200nm Gate Length Metamorphic $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ HEMTs on GaAs Substrates with 110GHz f_T *

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Abstract: 200nm gate-length GaAs-based InAlAs/InGaAs MHEMTs are fabricated by MBE epitaxial material and EBL (electron beam lithography) technology. Ti/Pt/Au is evaporated to form gate metals. A T-shaped gate is produced using a novel PMMA/PMGI/PMMA trilayer resist structure to decrease parasitic capacitance and parasitic resistance of the gate. Excellent DC and RF performances are obtained and the transconductance (g_m), maximum saturation drain current density (J_{DSS}), threshold voltage (V_T), current cut-off frequency (f_T), and maximum oscillation frequency (f_{max}) of InAlAs/InGaAs MHEMTs are 510mS/mm, 605mA/mm, −1.8V, 110GHz, and 72GHz, respectively.

Key words: MHEMT; InAlAs/InGaAs; electron beam lithography; T-shaped gate
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1 Introduction

InAlAs/InGaAs high electron mobility transistors (HEMTs) on InP substrate have shown higher gain and lower noise at millimeter-wave frequencies than GaAs-based pseudormorphic HEMTs[1~3]. However, InP substrate is fragile, not available in large scale, and more expensive, so it is difficult to fabricate InP-based HEMTs at a high production level. On the other hand, GaAs substrate is more suitable for large scale MMIC production. In order to combine the advantages of GaAs and InP materials, GaAs-based MHEMTs were grown on semi-insulating GaAs substrates using a composition grading M-buffer. 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[4~6].

In 1988, a 120nm gate-length GaAs-based InAlAs/InGaAs MHEMT was reported in America for the first time[7]. 35nm T-shaped gate MHEMTs have been reported already with a f_T and f_{max} of 440 and 520GHz, respectively[8]. However, the research in this field in the mainland China is still in its infancy, and mostly focuses on optical lithography technology and not on e-beam lithography; the length was almost 1.0μm, seriously restricting the performance of the MHEMTs.

In this paper, 200nm gate-length GaAs-based MHEMTs are fabricated and excellent DC and RF performances are achieved. The g_m, J_{DSS}, V_T, f_T, and f_{max} of the InAlAs/InGaAs MHEMTs are 510mS/mm, 605mA/mm, −1.8V, 110GHz, and 72GHz, respectively. It is helpful to investigate MHEMT devices and MMICs further.

2 Device fabrication

The structure of the epitaxial materials is shown in Fig. 1.

The epitaxial wafers grown on semi-insulting GaAs substrates by MBE technology were provided by the Institute 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.

GaAs MHEMT structure 1			
Layer	Thickness/nm	Dopant	Concentration
$In_{0.53}Ga_{0.47}As$	20	Si	$5\times10^{18}cm^{-3}$
$In_{0.52}Al_{0.48}As$	18		
Si delta doped layer		Si	$4\times10^{12}cm^{-2}$
$In_{0.52}Al_{0.48}As$	4		
$In_{0.6}Ga_{0.4}As$	18		
InAlAs buffer	1000		
i-GaAs	300		
GaAs substrate			

Fig.1 Structure of the epitaxial materials

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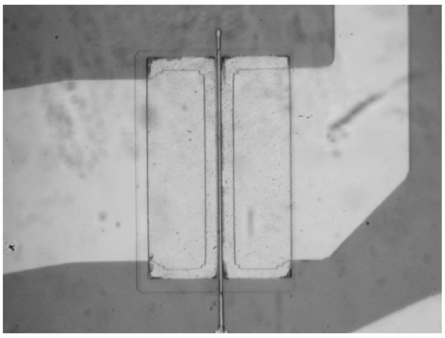

Fig. 2 Partial picture of the MHEMT device

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, which consists of polymethylmethacrylate (PMMA) / Polymethylglutarimide (PMGI) / polymethylmethacrylate (PMMA),[9] was exposed first by e-beam lithography (Leica EBML300) with an opening of 200nm. Citric acid-H_2O_2 solution was used for the gate recess process. Ti/Pt/Au were evaporated to form the gate metal and the metal lines were Ti/Au. A partial picture of the MHEMT device is shown in Fig. 2. Figure 3 shows a cross-sectional SEM photograph of the 200nm gate length T-shaped MHEMT with a wide head of about 400nm.

3 Results and analysis

DC and RF characterizations were performed using a probe station and on wafer RF probes from an Angilent 8510C. Typical transfer characteristics and DC output of a 0.2 × 100μm MHEMT device are shown in Fig. 4 and Fig. 5, respectively.

The pinch-off voltage V_T is −1.8 V. The device exhibits excellent *I-V* characteristics with a slight increase of output conductance at high V_{DS}, despite the small gate length. This indicates a low short channel

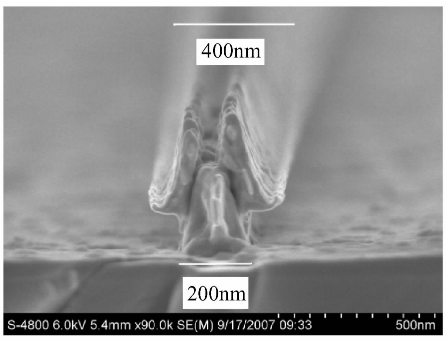

Fig. 3 SEM cross section of a 200nm gate

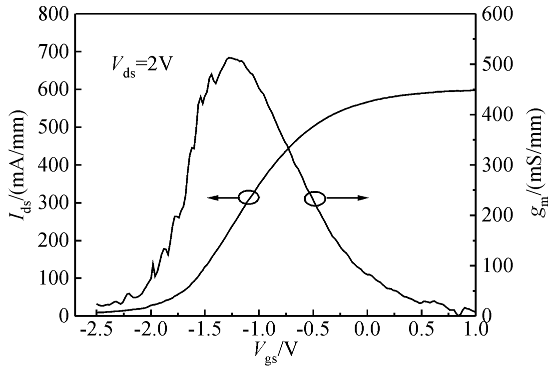

Fig. 4 Transfer characteristics of the MHEMT

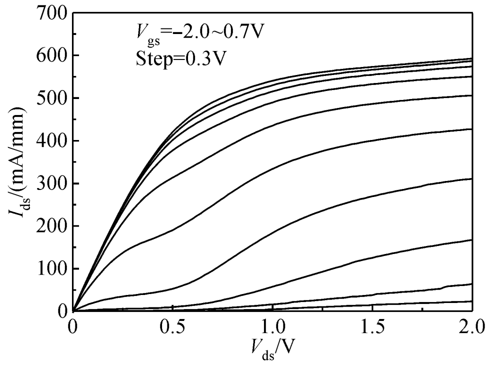

Fig. 5 DC characteristics of the MHEMT

effect. Moreover, good pinch-off characteristics and the saturation drain current are observed. The saturation drain-to-source current (I_{DSS}) is about 605mA/mm and the extrinsic transconductance of the device at 2V drain-source voltage is 510mS/mm. As shown in Fig. 6, the measured source to drain off-state breakdown voltage is 2.4V at a gate voltage of −2.0V. The high breakdown voltage is due to the lower I_{DSS} target caused by a longer recess.

The *S*-parameters for the MHEMT devices were measured from 0.1～40GHz, and current gain *H* and MAG/MSG, as a function of frequency are shown in Fig. 7. The small signal equivalent circuit was extracted at maximum transconductance bias condition, V_{gs} = −1.0V when V_{ds} = 1.0V. The measured *S*-parameters were fitted to a standard lumped element equivalent

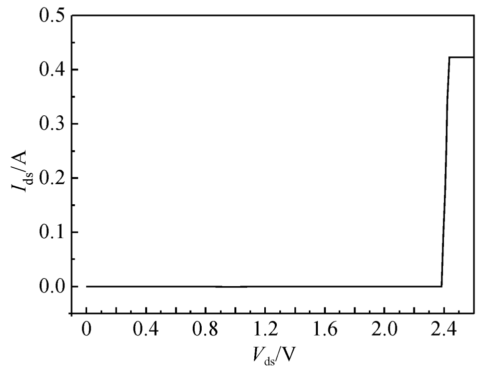

Fig. 6 S-D off-state breakdown characteristic of the MHEMT

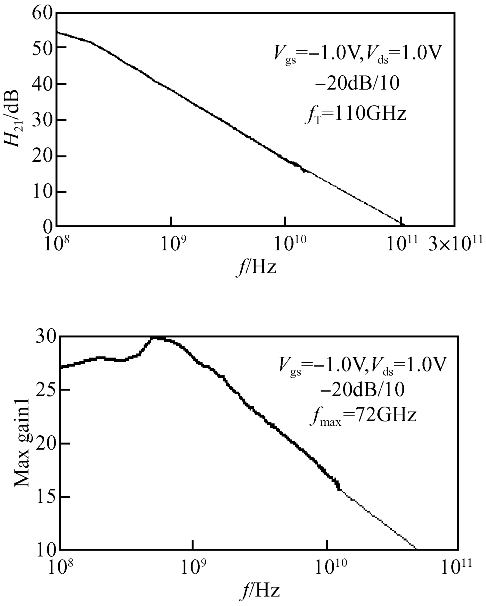

Fig.7　RF characteristic of the InAlAs/InGaAs MHEMT

circuit model including CPW transmission lines at the input and output. To －20dB/10 extrapolation, the fabricated 0.2×100μm MHEMT demonstrated a cut-off frequency of about 110GHz and a maximum frequency of about 72GHz. To our knowledge, this frequency performance is the highest ever reported for MHEMTs on GaAs substrate in China.

The excellent device performance of the 0.2μm manufactured MHEMT demonstrates that the T-gate process is compatible with the MHEMT process and can be practically used for MHEMT manufacturing.

4　Conclusion

200nm gate-length GaAs-based MHEMTs have been fabricated by EBL (electron beam lithography) technology. A T-shaped gate has been used to decrease the parasitic capacitance and parasitic resistance of the gate. The device exhibits excellent DC and RF characteristics. The transconductance (g_m), maximum saturation drain current density (J_{DSS}), threshold voltage (V_T), current cut-off frequency (f_T), and maximum oscillation frequency (f_{max}) of the InAlAs/InGaAs MHEMTs were 510mS/mm, 605mA/mm, －1.8V, 110GHz, and 72GHz, respectively. Consequently, the InAlAs/InGaAs MHEMTs are promising in millimeter wave devices and integrated circuits.

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200nm 栅长 $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ MHEMTs 器件 *

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摘要： 利用电子束光刻技术制备出 200nm 栅长 GaAs 基 InAIAs/InGaAs MHEMT 器件. Ti/Pt/Au 蒸发作为栅极金属. 同时为了减少栅寄生电容和寄生电阻，采用 3 层胶工艺，实现了 T 型栅. GaAs 基 MHEMT 器件获得了优越的直流和高频性能，跨导、饱和漏电流密度、域值电压、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，110GHz 及 72GHz，为进一步研究高性能 GaAs 基 MHEMT 器件奠定了基础.

关键词： MHEMT；InAIAs/InGaAs；电子束光刻；T 型栅

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