80 GHz DISTRIBUTED AMPLIFIERS WITH TRANSFERRED-SUBSTRATE HETEROJUNCTION BIPOLAR TRANSISTORS

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ABSTRACT

We report distributed amplifiers with 80 GHz bandwidth, 6.7 dB gain and ∼70 GHz bandwidth, 7.7 dB gain. These amplifiers were fabricated in the transferred-substrate heterojunction bipolar transistor integrated circuit technology. Transferred-substrate HBTs have very high f_{max} (>400 GHz) and have yielded distributed amplifiers with record gain-bandwidth product.

INTRODUCTION

Traveling-wave amplifiers (TWAs) are very broadband circuits with applications in instrumentation and wide-band radar receivers. TWAs based on several different HBT and HEMT technologies have been demonstrated [1, 2, 3, 4]. In TWAs, the amplifier gain-bandwidth product depends critically on the transistor f_{max}. To date, TWAs based on HEMTs [1] have demonstrated considerably higher bandwidths than those based on HBTs [4], primarily due to the higher f_{max} of HEMTs. Transferred-substrate HBTs have demonstrated >400 GHz f_{max} [5], comparable to that of high-performance InGaAs/InAlAs/InP HEMTs, and, should thus also yield TWAs with very high bandwidths. Here, we report first results with TWAs fabricated in the transferred-substrate HBT technology.

HBT TWA design differs considerably from that using HEMTs. The HBT transconductance - hence input capacitance ($C_{be} \simeq g_m/2\pi f_\tau$) - per unit HBT emitter area is large. To obtain the desired Bragg frequency, either very small HBTs must be used, or input capacitive division [6, 7, 3] must be employed. The higher HBT input resistance compared to that of HEMTs (r_{bb} *vs.* r_{gate}) favors the use of very high capacitive division ratios. TWA bandwidth is also strongly influenced by the frequency-dependent transmission line losses, which become dominant at high frequencies. The transferred-substrate HBT IC process incorporates low-loss microstrip lines on a Benzocyclobutene (BCB, $\epsilon = 2.7$) substrate. These low-loss transmission lines make high bandwidths feasible. With these design and technological improvements, we have fabricated TWAs with 6.7 dB gain and 80 GHz 0-dB bandwidth. The 3-dB bandwidth is 85 GHz. This is the highest gain-bandwidth product reported for a HBT distributed amplifier. At a different bias condition, the amplifier exhibits 7.7 dB gain and ∼70 GHz 0-dB bandwidth and 76 GHz 3-dB bandwidth.

CIRCUIT DESIGN AND FABRICATION

Fig. 1 shows a schematic circuit diagram of the distributed amplifier. The base and collector lines are composed of 75 Ω microstrip line sections. Cascode connected HBTs are used to reduce collector line losses. C_{div} is the division capacitor at the input of the common-emitter transistor Q1. A short length of microstrip is used at

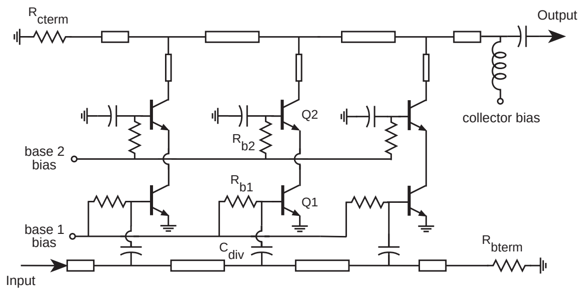

Figure 1: Schematic circuit diagram of the transferred-substrate HBT distributed amplifier.

the output of the cascode cell to improve velocity matching between the input and output lines. The microstrip lines, together with the division capacitor and the cascode stage synthesize 50 Ω input and output lines. R_{bterm} is the 50 Ω base-line termination resistor. R_{cterm}, the collector-line termination resistor is off-chip to sustain the high bias current, and is connected through a microwave probe. R_{b1} is a large resistor to bias the input of Q1. The base of the common-base transistor Q2 is biased through an independent supply. AC ground at this node is provided by large bypass capacitors. R_{b2} provides decoupling between the multiple cells and helps prevent oscillations from bias probe inductance. The collector bias is through a bias tee at the output of the chip. Amplifiers with 3 cascode cells were fabricated. Fig. 2 shows a photomicrograph of the fabricated chip. The die size is about 1.4 mm × 0.6 mm.

The transferred-substrate HBT IC fabrication procedure has been described in detail in [8]. Devices with emitter dimensions of 0.75 × 30 μm^2 and collector dimensions of about 1.8 × 34 μm^2

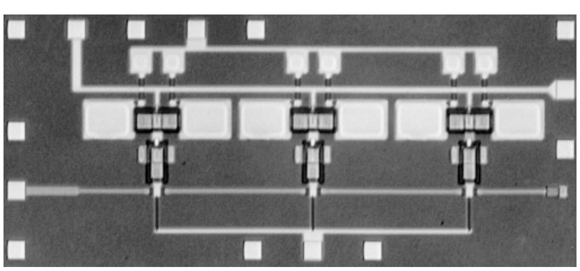

Figure 2: Photomicrograph of the fabricated amplifier IC.

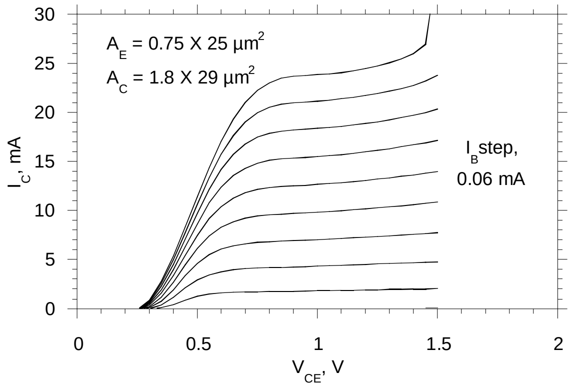

Figure 3: DC common-emitter characteristics of transferred-substrate HBTs.

were used in the amplifiers reported here. Fig. 3 shows typical DC common-emitter characteristics of devices on the current wafer. RF characteristics are shown in fig. 4. The extrapolated f_{max} and f_{τ} are 370 GHz and 160 GHz respectively, at the bias conditions shown. The amplifier is designed to operate close to these bias conditions.

RESULTS

The amplifiers were tested on-wafer using commercial network analyzers from DC-50 GHz and 75-110 GHz. Fig. 5 shows the forward gain of the amplifier under two different bias conditions. The solid curve shows a mid-band gain of about 6.7 dB. The 0-dB bandwidth (where the gain goes

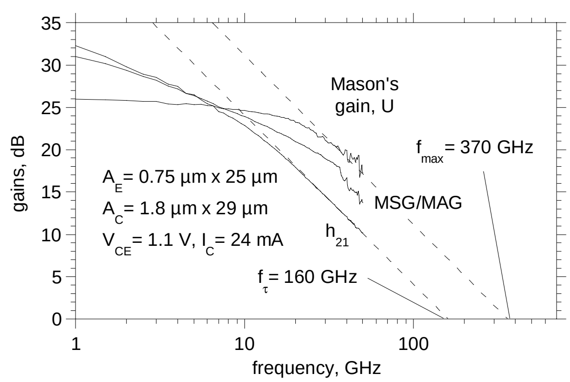

Figure 4: RF characteristics of transferred-substrate HBTs.

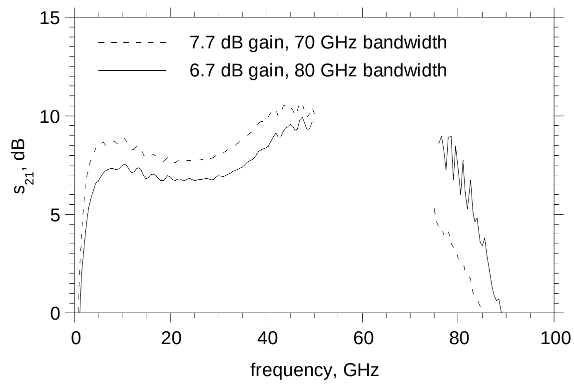

Figure 5: Measured forward gain s_{21} of the amplifier.

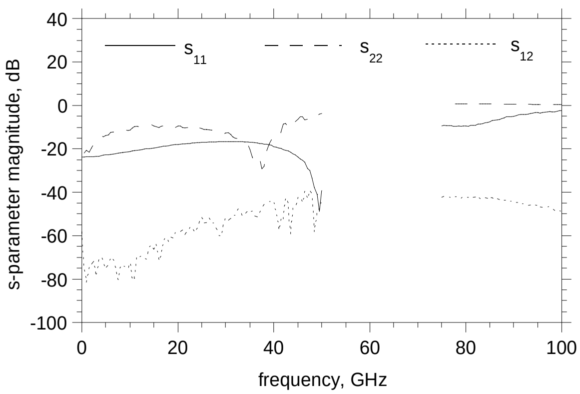

Figure 6: Measured return losses and reverse isolation of the amplifier.

below the mid-band gain) is 80 GHz. The 3-dB bandwidth is 85 GHz. The dashed curve shows the gain at a higher current density bias. The mid-band is 7.7 dB, the 0-dB bandwidth is $\sim$70 GHz and the 3-dB bandwidth is 76 GHz.

From this curve, we can also observe gain peaking at high frequencies. The gain-frequency response of TWAs is strongly impacted by device f_{max} and the designed Bragg frequency. During design, a conservative HBT model with a 200 GHz f_{max} was assumed. HBTs on the current wafer have 370 GHz f_{max} which results in the observed gain peaking. Given the 370 GHz f_{max}, redesigning the amplifier would permit bandwidths greater than 70-80 GHz. The low frequency cut-off is about 2 GHz and is determined by the transistor f_τ/β. Fig. 6 shows the input and output return losses and the reverse isolation. The amplifier output return loss s_{22} is poor at high frequencies because of the off-chip collector-line termination. The chip consumes about 250 mW of DC power.

CONCLUSIONS

We have designed and fabricated distributed amplifiers with 80 GHz bandwidth, 6.7 dB gain and $\sim$70 GHz bandwidth, 7.7 dB gain. These amplifiers have the highest gain-bandwidth product reported for a distributed HBT amplifier. The ICs demonstrate the potential of transferred-substrate HBTs for producing very high speed integrated circuits. Further improvements in the design of the amplifier, as well as in the intrinsic device technology will lead to wider bandwidth circuits.

ACKNOWLEDGMENTS

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References

[1] Agarwal B. et. al., “A 1-157 GHz InP HEMT traveling-wave amplifier”, to be presented, 1998 IEEE RFIC Symposium.

[2] Kimura S., et. al., “0-90 GHz InAlAs/InGaAs/InP HEMT distributed baseband amplifier IC”, Electronics Letters, vol. 31, no. 17, pp. 1430-1431, 1995.

[3] Kobayashi K. W., et. al., “A 50-MHz-55-GHz multidecade InP-based HBT distributed amplifier”, IEEE Microwave and Guided Wave Letters, vol. 7, no. 10, pp. 353-355, 1997.

[4] Suzuki H. et. al. , “InP/InGaAs HBT ICs for 40 Gbit/s optical transmission systems”, GaAs IC Symposium Technical Digest, 1997, pp. 215-218.

[5] Q. Lee et. al., "A $>$ 400 GHz f_{max} transferred-substrate heterojunction bipolar transistor IC technology", to appear, IEEE Electron Device Letters, March 1998.

[6] Ayasli Y., et. al., "Capacitively coupled traveling-wave power amplifier", IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, 1988, pp. 5-8.

[7] Pusl J., et. al., "Capacitive division traveling wave amplifier with 340 GHz gain-bandwidth product", IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, 1995, pp. 175-178.

[8] Agarwal B. et. al., "A 50 GHz feedback amplifier with AlInAs/GaInAs transferred-substrate HBT", International Electron Devices Meeting Technical Digest, 1997, 743-746.