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Power Characteristics of Metamorphic $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ HEMTs on GaAs Substrates with T-Shaped Gate*

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Abstract: 200nm gate-length power InAlAs/InGaAs MHEMTs with T-shaped gate are characterized for DC, RF, and power performance. The MHEMTs show excellent DC output characteristics with an extrinsic transconductance of 510mS/mm and a threshold voltage of -1.8V. The f_T and f_{max} obtained for the 0.2μm × 100μm MHEMTs are 138 and 78GHz, respectively. Power characteristics are obtained under different frequencies. When input power (P_{in}) is -0.88dBm (or 2.11dBm), the MHEMTs exhibit high power characteristics at 8GHz. Output power (P_{out}), associated gain, power added efficiency (PAE) and density of P_{out} are 4.05(13.79)dBm, 14.9(11.68)dB, 67.74(75.1)%, 254(239)mW/mm respectively. These promising results are on the path to the application of millimeter wave devices and integrated circuits with improved manufacturability over InP HEMT.

Key words: MHEMT; InAlAs/InGaAs; power characteristics; T-shaped gate
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1 Introduction

For high frequency power applications, the device must have improved channel confinement, higher electron mobility, shorter gate length, and higher breakdown voltage. Thus far these goals have been best met with InP HEMT due to its superior carrier transport characteristics and carrier confinement[1]. This is primarily due to the high indium content InGaAs channel, which is lattice-matched to the InP substrate. However, InP substrates have some drawbacks including fragility, small wafer size and high cost. Attempts have lately been made to grow GaAs-based InAlAs/InGaAs metamorphic HEMTs (MHEMTs) [2~6]. InAlAs/InGaAs MHEMTs on GaAs substrates have provided very promising advantages over the structures grown on InP substrates. MHEMT allows a range of InGaAs channel compositions (30% ~80%) to be grown on GaAs substrates with a compositionally graded buffer layer, which are less brittle, less expensive, and available in the size up to 150mm in diameter. MHEMTs contain advantages of both InP-based HEMTs and GaAs substrates. GaAs-based MHEMTs by MBE material have emerged as an attractive, low cost alternative to InP-based HEMTs for high performance, low noise and power applications[7~9].

In 1988, a 120nm Gate-length GaAs-based InAlAs/InGaAs MHEMT was reported in America at the first time[10]; 35nm T-shaped gate MHEMT also has been reported by now, and f_T and f_{max} were 440 and 520GHz[11]. However, the research in this field in the mainland of China is still in its infancy, and mostly focused on optical lithography technology but few on E-beam lithography and power characteristics of MHEMT. The gate length was almost 1.0μm, and the power advantage of MHEMTs has been seriously restricted.

In this paper, 200nm gate-length GaAs-based MHEMTs are fabricated, and excellent DC, RF and power performances are achieved. G_m, J_{DSS}, V_T, f_T and f_{max} of InAlAs/InGaAs MHEMTs are 510mS/mm, 605mA/mm, -1.8V, 138GHz and 78GHz respectively. At 8GHz, when P_{in} is -0.88 (or 2.11) dBm, P_{out}, associated gain, power added efficiency (PAE) and density of P_{out} are 4.05(13.79)dBm, 14.9 (11.68)dB, 67.74(75.1)%, 254(239)mW/mm respectively. It is very helpful to further investigate MHEMT devices and MMICs.

2 Devices fabrication

The structure of epitaxial materials is shown in Fig. 1. The epitaxial wafers grown on SI GaAs substrates by MBE technology were provided by Insti-

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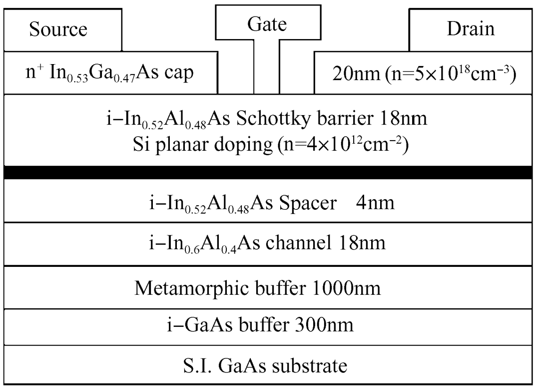

Fig. 1 Structure of the epitaxial materials

tute of Physics, Chinese Academy of Sciences. The structure is composed of a 300nm GaAs layer, a 1000nm M-buffer with grading composition, an 18nm InGaAs channel (In composition is 0.6), a 4nm InAlAs spacer, a planar doping layer, an 18nm InAlAs Schottky barrier layer, and a 20nm n^+ InGaAs cap layer.

Device fabrication started with mesa-isolation for the MHEMT devices using a conventional wet etching process. The source and drain electrodes of GaAs-based MHEMTs were fabricated by conventional evaporation and lift-off processes, and ohmic contacts were formed using a new six-layer ohmic system (Ni/Ge/Au/Ge/Ni/Au). For the T-gate process, the novel tri-layer resist that consists of polymethylmethacrylate (PMMA) / Polymethylglutarimide (PMGI) / polymethylmethacrylate (PMMA) [12] was exposed first by e-beam lithography (Leica EBML300) with an opening of 200nm. Citric acid-H_2O_2 solution was used for gate recess process, Ti/Pt/Au were evaporated to form gate metal, and metal lines were Ti/Au. Figure 2 shows a cross-sectional SEM photograph of 200nm gate length T-shaped MHEMT with a wide head of about 400nm.

3 Results and analysis

DC and RF characterization were performed using a probe station and on-wafer RF probes from Angilent 8510C. Typical transfer characteristics of a $0.2\times100\mu m$ MHEMT device are shown in Figs. 3 and 4, respectively.

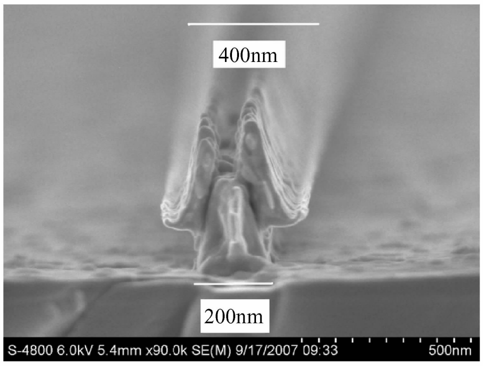

Fig. 2 SEM cross section of a 200nm gate

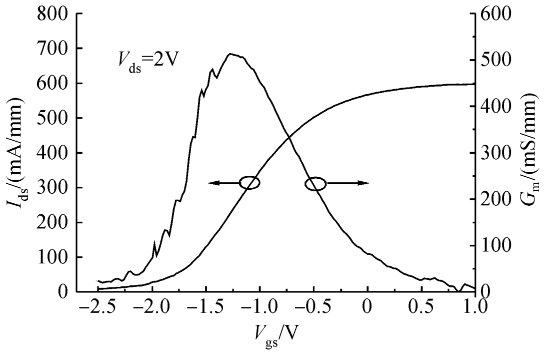

Fig. 3 Transfer characteristics of MHEMT

As shown in Fig. 3, the device exhibits excellent *I-V* characteristics with a slight increase in output conductance at high V_{ds}, good pinch-off characteristics, and the saturation drain current. The pinch-off voltage V_T was $-1.8V$; the saturation drain-to-source current (I_{dss}) was about 605 mA/mm; and the extrinsic transconductance of the device at 2V drain-source voltage was 510 mS/mm. These excellent DC characteristics can be explained by the drastic reduction of gate resistance owing to the T-shaped gate with a wide head of about $0.4\mu m$.

Figure 4 shows the measured current gain *H* and maximum available gain (MAG) curves derived from *S*-parameter measurements for a 200nm gate-length device, biased at $V_{ds}=1.0V$ and $V_{gs}=-1.0V$. From the current gain characteristics, a maximum unity current gain cut-off frequency (f_T) of 138GHz was determined using $-20dB$/decade roll-off. At the same time, a maximum frequency of oscillation (f_{max}) of 78GHz was obtained from the MAG measurements. To our knowledge, this frequency performance is the highest ever reported for MHEMTs on GaAs substrate in the mainland of China.

Power measurements were performed on-wafer using the load-pull system at 8, 26, 35, 40GHz, and the

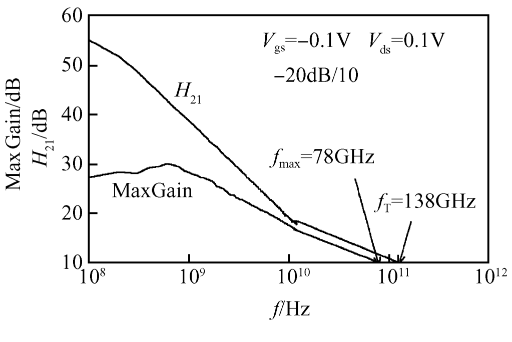

Fig. 4 RF characteristic of InAlAs/InGaAs MHEMT

Table 1 Power characteristics at different frequencies

Frequency /GHz	P_{in} /dBm	P_{out} /dBm	Gain /dB	PAE /%
8	−0.88	14.05	14.9	67.7
	2.11	13.79	11.68	75.1
26	9	12.8	3.86	35.5
35	6.7	11.2	3.65	19.4
40	3	5.6	2.6	3.6

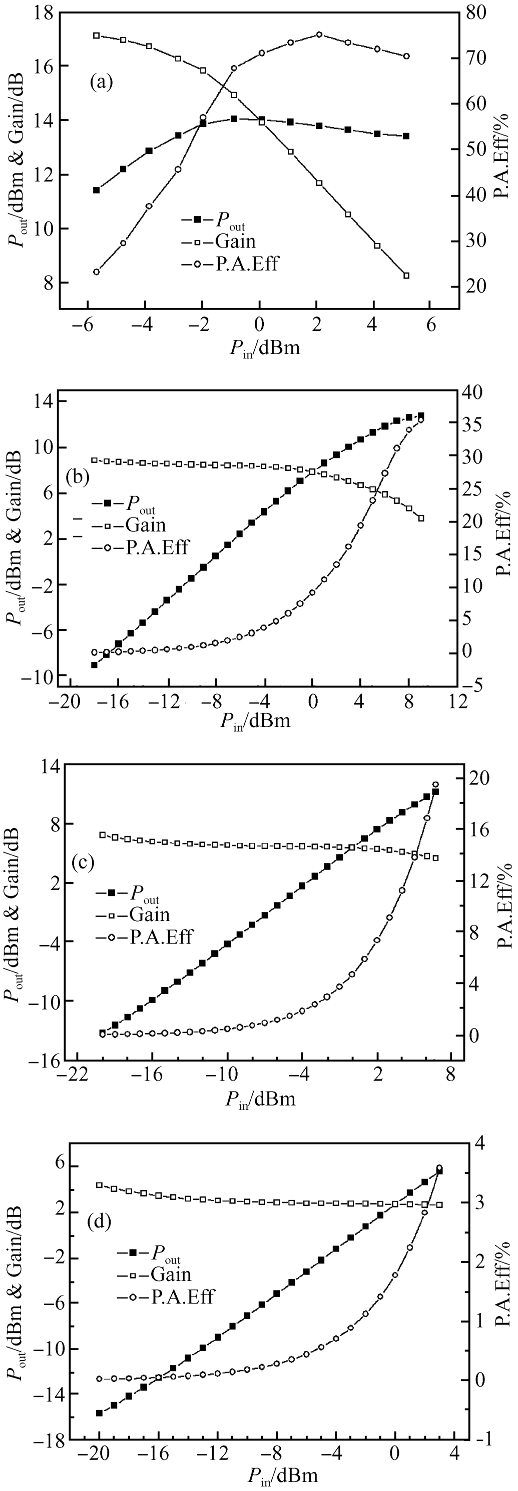

Fig.5 (a) Power characteristics of MHEMT at 8GHz; (b) Power characteristics of MHEMT at 26GHz; (c) Power characteristics of MHEMT at 35GHz; (d) Power characteristics of MHEMT at 40GHz

results are shown in Table 1 and Fig. 5. V_{gs}, V_{ds} were fixed at −1.0, 2.0V. At 8GHz, excellent power characteristics were obtained. The maximum output power, power-added efficiency (PAE) and gain were plotted in Fig. 5. When P_{in} was −0.88dBm, the device generated maximum output power of 14.05dBm, power gain of 14.9dB and PAE of 67.7%. When P_{in} was 2.11 dBm, the device generated maximum output power of 13.79dBm, power gain of 11.68dB and PAE of 75.1%. The density of output power was 239mW/mm. To the best of our knowledge, this is the maximum power density and drain biasing of any MHEMT reported in the mainland of China, demonstrating MHEMT's ability to deliver excellent power and gain at millimeter wave frequencies. However, compared to foreign results[1], the density of output power is poor. An increase in doping density of InAlAs Schottky barrier layer would be useful to get better power characteristics.

At 26, 35, 40GHz, the maximum output power, gain and power-added efficiency (PAE) were 12.8dBm (11.6, 5.6dBm), 3.86dB (3.65, 2.6dB) and 35.5% (19.4%, 3.6%) respectively. As shown in Table 1, we can see that the maximum output power, gain and power-added efficiency (PAE) have reduced gradually from 8 to 40GHz, which owned to the design of this preliminary device based on an inaccurate large signal device model. In load-pull test, we found that additional tuning was required at the output to obtain best performance. These were power matched at a potentially non-optimal power load for this MHEMT material, and better power performance may be achieved with a different load target.

4 Conclusion

The 200nm gate-length power MHEMTs with T-shaped gate were characterized for DC, RF, and power performances. The MHEMT device showed the DC output characteristics with an extrinsic transconductance of 510mS/mm and a threshold voltage of −1.8V. The f_T and f_{max} obtained for the $0.2\mu m \times 100\mu m$ MHEMT device were 138 and 78GHz. Power characteristics were obtained at different frequencies. When P_{in} was −0.88 (or 2.11) dBm, The MHEMTs exhibited excellent power characteristics at 8GHz, P_{out}, associated gain, power added efficiency (PAE) and density of P_{out} were 4.05 (13.79) dBm, 14.9 (11.68) dB, 67.74 (75.1)%, 254 (239) mW/mm respectively. Consequently, these demonstrate MHEMT's ability to deliver excellent power and gain at millimeter wave frequencies. The InAlAs/InGaAs MHEMTs are promising in the application of millimeter wave devices and integrated circuits.

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T形栅 $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ MHEMTs 功率器件*

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摘要: 利用电子束光刻技术制备了200nm栅长GaAs基T型栅InAlAs/InGaAs MHEMT器件.该GaAs基MHEMT器件具有优越的直流、高频和功率性能,跨导、饱和漏电流密度、阈值电压、电流增益截止频率和最大振荡频率分别达到510mS/mm,605mA/mm,-1.8V,138GHz和78GHz.在8GHz下,输入功率为-0.88(2.11)dBm时,输出功率、增益、PAE、输出功率密度分别为14.05(13.79)dBm,14.9(11.68)dB,67.74(75.1)%,254(239)mW/mm,为进一步研究高性能GaAs基MHEMT功率器件奠定了基础.

关键词: MHEMT; InAlAs/InGaAs; 功率特性; T型栅

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