A Monolithic HBT-Regulated HEMT LNA by Selective MBE

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Abstract—**We demonstrate here the monolithic integration of an HBT operational amplifier and a HEMT low-noise amplifier to achieve an elegant single-chip solution to the problem of HEMT current regulation. We have developed a novel method of achieving monolithic HEMT-HBT integration by selective MBE and a unique merged-processing technology. Pseudomorphic 0.2 μm gate-length InGaAs-GaAs-AlGaAs HEMT's and 2 $\times$ 10 μm^2 GaAs-AlGaAs-InGaAs HBT devices have been incorporated into the same microwave circuit for the first time with no degradation in the intrinsic device performance of either device technology.**

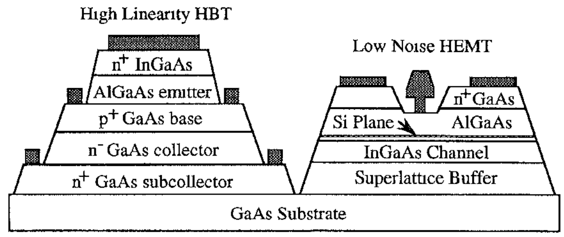

Fig. 1. Schematic diagram of device profiles used for monolithic HEMT-HBT integration.

I. Introduction

THE THRESHOLD voltage of high electron mobility transistors is a sensitive function of the device profile and the gate process. Subtle wafer-to-wafer variation in both the HEMT material profile and the HEMT gate process results in wafer-to-wafer variation in the device threshold voltage. In addition, there can be fluctuations in the threshold voltage between adjacent devices on the same wafer. In order to maintain a relatively constant bias current, HEMT devices and integrated circuits require a means for bias regulation which is tolerant of this variation in threshold voltage.

The most common method of HEMT self-bias at present is through the use of an off-chip regulator integrated with the HEMT chip in a hybrid microwave assembly. However, the typical hybrid current regulator is relatively cumbersome in terms of integration complexity, size, and weight. Resistive self-bias techniques are commonly used in MESFET technology, but are more difficult to achieve in HEMT technology due to the greater sensitivity of the HEMT threshold characteristics compared to those of the MESFET. A monolithic HEMT regulator circuit integrated with a HEMT LNA has been described previously [1]. While the active HEMT regulator approach can improve bias regulation, it is still sensitive to on-wafer threshold variation.

We demonstrate here an alternative bias-regulation technique for a pseudomorphic InGaAs-GaAs-AlGaAs HEMT LNA using an on-chip HBT operational amplifier. The monolithic HEMT-HBT integration was achieved by selective MBE and a unique merged-processing technology. This HEMT-HBT integration technique provides an elegant solution to the problem of HEMT regulation. It takes advantage of the inherent performance advantages of HBT's for operational amplifier circuits, while maintaining the low-noise and high-gain performance of the HEMT LNA. In addition, this monolithic HEMT-HBT integration approach is less expensive and inherently more reliable than a hybrid approach to HEMT regulation.

The techniques used to achieve monolithic HEMT-HBT integration are similiar to those used to achieve monolithic complementary npn-pnp HBT integration [2]. The HBT is grown first by MBE, patterned with silicon nitride, and etched to form HBT islands. The pseudomorphic InGaAs-GaAs-AlGaAs HEMT material is deposited [3]. The HBT Be base dopant diffuses $\sim$ 2.5 nm into the AlGaAs emitter during the HEMT regrowth, consistent with substitutional Be diffusion [4]. The HEMT low noise amplifier and HBT operational amplifier are fabricated monolithically using a merged HEMT-HBT process [5]. The fabricated HEMT and HBT devices are shown schematically in Fig. 1. The selective MBE, merged HEMT-HBT process, and discrete device performance results are described in detail in [6].

Current-voltage characteristics for a 2 $\times$ 10 μm^2 single-emitter HBT are shown in Fig. 2, where $\beta \sim 50$ at $Ic \sim$ 4 mA. The HBT device microwave performance was consistent with baseline HBT devices, with $f_T \sim 21$ GHz and $f_{max} \sim 50$ GHz for quad-2 $\times$ 10 μm^2 emitters. The HEMT material and devices appear likewise unaffected by the process described above, even though Si_3N_4-cladded HBT islands are in close proximity to the HEMT material during growth. Fig. 2 shows current-voltage characteristics for an 80 μm gate-width device with $g_m \sim 600$ mS/mm and $I_{max} \sim 600$ mA/mm. These HEMT devices had baseline microwave performance with $f_T \sim 70$ GHz.

A schematic circuit diagram of an HBT-regulated HEMT low noise amplifier is shown in Fig. 3. The HEMT amplifier

Manuscript received November 3, 1994
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IEEE Log Number 9409018.

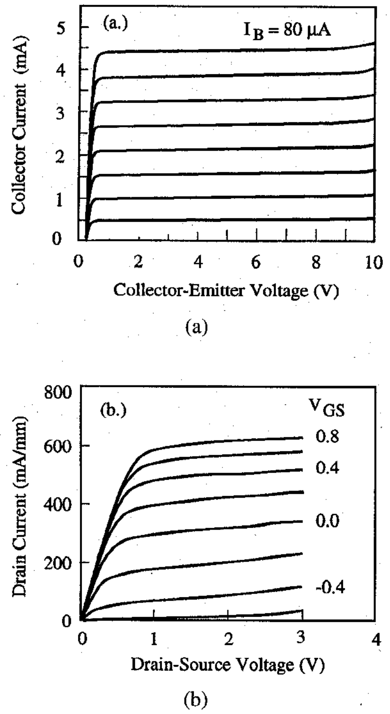

Fig. 2. Current-voltage characteristics of (a) single-emitter $2 \times 10\ \mu m^2$ GaAs-AlGaAs-InGaAs HBT and (b) $0.2 \times 80\ \mu m^2$ T-gate pseudomorphic InGaAs-GaAs-AlGaAs HEMT, both fabricated by selective MBE and merged HEMT-HBT process.

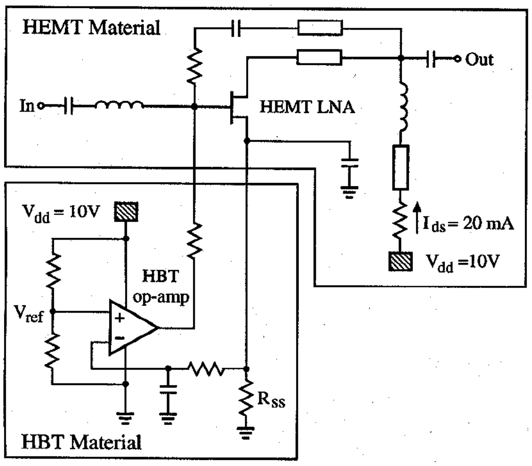

Fig. 3. Circuit schematic of monolithic HBT-regulated HEMT low noise amplifier.

is designed for 5–10 GHz operation with 10 dB of gain and 3 dB noise figure. The low noise amplifier is a single-stage feedback design using a single 200 μm-wide 0.2 μm gate-length HEMT. The bias current of the HEMT can be regulated to ±5% using the on-chip HBT current regulator, which consumes 5 mA through a 10 V positive supply. A photograph of the fabricated monolithic HEMT-HBT circuit is shown in Fig. 4. A comparison of the performance of HEMT low-noise amplifiers fabricated by our baseline HEMT-only process and those fabricated using the merged HEMT-HBT described here is shown in Fig. 5. The HEMT-only amplifiers

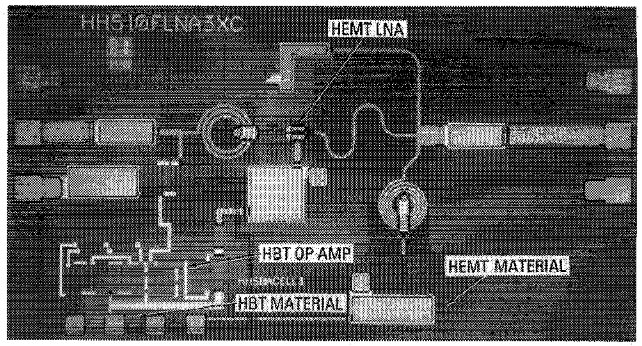

Fig. 4. Photograph of fabricated monolithic HBT-regulated HEMT low noise amplifier.

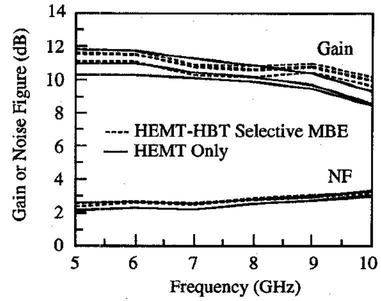

Fig. 5. Gain and noise figure comparison of HEMT LNA's fabricated using selective MBE and a merged HEMT-HBT process, and HEMT LNA's fabricated using baseline MBE and a HEMT-only process.

are not current regulated, but are otherwise equivalent to the HBT-regulated version. The HEMT-only and monolithic HEMT-HBT amplifiers have essentially identical gain and noise performance across the 5–10 GHz band. In fact, the amplifiers fabricated by the merged HEMT-HBT process have a slight gain advantage above about 9 GHz, which we attribute to normal process variation.

The motivation for using HBT rather than HEMT regulation of the LNA is driven by the lower power consumption and higher performance of an HBT operational amplifier compared to a HEMT operational amplifier. The order of magnitude greater transconductance of the HBT results in a higher-gain op-amp using only ~20% of the power of a HEMT op-amp. HBT's also have very precise threshold-matching characteristics compard to HEMT's. The difference in threshold for the HBT differential input stage is less than 1 mV, compared to ~10 mV for the HEMT differential input stage. This is an advantage for the HBT op-amp since the threshold error directly contributes to the error in the regulated current source. In addition, HBT's offer voltage reference functions which can be designed to be temperature dependent and provide temperature compensation of the microwave performance of the HEMT amplifier. For instance, HBT junction diodes with known temperature coefficients can be weighted in a compensation network, providing a graceful method for temperature compensation.

In conclusion, we have demonstrated a monolithic HBT-regulated HEMT low noise amplifier fabricated using selective MBE and a HEMT-HBT merged process. The HEMT and

HBT devices show no performance degradation associated with the additional selective MBE and merged process steps required to fabricate a monolithic HEMT-HBT integrated circuit. We believe the ability to integrate HEMT and HBT devices without sacrificing discrete device performance will enable a new class of multifunction microwave circuits.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance of Tom Block, An-Chich Han, Tim Naeole, Po-Hsin Liu, and Annika Freudenthal in the production of these results.

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