Low Noise Metamorphic HEMTs with Reflowed Submicron T-Gate

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***Abstract* — A submicron T-gate fabricated using E-beam lithography and thermally reflow process was developed and was applied to the manufacture of the low noise metamorphic high electron-mobility transistors (MHEMTs). The $In_{0.53}Al_{0.47}As/InGaAs$ MHEMT uses $In_xAl_{1-x}As$ as the buffer layer between GaAs substrate and the InP lattice-matched HEMT structure. The T-gate developed has a gate length of 0.13 µm formed by thermally reflowed technology. The fabricated MHEMT has a saturation drain current of 200 mA/mm and a transconductance of 750 mS/mm at V_{DS} = 1.2V. The noise figure for the 160 µm gate-width device is less than 1 dB and the associated gain is up to 14 dB at 18 GHz. The device demonstrates a cut-off frequency f_T of 154 GHz and a maximum frequency f_{max} of 300 GHz.**

I. INTRODUCTION

For the high-frequency wireless applications, metamorphic HEMT using an $In_xAl_{1-x}As/In_xGa_{1-x}As$ heterrostructure grown on GaAs substrate [1,2] constitutes a good alternative to pseudomorphic AlGaAs/InGaAs/GaAs HEMTs (PHEMTs) and to lattice matched InAlAs/InGaAs/InP HEMTs (InP-HEMTs). A strain relaxed, compositionally graded metamorphic buffer layer is used to accommodate the large lattice mismatch between the top layers and the substrate. The metamorphic HEMT has received much attention recently due to its capability to combine the advantage of the InP-based structure and the GaAs substrate [3]. Based on the InP-lattice matched structure, the metamorphic HEMT developed shows excellent electrical performance and is suitable for high frequency application [4]. In order to achieve superior RF performance for the communication application, short gate length is required for the compound semiconductor field effect transistors. The gain and noise characteristics of the MESFETs and HEMTs at high frequency are strongly dependent on the gate length (Lg) and the gate resistance values. T-shaped gates are generally used for the MESFETs and HEMTs to maximize the device performance.

Different lithography methods have been developed for T-gates in recent years [5,6]. For examplet, multilayer photo resist processes have been used to obtained submicron T-shaped gates [7]. In order to further improve device performance, dielectric deposition process with etching back technology have been widely used to form dielectric sidewall and shrink the gate length that is originally limited by the lithography resolution [8]. However, tightly controlled process and relatively complicated steps with long process time are required for the about processes.

The thermally reflowed process is another choice for gate shrinking technology and has previous reported [9]. However, thermally reflowed process with E-Beam photo resistor for MHEMTs has never been reported. In this case, the T-shaped gate profile after E-beam lithography is thermally treated by hotplate and the gate length is then shortened from 0.25 µm down to 0.13 µm. The reflowed gate process is a simple, relatively inexpensive and flexible process, which is also free of plasma damage and can be applied to the fabrication of devices for high frequency applications.

II. PROCESS FLOW

The epitaxial layers of the metamorphic HEMT with $In_xAl_{1-x}As$ buffer layer were grown by molecular beam epitaxy (MBE) on GaAs substrate. The sequence for the device fabrication is as follows. The mesas were isolated by wet chemical etch and ohmic contacts were formed by evaporating Au/Ge/Ni/Au metallic layers and then alloyed at 320°C using RTA. The Ti/Pt/Au were deposited as Schottky gate metal after recess by succinic-base solution and then lift-off with acetone. The schematic geometry of the device is shown in Fig.1.

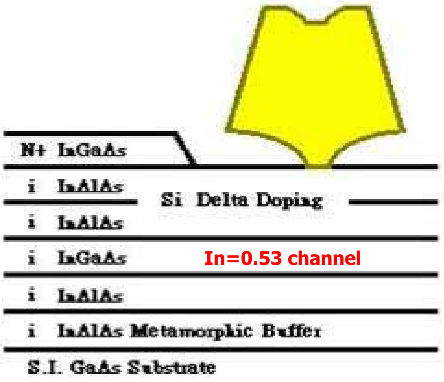
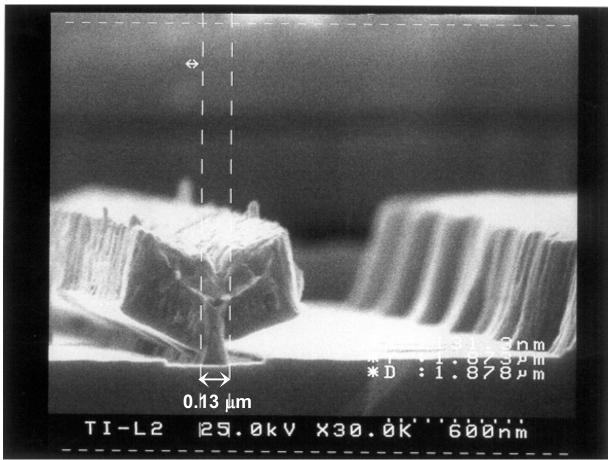


Fig. 1. Schematic geometry of the MHEMT.

During the reflowed T-gate process, the T-gate was fabricated first by E-beam lithography with gate length of

0.25 µm and went through thermal reflowed treatment at 115°C on a hotplate for 60 sec to reduce the gate length to 0.13 µm. The reflowed temperature was optimized recipe after testing different reflowed time. In order to verify the relationship of Lg and device characteristics, the MHEMT with non-reflowed T-gate was also fabricated. The micrographs with the same scale illustrate the cross section of the two type of T-gate in Fig. 2.(a) non-reflowed and (b) refolwed. In the Fig. 2(b), we can find that although the T-gate profile was changed slightly by reflowed process, it did not affect the recess process and the contact formation of T-gate to InAlAs layer.

(a) Non-reflowed



(b) Reflowed at 115°C for 60 sec

Fig. 2. The SEM micrograph with the same scale of the (a) Lg = 0.25 µm without-reflowed and (b) Lg = 0.13 µm reflowed Ti/Pt/Au T-gate on the MHEMTs.

After T-gate formation, the silicon nitride film was deposited as passivation layer by PECVD. Finally, the airbridge and top metal were formed with 2 µm of plating Au.

III. EXPERIMENTAL RESULTS

The I-V and the transconductance characteristics of the MHEMT with 4 x 40 µm gate-width fabricated using the 0.13 µm thermal reflowed T-gate are shown in Fig. 3. and Fig. 4.

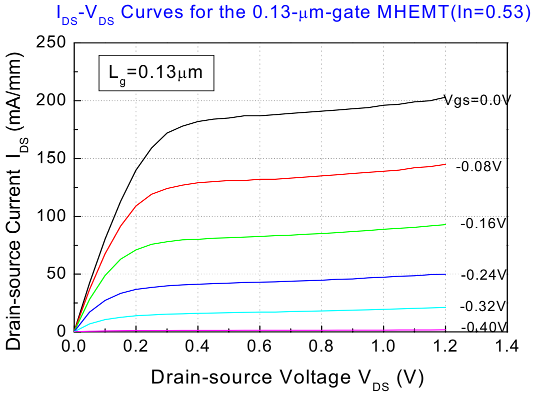


Fig. 3. I-V characteristics of 0.13 µm x 160 µm MHEMT.

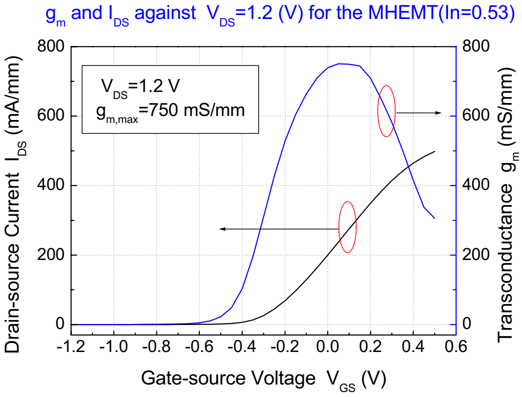


Fig. 4. Transconductance of 0.13µm x 160µm MHEMT.

The device exhibits a good pinch-off characteristics and the saturation drain current (I_{DSS}) is 200 mA/mm. The transconductance (g_m) of the device at 1.2 V drain-source voltage (Vds) is 750 mS/mm and the pinchoff voltage is 500 mV. The gate to drain breakdown voltage measured is 10 V at a gate reverse current of 1 mA/mm. The S parameters for the MHEMT devices were measured from 1 to 40GHz and current gain H_{21}, MAG/MSG, and unilateral gain U as a function of frequency are shown in Fig. 5.

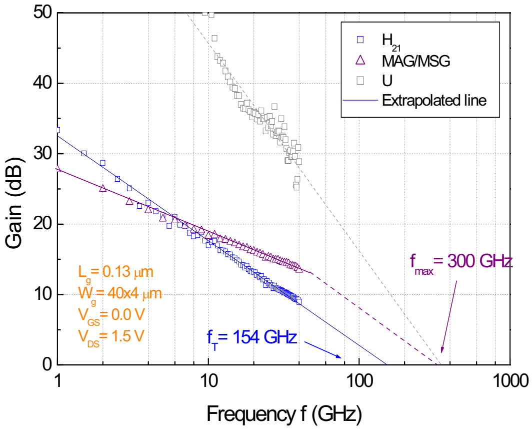


Fig. 5. Typical current gain H_{21}, MAG/MSG, and unilateral gain U as a function of frequency of 0.13 µm x 160 µm MHEMT.

T-gate type of the MHEMT	Lg(um)	gm(mS/mm)	Idss@1.2V (mA/mm)	V_{BR}(V)	f_T(GHz)	f_{max}(GHz)	NF@18GHz (dB)
Non-reflowed T-gate	0.25	700	240	8	105	180	1.18
Reflowed T-gate	0.13	750	200	10	154	300	0.99

TABLE I

SUMMARY OF DEVICE PERFORMANCE OF THE MHEMT WITH NON-REFLOWED AND REFLOWED T-GATE.

The f_T and f_{max} obtained for the 0.13 x 160 μm^2 MHEMT were 154 GHz and 300 GHz, respectively. In addition, the measurement of the noise figure (NF) and associated gain (Ga) have been performed in the frequency range between 2 and 18 GHz and the results are shown in Fig. 6. The NF measured up to 18 GHz is less than 1 dB with associated gain of 14dB at 18 GHz.

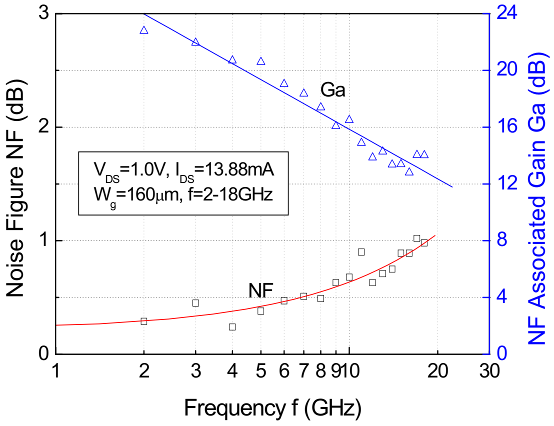


Fig. 6. Noise Figure and associated gain as a function of frequency at V_{DS} = 1V and I_{DS} = 13.88 mA of 0.13 μm x 160 μm MHEMT.

Table I summarize the measured electrical performance of the MHEMT with non-reflowed and reflowed T-gate. Although transconductance of the MHEMT with reflowed T-gate did not increase obviously, the f_T and f_{max} were improved evidently from 105 to 154 GHz and 180 to 300 GHz. The superior RF performance were due to the reflowed T-gate shrinkage from 0.25 μm to 0.13 μm.

IV. CONCLUSION

A metamorphic HEMT manufactured with reflowed submicron T-gate using E-beam lithography for high frequency wireless applications has been developed. The excellent device performance of the Lg = 0.13 μm metamorphic HEMT demonstrated shows that the reflowed T-gate process developed is compatible with the metamorphic HEMT process. Noise figure of the fabricated metamorphic HEMT for 160 μm gate-width device is less than 1dB and the associated gain is about 14dB at 18GHz. The device demonstrates a cut-off frequency f_T of 154GHz and a maximum frequency f_{MAX} up to 300GHz. The excellent device performance of the 0.13 μm MHEMT demonstrated that the reflowed T-gate process developed is compatible with the MHEMT process and can be practically used for MHEMT manufacturing.

ACKNOWLEDGEMENT

The authors would like to acknowledge the assistance and support of the National Science Council, Taiwan, R.O.C., under the Contract: NSC912215E009036, and thank National Nano Device Laboratories RF group for S-parameter measurements.

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