Class-A SiGe HBT Power Amplifiers at C-Band Frequencies

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Abstract—**In this letter we report on the first experimental investigations of the power-handling capabilities of SiGe heterojunction bipolar transistors (HBT's) at C-band frequencies. Multifinger HBT's in common-emitter (CE) and common-base (CB) configuration were matched using high Q matching networks. At a frequency of 5.7 GHz the CE and the CB class A amplifier exhibit a 1-dB compression output power of 18 and 20 dBm, respectively. A power-added efficiency (PAE) of more than 30% and a output power density of 1 mW/μm^2 at 4 V V_{CB} were observed.**

I. Introduction

POWER amplifiers operating at low supply voltages are one of the key elements in handheld telephones, wireless LAN's, and radio and radar applications. Useful power capability at microwave frequencies is determined mainly by the maximum frequency of oscillation [1]. In silicon bipolar transistors the base sheet resistance of several $k\Omega/\square$ leads to relatively high base resistances and hence to a degradation in RF performance. Only the reduction of the emitter line width to submicron and quarter-micron dimensions coupled with a introduction of E-beam or X-ray lithography can shift the frequency limit to higher values [1]. Therefore, amplifiers with silicon bipolar transistors are mainly limited to S-band frequencies. For higher frequencies III-V compound semiconductor devices, FET's, as well as HBT's were typically used. In particular, AlGaAs/GaAs HBT's have reached output power densities up to 10 mW/μm^2 due to breakdown voltages in excess of 25 V [2]. However, when the supply voltage is limited to 3.5 V, a smaller output power density of 0.78 mW/μm^2 was observed [3].

Recent development in SiGe heterostructure bipolar transistor technology and device optimization lead to a maximum transit frequency and maximum frequency of oscillation of 116 [4] and 120 GHz [5], respectively, without resorting to submicron lithography. Furthermore, from the dc output characteristics a power density of 1.3 W/mm emitter length or 1.3 mW/μm^2 was predicted [6]. The aim of this letter is the experimental verification of this prediction with a one-stage SiGe power amplifier at a frequency of 5.7 GHz.

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II. Device Technology

First, buried layers with a sheet resistance of 5 $\Omega/\square$ were formed by arsenic ion implantation and subsequent annealing. Then, the HBT layer structure was grown in one step by MBE. The layer sequence is as follows: 250-nm $8 \cdot 10^{16}$ cm^{-3} Sb-doped collector layer, 7-nm undoped SiGe collector spacer layer, 25-nm $1 \cdot 10^{20}$ cm^{-3} B-doped $Si_{0.7}Ge_{0.3}$ base, 3-nm undoped SiGe emitter spacer, 50-nm $2 \cdot 10^{18}$ cm^{-3} emitter layer, and 250-nm $2 \cdot 10^{20}$ cm^{-3} emitter contact layer, both doped with Sb. The transistor structure was fabricated using a double mesa process with selfaligned base contacts. The contact pads were separated by a special groove etching in order to reduce the parasitic capacitances [7]. No passivation layer was used.

III. Experimental Results and Discussion

For the application as power amplifiers ten-finger SiGe HBT's with an emitter area of 0.8×10 μm^2 each separated by 1.5 μm were used (see Fig. 1). From dc measurements a common emitter current gain of 20 was observed for unpassivated devices. The maximum available current, which can be drawn from the collector, was approximately 100 mA. This corresponds to an emitter current density of 10^5 Acm^{-2}. No current crush was observed on the I-V output characteristics, due to the high thermal conductivity of the silicon substrate. The dc base-collector and collector-emitter breakdown voltages are 6 and 5 V, respectively. The ac collector-emitter breakdown voltage in excess of 9 V surpasses the occurence of a soft dc breakdown at 5 V, indicating a trap-related breakdown mechanism. All transistors were characterized on-wafer in CB configuration on a HP8510C network analyzer. The transit frequency was found to be 24 GHz. The more important figure, the maximum frequency of oscillation derived from the unilateral gain, exceeds 48 GHz.

The multifinger transistors were thinned to a die thickness of 150 μm and mounted on a brass heat sink using silver-filled epoxy adhesive. The thermal resistance was extracted from dc measurements to 180 K/W [8]. The transistors were bonded into a microstrip circuit on a RT/duroid 5880 substrate with 250 μm thickness, which contains a high Q matching network at the input and output port of the device. The power measurement setup consists of a WILTRON 69247B microwave signal generator, bias-blocks, the amplifier, the HP437B power meter, and the HP8563E Spectrum Analyzer, as depicted in Fig. 2. The matching networks consist of a $\lambda/2$ microstrip line and additional open-stub elements to obtain

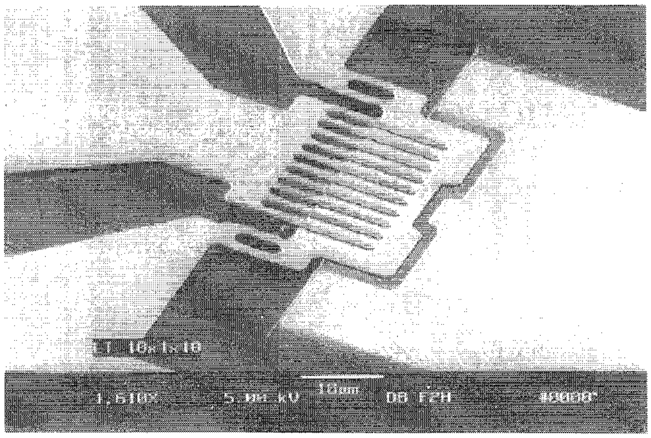

Fig. 1. SEM photograph of the used 10-finger SiGe HBT.

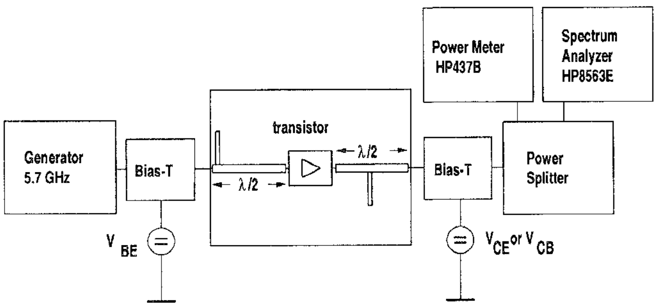

Fig. 2. Measurement setup for the fully matched one-stage power amplifier.

in- and output match. In both CE and CB configurations, the output matching was chosen for maximum output power. In reference measurements the sum of transformation losses, including SMA connectors, was found to be 1.7 dB. However, no deembedding was used in our investigations.

The optimum power performance of the CE class A amplifier was found at a collector-emitter voltage V_{CE} of 4 V and a collector current I_C of 50 mA. The power saturation curve and the power added efficiency are shown in Fig. 3. In the linear region a power gain of 8.5 dB was available. At the 1-dB compression point an output power of 18 dBm was observed. The power-added efficiency reaches values in excess of 30%. The optimum bias conditions for the CB class A amplifier were $V_{CB} = 4$ V and $I_C = 60$ mA. Again, in the linear region a power gain of 8.5 dB was obtained and the 1-dB compression point was found at 20 dBm output power. In order to estimate the maximum RF output power $P_{2,\mathrm{opt}}$ from dc parameters the formula

$$P_{2,\mathrm{opt}} = \frac{U_2 I_2}{2}$$

was used. In class A amplifiers the voltage- and current-swing is assumed to two times the dc output voltage U_2 and dc output current I_2. The calculated value for the above mentioned bias conditions is 120 mW, which is in good agreement with the measured 1-dB compression output power $P_{1\mathrm{dB}}$ of 100 mW (20 dBm) in Fig. 3, corresponding to 1 mW/μm^2 RF output power density.

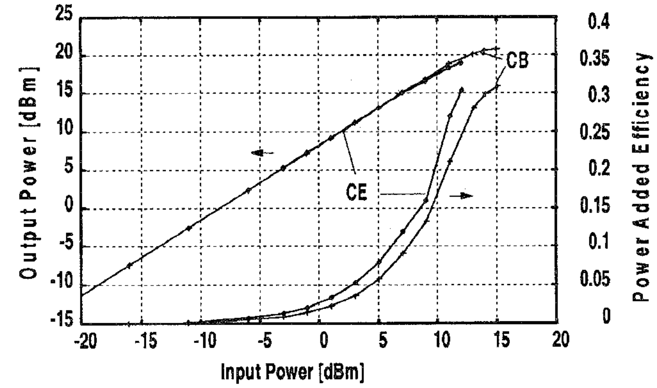

Fig. 3. Output power characteristics and power-added efficiency for a one-stage CE SiGe HBT amplifier ($V_{CE} = 4$ V, $I_C = 50$ mA) and a one-stage CB SiGe HBT amplifier ($V_{CB} = 4$ V, $I_C = 60$ mA).

As in the CE case the power-added efficiency exceeds 30%. Additionally, in the CB amplifier the influence of several output matching schemes were investigated. When matched for maximum gain, the amplifier exhibits a linear power gain of 21 dB and 11 dBm saturated output power, at $V_{CB} = 2$ V and $I_C = 70$ mA.

IV. Conclusion

The RF power performance of fully matched SiGe HBT class A power amplifier in CE and CB configurations at a frequency of 5.7 GHz was measured for the first time. The output matching scheme mainly determines the power and gain performance of the SiGe HBT amplifiers. The best results were achieved with CB power amplifiers. For the power optimum output match an output power of 20 dBm with 7.5 dB gain and 30% power-added efficiency were observed at the 1-dB compression point. However, optimizing the output match for maximum gain at 1-dB compression a power of 11 dBm in conjunction with 21-dB power gain in CB configuration were achieved.

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