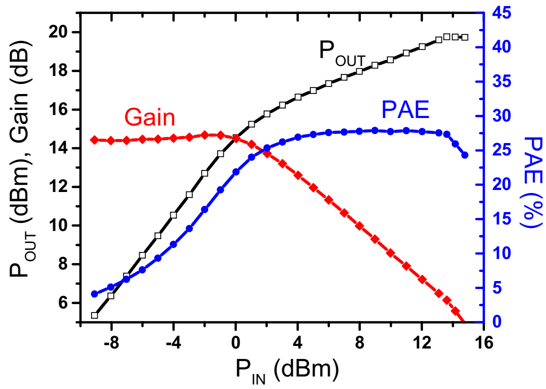

Fig. 3 Power characteristics of a 5×10μm^2 device biased at V_{CE} =4.0V and I_C =20mA. The source impedance was 50Ω and load impedance was 38+j31Ω.

Fig. 3 shows the power sweep results of the 5×10μm^2 device at I_C =20mA and an increased V_{CE} of 4.0V. The measurement was performed without harmonic tuner. The source impedance was set at 50Ω and load impedance at 38+j31Ω. Maximum power gain of 14.5dB was achieved for small signal input. The output power at 1dB-compression was 15.8dBm (corresponding to 0.76mW/μm^2) with associated PAE of 25%. It is worth noting that even though the InP/GaAsSb/InP DHBT may exhibit a small DC gain degradation accompanied by an increase of base ideality factor [5], neither the load-pull contours nor the output power at 1dB-compression showed variation after subjecting the device to a similar DC and microwave power stress for a few hours.

IV. Design and Realization of The Transimpedance Amplifier

The above presented high-speed and high-frequency results have shown that InP/GaAsSb/InP devices are ideal candidates for high speed demanding transmission systems where large dynamic input power range is desired. 2×10μm^2 devices biased at low I_C (~2-3mA) with f_T/f_{max} of 32GHz (Fig. 1) were selected for the design of a low-power InP/GaAsSb/InP transimpedance amplifier in MMIC configuration. The schematic of the transimpedance amplifier employed in this work is shown in Fig. 4. The circuit consists of a 1-stage buffer amplifier in shunt-shunt feedback configuration and the feedback resistor was set to 330Ω. The currents flowing through the gain stage, the first and second buffers were 4mA, 3mA, and 1mA respectively. A photograph of the fabricated circuit is shown in Fig. 6. The DC operation conditions were selected according to the above configuration based on the DC characteristics of each device.

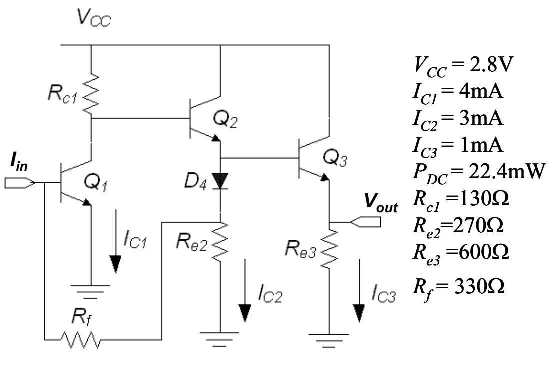

Fig. 4. Circuit configuration of the low-power transimpedance amplifier using InP/GaAsSb/InP DHBTs

The small-signal performance of the transimpedance amplifier was measured by sweeping the dc power supply from 2.1V, the point when the circuit starts to turn on, to the desired value of 2.8V. By monitoring the input and output voltages simultaneously, one could monitor the bias current for each device and the dynamic increase of gain and bandwidth. Fig. 5 shows the transimpedance gain Z_T ($50\times|S_{21}|/(1-|S_{11}|)$, $|S_{21}|$, and input reflection $|S_{11}|$ when the circuit was biased at Vcc=2.8V, which corresponds to the best tradeoff between gain-bandwidth and dc power consumption. A transimpedance gain of 46dBΩ over a bandwidth of 9.5GHz was achieved corresponding to a gain-bandwidth product of 1.88 THz-Ω. The overall current from the power supply was 8.0mA corresponding to a power consumption of only 22.4mW. The amplifier achieved a good Gain-Bandwidth-Product per dc power figure-of-merit (GBP/Pdc) of 1.48GHz/mW. The above results are comparable with those of more mature conventional SHBT technologies [6-9] but were obtained from the very first MMIC demonstration of the new Sb-based InP DHBT technology.

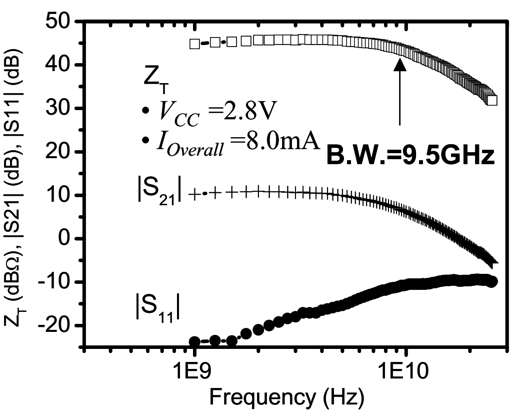

Fig. 5 Transimpedance gain Z_T, $|S_{21}|$, and $|S_{11}|$ as a function of frequency when V_{CC}=2.8V. The total power consumption of the circuit was 22.4mW.

The measured discrete device characteristics suggest that the GaAsSb InP-based transimpedance amplifiers may be operated under a wide range of dynamic power levels.

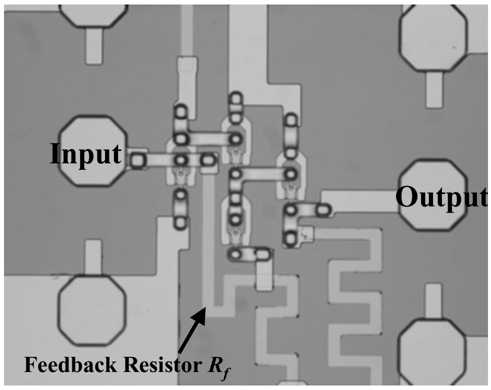

Fig. 6 Photograph of the fabricated MMIC Sb-based InP DHBT transimpedance amplifier

V. Conclusion

In summary, high frequency and power characteristics of InP/GaAsSb/InP DHBTs are investigated and the results show large 1dB-compressed output power and high efficiency due to the use of InP collector. A low-power transimpedance amplifier using the novel InP/GaAsSb/InP DHBT technology was demonstrated. It exhibited a gain of 11.0dB, 9.5GHz bandwidth, 46dBΩ transimpedance, and a corresponding gain-bandwidth product of 1.88 THz-Ω. The obtained results suggest that transimpedance amplifiers biased at large V_{CE} and I_C may be used in applications where input signals with large dynamic range are present.

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