# High Performance Metamorphic HEMT with 0.25 µm Refractory Metal Gate on 4” GaAs Substrate

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## Abstract

High performance metamorphic high electron mobility transistors (MHEMTs) on 4-inch GaAs substrate with a refractory metal gate are reported. A MHEMT with 0.25 µm gate length yields an extrapolated $f_T$ of 115 GHz at drain bias of 1 V and a $f_{max}$ of 300 GHz at drain bias 2 V with an average gain of 13.7 dB at 60 GHz. Furthermore the MHEMT with a refracory metal gate demonstrates good thermal stability and promising accelerated DC life tests.

## Introduction

GaAs-based metamorphic HEMTs (MHEMT) have become attractive as an alternative technology to InP - based HEMTs for low noise and power applications [1,2] . MHEMTs combine the advantageous performance of InP HEMTs and the ease of manufacture on GaAs wafers with low cost 4” and 6” substrates. In this paper, we present the fabrication, performance and thermal stability of the first MHEMT with 0.25 µm refractory metal gate, on 4-inch GaAs substrate. We use refractory material instead of the commonly used TiPtAu metallization to avoid gate sinking effects and so improve reliability. For high throughput gate manufacturing and the reduction of the fabrication cost, optical lithography with i-line stepper and a SiN sidewall spacer process are used.

## Fabrication

Epitaxial growth was carried out in an MBE system on 4-inch semi-insulating GaAs substrates. The metamorphic buffer is grown at 450°C and its composition is graded from $Al_{0.48}Ga_{0.52}As$ to $Al_{0.48}In_{0.52}As$ over 1 µm by increasing the In flux and simultaneously decreasing the Ga flux. A 250 nm $Al_{0.48}In_{0.52}As$ layer is subsequently grown on this buffer. The structure consists of a double heterojunction layer in which planar doping is placed both above and below the undoped $In_{0.53}Ga_{0.47}As$ channel, an $In_{0.52}Al_{0.48}As$ Schottky layer and an undoped InGaAs cap layer. The mobility and carrier density of the heterostructure was $4x10^{12}$ $cm^{-2}$, respectively, at 300 K. After the mesa-isolation, gate manufacturing starts by PECVD SiN deposition. Then, resist openings are formed by optical lithography, with an i-line stepper, having a numerical aperture of 0.4, and are transferred to the SiN film by dry etching using an ICP system. The gate recess is etched using succinic acid and followed by the deposition of SiN sidewall spacer. Dry etching the dielectric spacer enables a final gate length of 0.25 µm. Next, thermally stable refractory metal is sputtered for gate metal. Gate fingers are reinforced by a broader overlay metal to reduce the gate resistance. Finally, unused parts of refractory metal are removed using dry-etching. AuGeAu ohmic contacts are established self-aligned to the T-gate and annealed on hotplate. The SEM in figure 1 illustrates a cross section of the 0.25 µm T-gate formed by optical lithography and SiN sidewall spacer

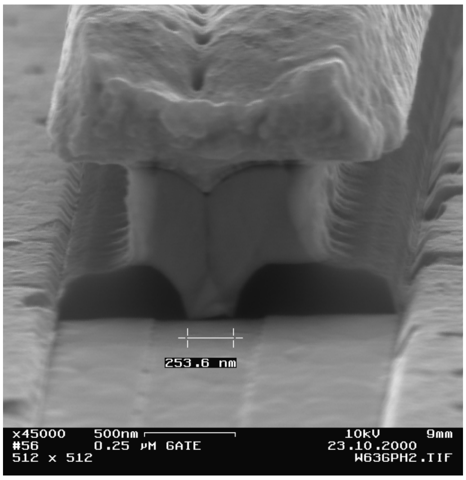

Fig.1 : SEM picture of cross section of the 0.25 µm gate.

## Device Characteristics

The output I-V and transfer characteristics of the 0.25 x 20 µm$^2$ MHEMT are shown in figs. 2 and 3. The device exhibits no kink effect and a good pinch-off in the I-V, an open channel resistance of 0.9 ς.mm and $I_{DSmax}$ = 700 mA/mm. The average DC transconductance at 1 V drain bias is 700 mS/mm and the threshold voltage is 600 mV.

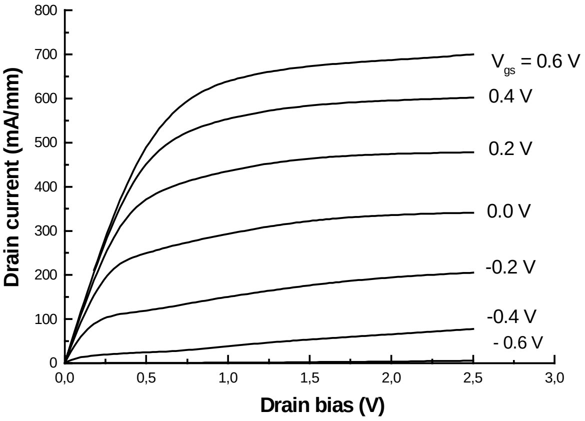

Fig.2 : I-V characteristics of 0.25 µm x 20 µm MHEMT.

On 4ŧ substrate, the standard deviation of peak-$g_m$ and $V_{th}$ is 63 mS/mm and 50 mV, respectively, at $V_{ds}$ = 1 V. The gate to drain breakdown voltage measured is 5 V at a gate reverse current of 1 mA/mm.

S-parameters were measured from 2-120 GHz, using on wafer probing for a 2x60 µm wide MHEMT with 1.3 µm drain–source spacing. Maximum stable gain (msg) and current gain, at drain bias of 1 V and 2 V are plotted in fig. 4. An $f_T$ of 115 GHz and $f_{max}$ of 250 GHz are obtained at $V_{ds}$ = 1 V and at $V_{ds}$ = 2 V an $f_{max}$ of 300 GHz is extrapolated. A msg of 13.7 dB at 60 GHz and 2 V drain bias is obtained, compared to 15 dB [3] with our 0.15 µm TiPtAu T-gate MHEMT. Such a high gain and no gate sinking effect make the MHEMT technology with 0.25 µm refractory metal gate a promising candidate for low noise and power applications from Ka to W band without to use e-beam lithography.

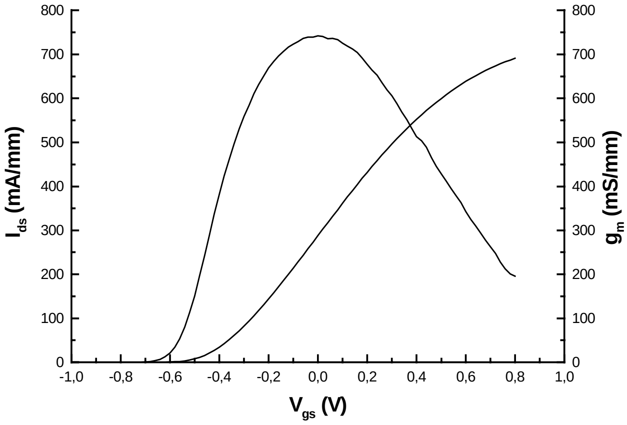

Fig.3 : Transfer characteristics of 0.5 µm x 20 µm MHEMT.

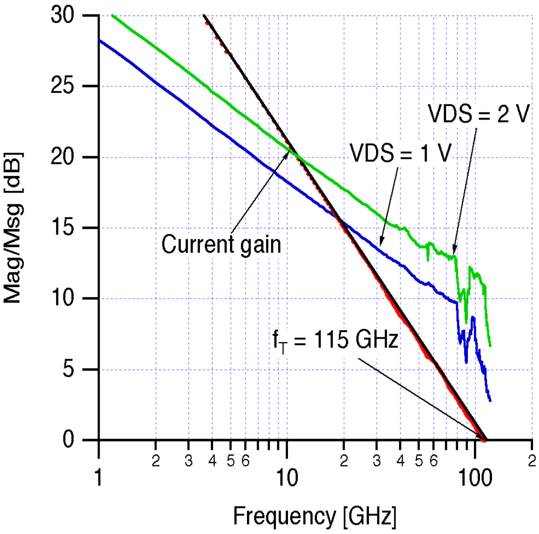

Fig.4 : Measured gain of 0.25 µm MHEMT ($W_g$= 2x60 µm ) at $V_{ds}$ = 1 V and 2 V from 1 – 120 GHz.

## Thermal stability

A wafer stabilization bake in nitrogen ambient is introduced as part of device fabrication to stabilize the device parameters ($V_{th}$ , $g_m$ ) [4] . In the case of MHEMT, with refractory metal gate, this step leads to a negative shift of the threshold voltage ( 60 mV ), due to improvement of the refractory metal - InAlAs interface damaged during the SiN spacer etching and the refractory metal sputtering. In order to determine the thermal stability of the MHEMTs , devices were stressed in nitrogen ambient at 250°C for 350 hours. Figure 5, shows the excellent thermal stability of the MHEMT after high temperature stress ( HTS ). The slight reduction in $g_m$ and $I_{ds}$ is related to the increase in drain and source resistance but no $V_{th}$ shift is observed when compared to TiPtAu gate metal. This behavior shows the stability of the refractory metal to the InAlAs interface and the active channel depth under the gate.

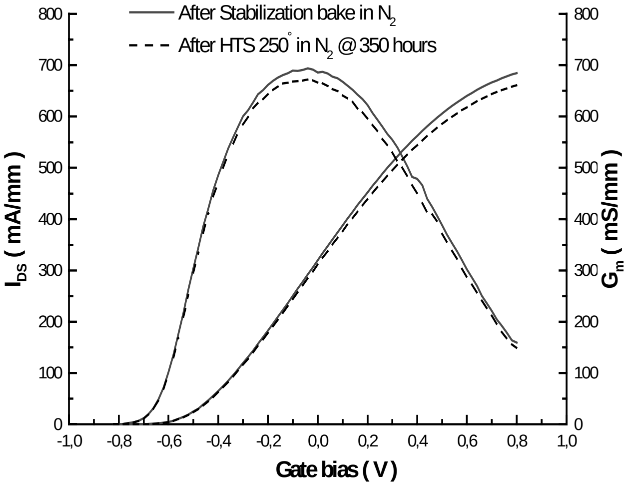

Fig.5 : Transfer characteristics of 0.25 µm MHEMT before ( solid line ) and after temperature stress (dashed line).

To demonstrate the reliability of metamorphic HEMT with 0.25 µm refractory metal gate , we started accelerated DC life tests on devices biased at $V_{ds}$ = 1 V and $I_{ds}$ = 280 mA/mm. The FET's were stressed in nitrogen ambient at 200°C, 220°C and 245°C and the transconductance was measured in-situ every 15 minutes. Figure 6 shows the relative change in peak-$g_m$. All devices show excellent thermal stability, which is promising for calculating the median time to failure ( MTTF ) from the Arrhenius plot, with a failure criterion of 10 % degradation in $g_m$. Figure 7 shows the relative change in $g_m$ for MHEMTs stressed at 440 mW/mm DC power dissipation ( $V_{ds}$= 2 V and $I_{ds}$ = 220 mA/mm ), in nitrogen ambient at 200°C and 220°C. These accelerated DC life tests are very promising to demonstrate reliable power MHEMTs with refractory metal as Schottky gate. Device degradation is mainly related to increase in $R_S$ and $R_D$.

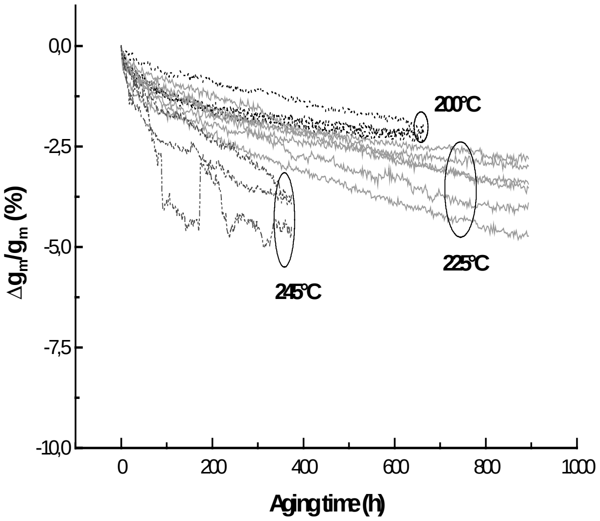

Fig.6 : Relative change in peak-$g_m$ of MHEMTs stressed in nitrogen ambient at $V_{DS}$ = 1 V and $I_{DS}$ = 280 mA/mm and $T_a$ = 200°C, 220°C and 245°C.

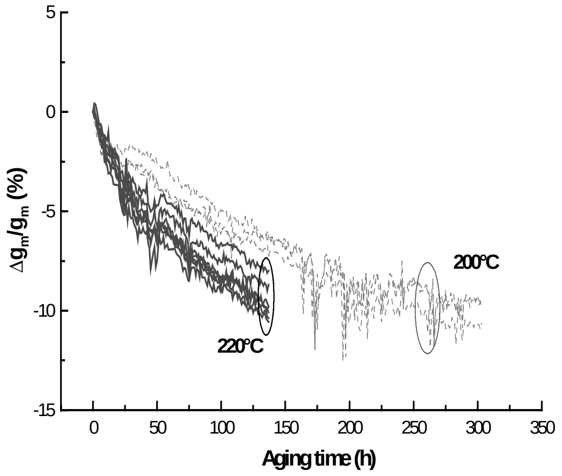

Fig.7 : Relative change in $g_m$ of MHEMTs stressed in nitrogen ambient at $V_{DS}$ = 2 V and $I_{DS}$ = 220 mA/mm and $T_a$ = 200°C and 220°C.

# Conclusion

We have demonstrated the fabrication, performance and thermal stability of MHEMTs with 0.25 µm refractory metal gate, on 4t̄ GaAs substrates, using i-line stepper and SiN sidewall spacer process for a low cost manufacturing technology. Thus, at IAF the reproducibility and improvement of MHEMT spacer technology is currently under development with a promise of high performance and reliability.

# Acknowledgment

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