90 GHz Amplifier Fabricated by a Low Cost PHEMT Technology

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Abstract — A medium power W-band amplifier has been designed and fabricated using a low cost production oriented PHEMT technology which is based only on optical stepper lithography. The 3-stage amplifier utilizes coplanar transmission lines which results in a compact chip size of 1x2 mm². A gain of 10.4 dB is achieved at a frequency of 92 GHz in conjunction with 10.6 dBm output power for 3 dB gain compression.

I. INTRODUCTION

The increased competition in the civil and military markets is the driving force for the industry to look for new cost reducing solutions even for ambitious products like W-band GaAs MMIC amplifiers. The HEMT110 process technology has been developed for commercial applications such as a chip-set for an automotive cruise control radar at 76-77 GHz [1, 2]. This technology is suited for a high volume production of low cost millimeter wave MMICs because only optical stepper lithography and no electron beam lithography is used in the fabrication process. This paper demonstrates that this low cost GaAs MMIC technology is well suited also for W-band amplifiers.

II. FABRICATION TECHNOLOGY

The HEMT110 process technology is an enhanced version of a well established and space qualified low noise fabrication technology [3, 4]. The delta doped double heterojunction pseudomorphic AlGaAs/InGaAs HEMTs are fabricated on 4" wafers. The process starts with an isolation of the active device areas with boron implantation. The gate is fabricated using an i-line wafer stepper in combination with phase shift masks and a SiN sidewall spacer process. The optical projection lithography offers much higher throughput compared to electron beam lithography and is suited for the high volume production of

low cost millimeter wave integrated circuits. Gate lengths of 0.12 µm are achieved with a typical variation of ±5 % across a wafer. The T-shaped gate consists of a refractory metal with a highly conductive gold overlay which results in high reliability and a low gate resistance. The source and drain contacts are established by Ge/Au/Ni/Au metallizations self aligned to the gate. Ohmic resistors are realized using the cap layer of the epitaxial structure or by an additional NiCr thin film for higher precision. The MMIC process is completed by metal-insulator-metal capacitors and three different interconnect metal layers including electroplated airbridges. Additional process information is described in [2].

The active devices exhibit a current gain cutoff frequency of f_T=110 GHz at normal operating conditions, i. e. 2 V drain source voltage and 250 mA/mm normalized drain current. A maximum frequency of oscillation f_{max}>200 GHz is extrapolated from measured S-parameters. The extrinsic transconductance is beyond 700 mS/mm and the saturation current exceeds 600 mA/mm. The gate drain breakdown voltage is better than 5 V. Minimum noise figures of 0.6 dB and 1.5 dB have been measured at 12 GHz and 26 GHz respectively.

III. AMPLIFIER DESIGN

The chipphoto of the 90 GHz amplifier is depicted in Fig. 1. The amplifier (chipsize 1x2 mm²) is designed in coplanar technology. The application of coplanar transmission lines avoids the need for a backside metallization and via holes. The reduced parasitic coupling of adjacent coplanar elements permits more compact designs compared with microstrip circuits. The coplanar technology in conjunction with the easier fabrication has an additional potential to reduce the cost of MMICs.

The amplifier consists of 3 stages all having the same principle topology which is shown in Fig. 2. PHEMTs with 4x40 µm gate widths are used in the first two amplifier

stages at the operating conditions $V_{DS}=3$ V, $I_{DS}=250$ mA/mm. The third stage utilizes a PHEMT with 4x60 µm gate width for increased output power.

The gate bias voltage is applied through a λ/4 long transmission line which is rf shorted at the end. A 50 Ω resistor in the gate bias network stabilizes the PHEMT for frequencies below 2 GHz. The parallel connection of a capacitor C_2 and a 100 Ω resistor at the gate electrode stabilizes the PHEMT for frequencies below 80 GHz. These elements reduce the gain at 90 GHz by approximately 0.5 dB but they assure stable operation for wire bond and flip chip mounting.

The drain bias network consists of a λ/4 long transmission line which is rf shorted at the end with a capacitor C_4. The 10 Ω resistor in the drain bias network has a significant stabilizing effect in the MHz region. This resistor supresses bias oscillations which can occur if the dc pads are wire bonded to external blocking capacitors. The rf matching is realized at the gate electrode using a shorted stub l_3 and at the drain with an open stub l_6 in combination with dc blocking capacitors C_1 and C_5.

IV. MEASURED RESULTS

The measured gain and match of the 3-stage W-band amplifier are depicted in Figs. 3 and 4. The amplifier is applicable in the frequency range from 86 to 94 GHz. The gain is higher than 8 dB in conjunction with input and output reflection coefficients better than -11 dB. The maximum gain is 10.4 dB at a frequency of 92 GHz.

The amplifier output power characteristic has been measured with a Gunn diode VCO in series with an electronically tunable attenuator in a 50 Ω system at 94 GHz. Fig. 5 shows the output power and gain characteristics versus the input power. The output power achieves 10.6 dBm for 3 dB gain compression. The amplifier demonstrates more than 12 dBm saturated output power.
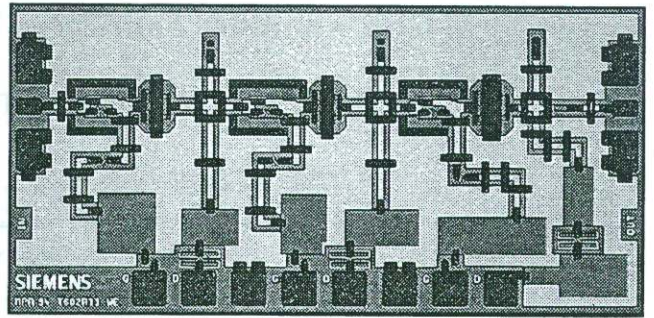

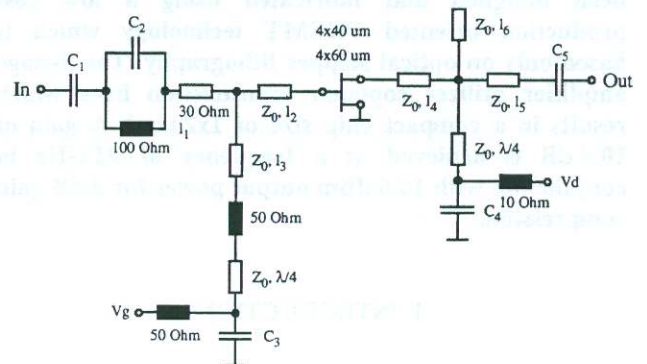Fig. 1: Chipphoto of the 3-stage 90 GHz amplifier.
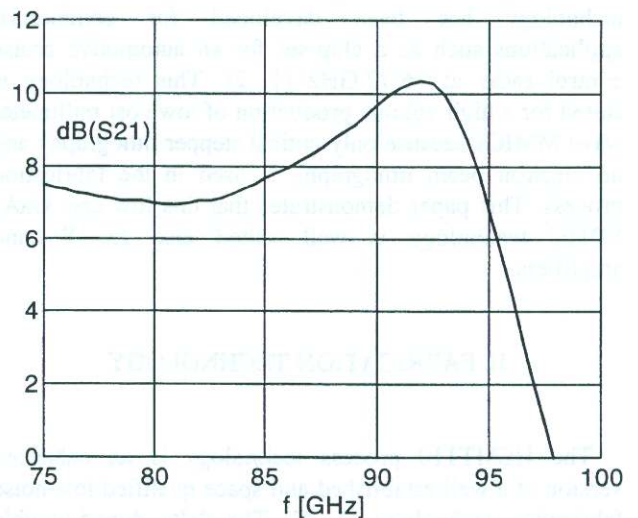

Fig. 2: Equivalent circuit model of one amplifier stage.
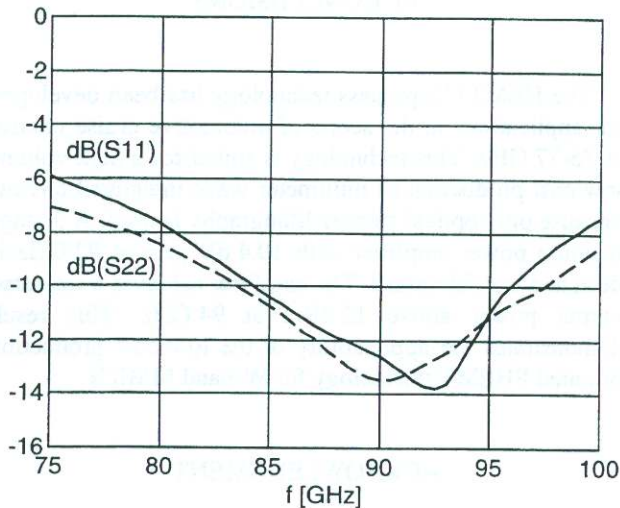

Fig. 3: Measured amplifier gain.

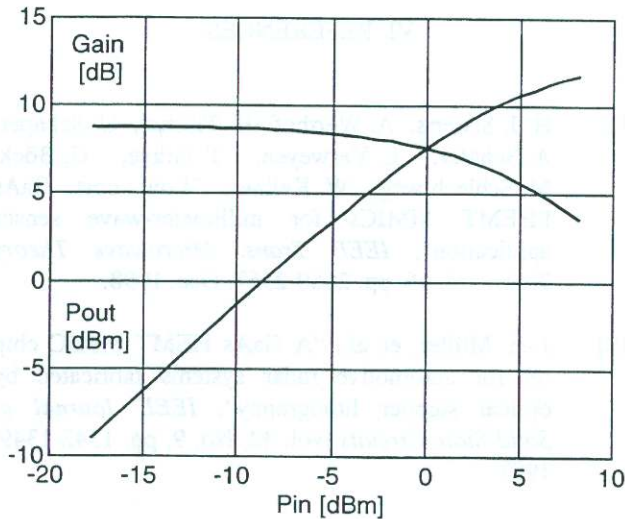Fig. 4: Measured amplifier input and output match.

Fig. 5: Measured amplifier output power and gain at 94 GHz.

V. PHEMT EQUIVALENT CIRCUIT MODEL

Very accurate models of the active and passive components are required for a first pass success design of W-band MMICs. Fig. 6 shows the topology of a HEMT small signal equivalent circuit model which fits the measured S-parameters up to 120 GHz. The values of some important equivalent circuit model parameters are C_{gs}=1.3 pF/mm, C_{gd}=0.15 pF/mm and G_m=1100 mS/mm for the operating conditions V_{DS}=3 V, I_{DS}=250 mA/mm.

The measured and simulated S-parameters of a HEMT110 with 2x40 μm gate width are depicted in Figs. 7, 8 and 9 in the frequency range from 0.5 to 120 GHz. The small signal equivalent circuit model permits an excellent fit of the measured S-parameters. Simultaneously not only the S-parameters but also the maximum available gain shown in Fig. 10 and the stability factor are modeled very accurately.
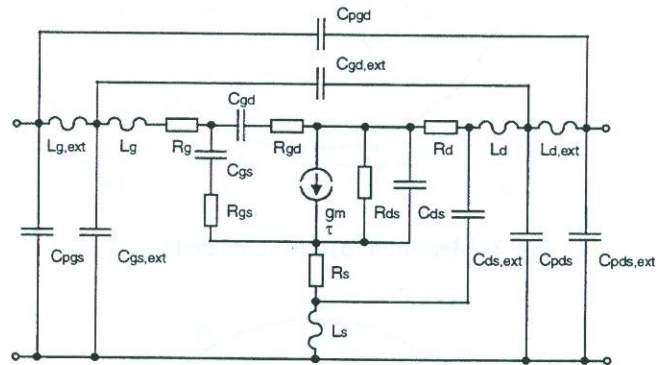

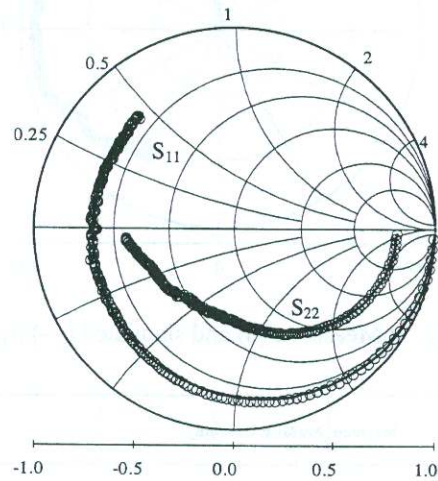Fig. 6: PHEMT small signal equivalent circuit model.

Fig. 7: Measured (o) and simulated (—) S_{11} and S_{22}.

Fig. 8: Measured (o) and simulated (—) S_{21}.

Fig. 9: Measured (o) and simulated (—) S_{12}.

Fig. 10: Measured (o) and simulated (—)
maximum available gain.

VI. CONCLUSIONS

The HEMT110 process technology has been developed for applications in the scope of automotive cruise control at 76-77 GHz. This technology is suited for a high volume low cost production of millimeter wave integrated circuits because only optical stepper lithography is used. A 3-stage medium power amplifier with 10.4 dB gain at 92 GHz is designed and fabricated. The amplifier achieves a saturated output power above 12 dBm at 94 GHz. This result demonstrates the applicability of the low cost production oriented PHEMT technology for W-band MMICs.

ACKNOWLEDGMENT

VI. REFERENCES

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[4]   T. Grave, "Optimization of GaAs-based HEMTs for microwave and millimeter wave IC applications", *Proc. 22nd Int. Symp. Compoun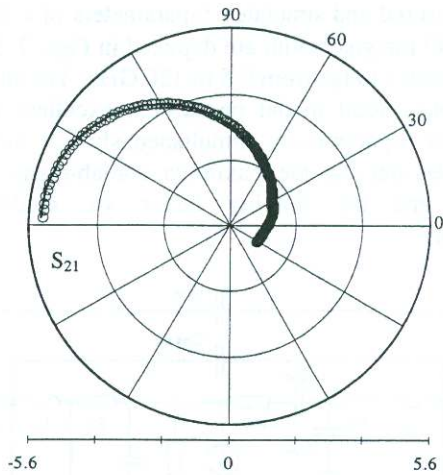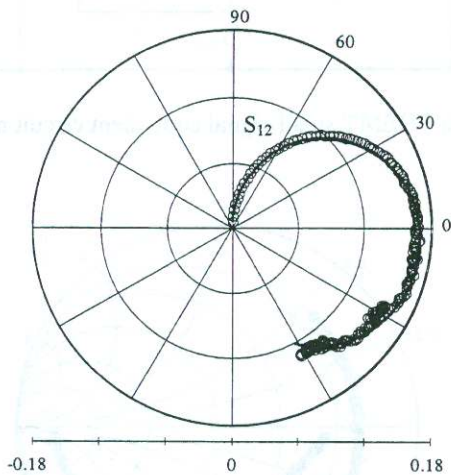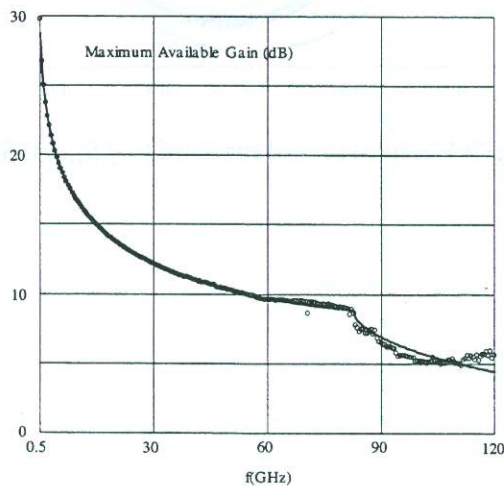d Semiconductors*, pp. 7-12, 1995.