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

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Abstract — InP/GaAs0.51Sb0.49/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 1.1µW gain, 9.5GHz bandwidth, 46dB transimpedance, and a corresponding gain-bandwidth product 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/μm² 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/GaAsSb/InP DHBT (Double Heterojunction Bipolar Transistor) technology is attractive for low dc power and high speed ICs due to its inherently low bandgap GaAsSb material and higher electron mobility compared to GaAs. The low bandgap material (Eg =0.72eV for GaAsSb) results in low fT (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/μm² 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/GaAs0.51Sb0.49/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 7×10¹⁷cm⁻³ followed by a 200Å thick n InGaAs and 900Å thick InP subcollector, and a 2500Å thick n- InP collector doped at 1×10¹⁷cm⁻³. The 400Å thick p'-doped GaAs0.51Sb0.49 base had a sheet resistance of 1150Ω/μm². The base was followed by a 750Å thick InP emitter doped at 3×10¹⁷cm⁻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 fT and fmax as a function of collector current IC of two GaAsSb DHBT devices with emitter sizes of 1×10µm² and 2×10µm² respectively. The best fT values obtained for 1µm and 2
µm devices are comparable (~120GHz; at similar collector current densities of 1.6mA/µm²). The best \( f_{\text{max}} \) 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 \( f_{\text{max}} \) is expected by optimizing the base contact resistance.

Fig. 1. High frequency performance of 1×10µm² and 2×10µm² devices with \( V_{CE} = 2.0 \text{V} \). 2×10µm² 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 5×10µm² device biased at \( V_{CE} = 2.8 \text{V} \) and \( I_C = 20 \text{mA} \) with 1dBm input power.

The source impedance was kept constant at 50Ω. Maximum output power of 15.3dBm with associated PAE of 36% was achieved at a load impedance of 47+j18Ω. 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 0.86mW/µm²) 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. 2×10µm² devices biased at low \( I_C = -2-3 \text{mA} \) with \( f_{\text{t}}/f_{\text{max}} \) 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.
configuration based on the DC characteristics of each device.

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 $V_{CC}=2.8V$, which corresponds to the best tradeoff between gain-bandwidth and dc power consumption. A transimpedance gain of 46dB over a bandwidth of 9.5GHz was achieved corresponding to a gain-bandwidth product of 1.88 THz. 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.

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

**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, 46dB transimpedance, and a corresponding gain-bandwidth product of 1.88 THz-$\Omega$. 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.

**ACKNOWLEDGEMENT**

The authors would like to thank Microlink Devices, Inc for material growth and Dr. Delong Cui from Teradyne, Inc. for valuable discussions. The support from ARL under contract DAAD19-02-2-0022, NSF/NASA/EPRI (Contract No. ECS 0233500) and NTT is greatly acknowledged.

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