First Demonstration of Low-Power Monolithic Transimpedance Amplifier using InP/GaAsSb/InP DHBTs

Xin Zhu[1], Jing Wang[1], and Dimitris Pavlidis[1,2]

[1]Department of Electrical Engineering and Computer Science
The University of Michigan, 1301 Beal Avenue, Ann Arbor, MI 48109-2122, USA
[2]Department of High Frequency Electronics, Institute of Microwave Engineering, Technische Universität
Darmstadt, Merckstrasse 25, D-64283 Darmstadt, Germany

Shuohung (Shawn) Hsu

Department of Electrical Engineering,
National Tsinghua University, 101, Sec. 2, Kuang-Fu Rd., Hsinchu 300, Taiwan, R.O.C.

Abstract — **A low-power transimpedance amplifier is presented based on novel InP/GaAsSb/InP DHBT technology. This is the first monolithic circuit demonstration using Sb-based InP DHBTs. Self-biased from a single 2.55 V dc supply, the broadband transimpedance amplifier in shunt-shunt feedback exhibited a 6.0 dB gain, 8.0 GHz bandwidth, 43 dBΩ transimpedance, and a corresponding gain-bandwidth of 1.13 THz-Ω while consuming only 15.3 mW dc power. The single-stage buffer amplifier achieved a good Gain-Bandwidth-Product per dc power figure-of-merit (GBP/P_{dc}) of 1.05 GHz/mW.**

Index Terms — **Heterojunction bipolar transistors, Microwave amplifiers, MMICs.**

I. INTRODUCTION

High speed, low-power demanding transmission systems are necessary for next generation optical and wireless communications. InP/GaAs$_{0.51}$Sb$_{0.49}$/InP DHBT (double hetero-junction bipolar transistors) technology is attractive for low dc power and high speed ICs due to its inherently low bandgap base material GaAsSb 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), which permits the implementation of uniform InP collectors without collector current blocking found in conventional InP collector DHBTs with an InGaAs base. Therefore, excellent microwave and DC performance may be obtained simultaneously using InP/GaAsSb/InP DHBTs without the need for complex circuit optimization. High-frequency performance with f_T and f_{max} surpassing 300GHz [1] has been demonstrated recently. High-power performance with large microwave power density of 1.6mW/μm^2 per emitter area at 5GHz [2] was also reported by the authors.

This work presents a low-power transimpedance amplifier based on novel InP/GaAsSb/InP DHBT technology. This is the first monolithic circuit demonstration of this kind.

II. DEVICE TECHNOLOGIES AND PERFORMANCE

The InP/GaAs$_{0.51}$Sb$_{0.49}$/InP DHBT structure was grown on nominal (001) InP substrate using MOCVD (metalorganic chemical vapor deposition). 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 of a 1×10μm^2 HBT biased at V_{CE}=2V and I_C=14.5mA. The f_T and f_{max} extrapolated by -20dB/decade are 121GHz and 99GHz respectively.

The f_T and f_{max} as a function of the collector current I_C for 1×10μm^2 and 2×10μm^2 devices are shown in Fig. 2. It can be

seen that while the best f_T's for 1μm and 2 μm devices are comparable (~120GHz; at similar collector current densities), the best f_{max} of 2μm devices is 40% less than that of 1μm devices due to the increased base-collector capacitance. To address the demands of low-power consumption and high yield MMICs, contact lithography and 2×10μm^2 devices biased at low I_C (~2-3mA) with f_T/f_{max} of 32GHz were selected for the design of the low-power transimpedance amplifier. For a given application-oriented transimpedance gain defined by the value of the feedback resistor R_f, the input referred current noise performance (1) of the amplifier can be improved by using lower collector and base current (I_{C1} and I_{B1}) for the input transistor, thus reducing its overall shot noise contribution.

$$\frac{\overline{i_{eq}^2}}{\Delta f} = 4kT\frac{1}{R_f} + 2qI_{B1} + 2qI_{C1}\frac{1}{g_{m1}^2}\omega^2 C_{\pi1}^2 \qquad (1)$$
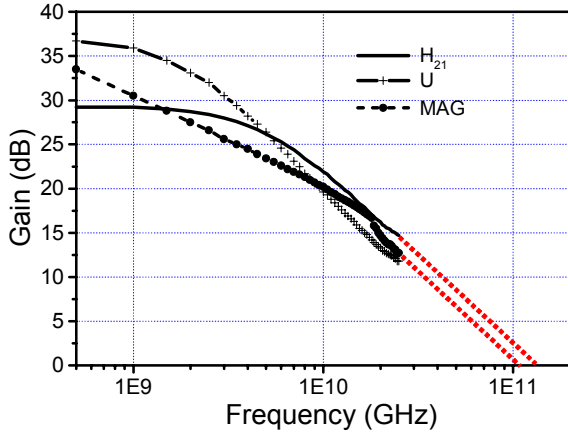

Fig. 1. Microwave performance of a $1\times10\mu m^2$ InP/GaAsSb/InP DHBT biased at V_{CE}=2V, I_C=14.5mA.
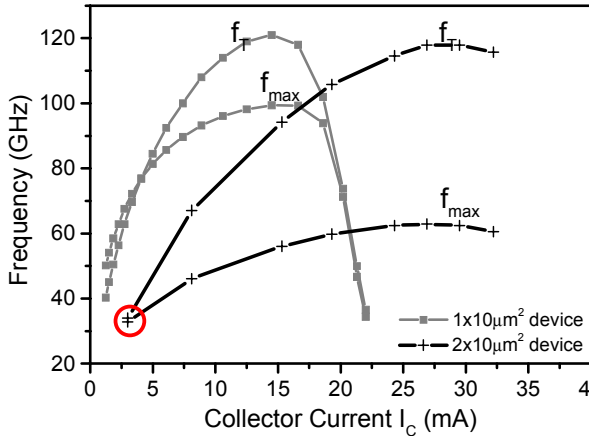

Fig. 2. High frequency performance as a function of collector current I_C for $1\times10\mu m^2$ and $2\times10\mu m^2$ devices respectively when V_{CE}=2.0V. $2\times10\mu m^2$ devices biased at low I_C (marked by the circle) were chosen for the low-power, low-noise transimpedance amplifier design.

Better transimpedance performance can be obtained by biasing the device at best f_T/f_{max} but dc power consumption and noise performance would in this case be sacrificed. Future work will explore amplifiers using devices with narrower emitters (≤1μm) for even better gain-bandwidth and power efficiency.

III. DESIGN AND REALIZATION OF TRANSIMPEDANCE AMPLIFIER

Fig. 3 shows the schematic of the transimpedance amplifier employed in this work, which consists of a 1-stage buffer amplifier in shunt-shunt feedback configuration. The input current signal (I_{in}) is amplified by the common-emitter gain stage (Q_1 and R_{C1}). The feedback network which consists of resistors R_f and R_{E2} stabilizes the transimpedance gain. Transistor Q_2 serves as a buffer to isolate the feedback network from the gain stage. Q_3 and R_{E3} behave as another buffer to isolate the feedback network from output load. The level-shift diode D_1 serves to lower the DC offset between input and output.
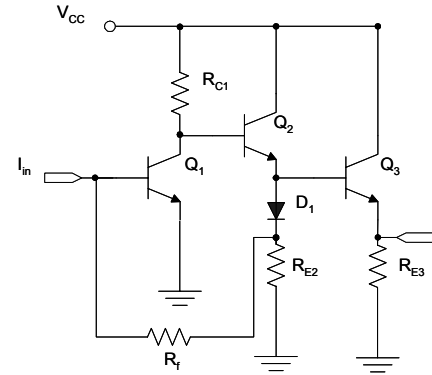

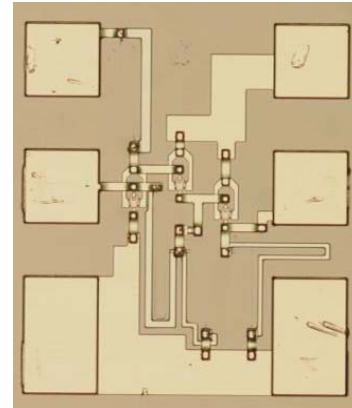Fig. 3. Schematic of the MMIC Sb-based InP DHBT transimpedance amplifier.

Fig. 4. Photograph of the fabricated MMIC Sb-based InP DHBT transimpedance amplifier. The chip size is as small as $300\times350\mu m^2$.

The DC operation conditions were selected according to the above configuration based on the DC characteristics of each device. Then circuit simulation was performed by using the small-signal S-parameter measurement (0.5GHz to 25.5GHz) results of discrete $2\times10\mu m^2$ devices under the corresponding DC biases. NiCr thin film resistors with sheet resistance of $10\Omega/sq$. were employed to properly bias the circuit and provide desired gain and bandwidth performance.

Fig. 4 shows a photograph of the fabricated transimpedance amplifier circuit using self-aligned InP/GaAsSb/InP DHBT MMIC technology. The chip size is as small as $300\times350\mu m^2$.

IV. TRANSIMPEDANCE AMPFLIER PERFORMANCE

The transimpedance amplifier was measured by sweeping of the dc power supply from 2.1V, the point when the circuit starts to turn on, to the desired value of 2.55V. The bias currents for each device and the dynamic increase of gain and bandwidth could be observed by monitoring the input and output voltages simultaneously,. The measured DC bias points matched closely to the design and showed very small offset between input and output voltages (i.e., <0.1V).

Fig. 5 shows the transimpedance gain Z_T ($50\times|S_{21}|/(1-|S_{11}|)$), $|S_{21}|$, and the input reflection ($|S_{11}|$) when the circuit was biased at Vcc=2.55V, the best balance between gain-bandwidth and dc power consumption. As can be seen, a transimpedance gain of 43dBΩ over a bandwidth of 8GHz was achieved corresponding to a gain-bandwidth of 1.13 THz-Ω. The overall power consumption was 15.3mW with a total supply current of 6.0mA.
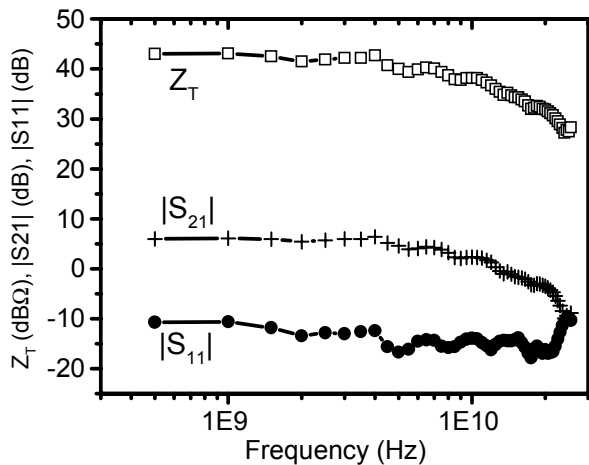

Fig. 5 Transimpedance gain Z_T, $|S_{21}|$, and input reflection $|S_{11}|$ as a function of frequency when V_{cc} =2.55V. The total power consumption of the circuit was 15.3mW.

V. CONCLUSION

High-frequency performance with f_T and f_{max} of 121GHz and 99GHz respectively was achieved using $1\times10\mu m^2$ InP/GaAsSb/InP DHBTs. A low-power monolithic transimpedance amplifier based on the novel device technology was demonstrated for the first time. The amplifier utilized $2\times10\mu m^2$ devices biased at low collector current levels for high-yield, low-power, and low-noise applications. Self-biased from a single 2.55 V dc supply, the broadband transimpedance amplifier in shunt-shunt feedback exhibited a 6.0 dB gain, 8.0 GHz bandwidth, 43 dBΩ transimpedance, and a corresponding gain-bandwidth of 1.13 THz-Ω while consuming only 15.3 mW dc power. The results are comparable with those of more mature conventional HBT technologies [3]–[4] but were obtained from the very first MMIC demonstration of a new Sb-based InP DHBT technology. Improved results are expected by using DHBTs with 1μm-emitter or less. Depending on the applications, the devices can be biased at higher current levels for better gain and bandwidth while power consumption has to be sacrificed. Results under these conditions are under investigation.

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