A COPLANAR 94 GHz LOW-NOISE AMPLIFIER MMIC USING 0.07 μm METAMORPHIC CASCODE HEMTs

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Abstract — **A 94 GHz low-noise amplifier MMIC (LNA) has been developed, based on a coplanar technology utilizing 0.07 μm depletion type metamorphic HEMTs (MHEMTs). The realized single-stage cascode LNA achieved a small-signal gain of more than 12 dB and an average noise figure of 2.3 dB over the bandwidth from 80 to 100 GHz. With an indium content of 80 % in the channel a 2 x 30 μm MHEMT device has shown a transit frequency (f_t) of 290 GHz, an extrinsic transconductance of 1450 mS/mm and a maximum stable gain (MSG) of 11 dB at 94 GHz. Using two HEMTs connected in cascode configuration the MSG could be increased to 22 dB. To stabilize the cascode device and to increase the bandwidth of the amplifier circuit a resistive feedback was integrated into the HEMT in common-gate configuration. Coplanar topology in combination with cascode transistors resulted in a chip-size of only 1 x 1 mm^2.**

I. Introduction

Passive and active imaging systems raise the demand for high speed and low noise transistors with low power dissipation. Thus, an increasing interest in indium phosphide (InP) based devices and circuits at microwave and millimeter-wave frequencies exists, due to the high low-field electron mobility, the high peak electron velocity and the high sheet-carrier density in InP-based HEMTs. As a result of these excellent transport properties, InP devices clearly outplay the established GaAs technologies in terms of noise figure, gain and power added efficiency (PAE) [1]-[5]. Their superior characteristics are found in the low noise applications for passive imaging systems and in active phased-array radars, where a multiplicity of low-noise amplifiers with high gain and low power consumption are preferred to ensure a proper thermal management.

In this paper, we report on the development of a coplanar single-stage LNA MMIC, using 0.07 μm metamorphic cascode HEMT technology. Compared to InP substrates, the MHEMT technology is less expensive, taking advantage of the rapidly growing size of GaAs wafers, up to 6 inches today. Coplanar waveguide (CPW) technology is very attractive at millimeter and submillimeter wave frequencies, due to the simplified fabrication without backside processing, the high isolation between adjacent lines and its compatibility for flip-chip packaging. The cascode devices demonstrate approximately twice the gain compared to conventional HEMTs in common source configuration, requiring the same chip area [6]. Due to the very high maximum available gain of the cascode HEMT, a resistive feedback was integrated into the transistor in common gate configuration to increase both, the stability and the bandwidth of the amplifier circuit [7]. The realized metamorphic cascode LNA MMIC demonstrates a gain and noise performance equivalent to that of InP-based HEMT technology.

II. Technology

The W-band low-noise amplifier MMIC was fabricated using the InAlAs/InGaAs material system with $In_{0.52}Al_{0.48}As/In_{0.80}Ga_{0.20}As/In_{0.53}Ga_{0.47}As$ composite channel HEMTs grown by molecular beam epitaxy (MBE) on 4-inch semi-insulating GaAs substrates. For the metamorphic buffer a linear $In_xAl_yGa_{1-x}As$ $(x = 0 \rightarrow 0.52)$ transition in composition was used. The active devices consist of T-shaped 0.07 μm Ti-Pt-Au gates, which were defined by e-beam lithography and passivated with 250 nm CVD silicon nitride. With an indium content of 80 % in the channel an average extrinsic transit frequency of f_t = 290 GHz, and a maximum oscillation frequency of f_{max} = 340 GHz were achieved for a 2 x 30 µm common source device as shown in Fig. 1.

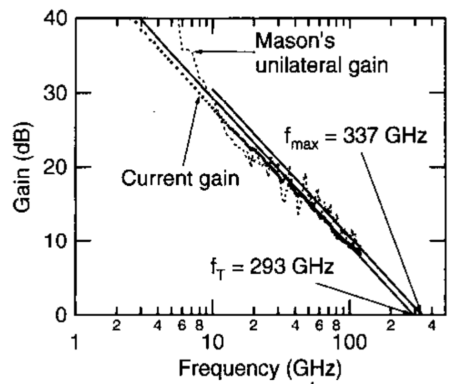


Fig. 1: Measured Mason's unilateral gain and current gain of a 2 x 30 µm common source device and extrapolated f_t and f_{max}.

The gate-drain breakdown voltage defined at 1 mA/mm of drain current was 2.8 V. With a drain bias of 1 V and a peak-gm gate bias of 0.25 V an extrinsic transconductance of 1450 mS/mm was measured. To realize an amplifier circuit with large bandwidth and high gain, transistors in cascode configuration were used which show a maximum stable gain of 22 dB at 94 GHz as illustrated in Fig. 2.

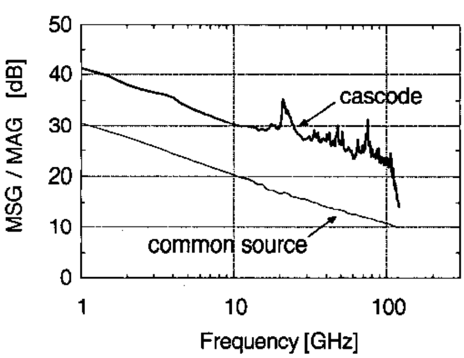
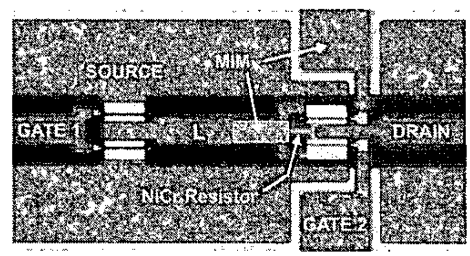


Fig. 2: Measured MSG/MAG performance of an unstabilized 2 x 30 µm cascode MHEMT and a 2 x 30 µm common source MHEMT.

III. Circuit Design

In order to stabilize the cascode device, we separated the HEMT in common source and the HEMT in common gate configuration by a short section of coplanar transmission line (L), as shown in Fig. 3 (a). Due to the very high gain of the MHEMT devices an additional resistive feedback was realized by employing a NiCr resistor between the source and the drain contact of the common gate FET. This feedback is used to stabilize the cascode device and also to increase the bandwidth of the amplifier circuit. Furthermore, a metal-insulator-metal (MIM) capacitor was integrated between the resistor and the coplanar interstage network to ensure a stable DC-bias point of the cascode HEMT. The schematic of the cascode configuration together with the resistive feedback network is shown in detail in Fig. 3 (b).

(a)



(b)

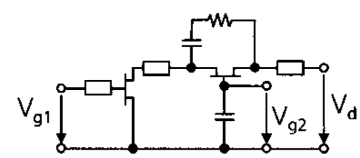


Fig. 3: (a) Photograph of a 2 x 30 µm cascode MHEMT with very compact integrated resistive feedback and (b) its schematic representation.

A chip photograph of the W-band amplifier MMIC is shown in Fig. 4. The circuit consists of a single cascode MHEMT stage with a gate width of 4 x 15 µm. The four-finger FET was chosen, because of its lower gate resistance and therefore an approximately 0.5 dB lower noise figure compared to a two finger device. The second gate of the cascode HEMT was RF-grounded via an MIM capacitor of 5.5 pF. The use of space saving coplanar waveguide technology results in an over-all chip-size of only 1 x 1 mm^2.

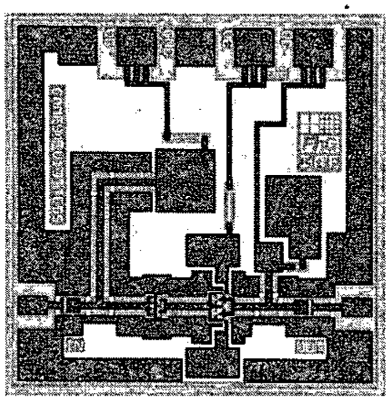


Fig. 4: Chip photograph of the 94 GHz LNA. The chip-size is 1 x 1 mm^2.

Figure 5 illustrates the schematic diagram of the amplifier circuit. Conventional reactive matching technique was used for the circuit design. The optimum length of 105 µm for the interstage transmission line (L) was chosen to ensure unconditional stability of the amplifier MMIC. Additionally, a 225 Ω NiCr resistor in combination with a 120 fF series capacitor was used in the feedback path. Low impedance thin film microstrip lines (TFMS) were utilized in the bias network to prevent unwanted low-frequency oscillations. The TFMS lines consist of the same SiN layer, which is used as the dielectric for the MIM capacitors.

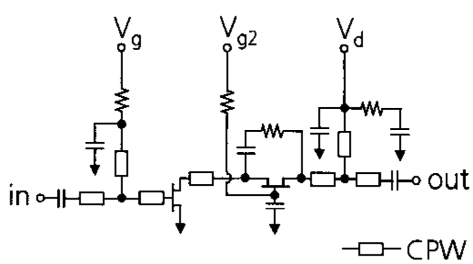


Fig. 5: Schematic diagram of the coplanar 94 GHz low-noise amplifier circuit.

IV. Measurements and Results

In Fig. 6 the simulated and on-wafer tested S-parameters of the amplifier circuit are shown from 70 to 120 GHz. A linear gain of 13 dB was achieved at 94 GHz. The measured input return loss was 8 dB and the output return loss was 18 dB at the frequency of operation. The comparison between simulated and measured S-parameters shows very good agreement over the entire frequency range.

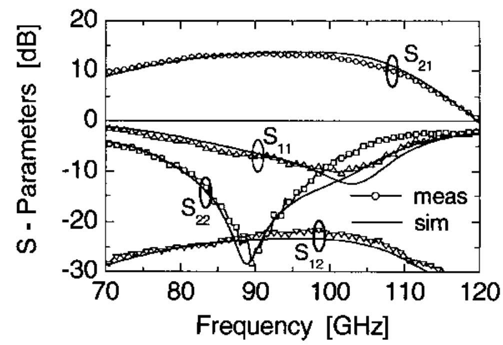


Fig. 6: Measured and simulated S-parameters of the LNA.

The measured noise figure and associated gain of the single-stage LNA are shown in Fig. 7. These measurements were performed at room temperature (293 K) from 80 to 100 GHz. A minimum noise figure of 2.1 dB with an associated gain of 13 dB was obtained at 94 GHz. The average noise figure was 2.3 dB with a small-signal gain of more than 12 dB over the entire frequency range.

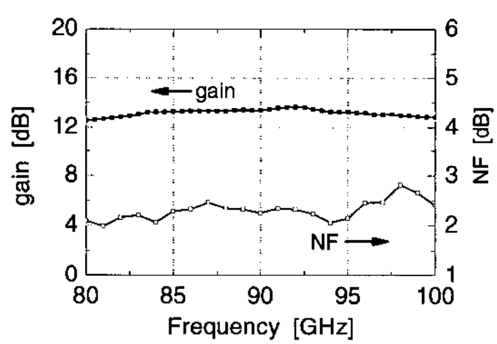


Fig. 7: Measured small signal gain and noise figure of the 94 GHz LNA.

A wafer mapping of the cascode LNA MMICs demonstrate the high uniformity and yield of our 0.07 µm metamorphic HEMT technology. The gain variation over the amplifiers from all 35 measured cells was as low as ± 0.6 dB, as illustrated in Fig. 8.

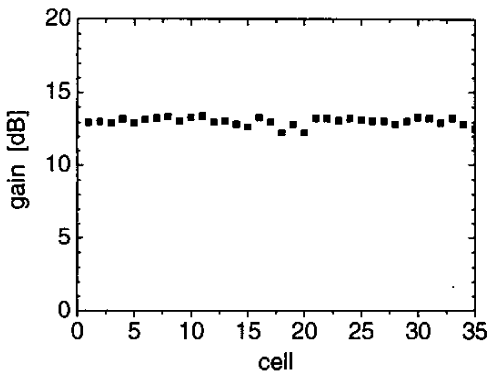


Fig. 8: Wafer mapping of the LNA gain in all 35 cells demonstrating the uniformity and yield of the 0.07 µm MHEMT technology.

Table I shows a comparison of published results of state-of-the-art W-band InP and metamorphic low-noise amplifier MMICs. This overview is dominated by InP devices. Our metamorphic HEMT technology demonstrates a competitive and even superior noise and gain performance. In addition, the use of cascode FETs utilized in this work leads to a two times higher gain-per-stage ratio compared to conventional single-gate devices.

TABLE I

COMPARISON OF REPORTED W-BAND HEMT MMIC LNAS

Freq [GHz]	NF [dB]	Gain [dB]	Gain/ Stage [dB]	HEMT	Device Size [µm²]	Ref.
95	2.5	20	5	InP	n.a.	[1]
94	2.9	18	6	InP	n.a.	[2]
94	3.2	16	4	InP	40 x 0.1	[3]
94	3.3	12	6	InP	n.a. x 0.1	[4]
90	2.8	17	n.a.	MHEMT	n.a.	[8]
89	4.8	14	4.7	MHEMT	30 x 0.1	[9]
94	2.3	13	13	MHEMT	60 x 0.07	this work

V. CONCLUSIONS

A single-stage 94 GHz cascode low-noise amplifier was realized, achieving an average noise figure of 2.3 dB with a small signal gain of more than 12 dB between 80 and 100 GHz measured at room temperature. This amplifier demonstrates the excellent noise and gain performance of our advanced 0.07 µm metamorphic HEMT technology for W-band applications. The use of cascode devices utilizing integrated resistive feedback improved bandwidth and ensured stable operation of the circuit. These results clearly demonstrate that metamorphic HEMT technology on 4-inch GaAs substrates is, at millimeter-wave frequencies, competitive in performance and of advantage in costs when compared to devices on InP substrates.

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