Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 94-95

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Transconductance Linearity Improvement of E-pHEMT with High Vg.on

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1. Introduction

Enhancement mode-pHEMT (E-pHEMT) is in severe competition with HBT for handset PA market. E-pHEMT has the merit of single power supply over depletion mode pHEMT. But it has narrower gate voltage swing. There have been many researches to obtain high gate forward turn-on voltage for larger gate swing range. [1] We developed E-pHEMT with high gate forward turn-on voltage of 1.4V. But transconductance (Gm) reduction at high Vgs defied efforts for higher Vg.on.

In this paper we present the origin of E-pHEMT's Gm reduction at high Vgs and ways to improve it.

2. Origin of transconductance reduction at high Vgs

Parasitic MESFET phenomenon was known to be the main cause of Gm reduction at high Vgs. [2] Kwyro Lee et al calculated electron density in channel and barrier as a function of gate voltage. [2] According to the calculation, channel electron density doesn't increase linearly with Vgs but saturates at a certain Vgs. At higher Vgs barrier electron density increases rapidly to keep Gauss's Law and even exceeds channel electron density. Due to the low electron mobility of barrier, transconductance reduction occurs at high Vgs. But this calculation overestimated barrier carrier density by neglecting gate current.

We performed 2-D device simulation using ATLAS and MINIMOS-NT. We calculated electron carrier density taking into account gate current with drain and source electrode shorted. Fig. 1 shows electron carrier density as a function of Vgs. Our simulation shows far less barrier carrier density at large gate bias than the previous results [2]. The portion of barrier electron density is less than 10% of total sheet carrier density. Channel electron density continues to increase at large gate bias. Parasitic MESFET phenomenon is not enough to explain severe Gm reduction.

The origin of Gm reduction of E-pHEMT is low and finite carrier density of channel layer of ungated area. Carrier density of channel layer of ungated area is not a function of gate bias, while that of gated area is a linear function of gate bias. E-pHEMT has rather low sheet carrier density for positive threshold voltage. If Vgs is over 0.7V, channel electron density under gate begins to exceed that of ungated area. Table. 1 shows channel carrier densities of each area at the gate bias of 1.2V. Channel carrier densities of ungated areas are much less than that of gated area. Then the channel electron density of ungated area becomes bottleneck for current increase.

The degree of current saturation is dependent on how easily electron can flow from the channel layer of ungated area to ohmic contact. E-pHEMT, adopting wide band-gap barrier layer for high Vg.on, shows severe Gm reduction.

3. Improve the transconductance linearity

Increasing the carrier density of ungated area is a direct but inapplicable solution that accompanies threshold voltage shift. We adopted ways that facilitate electron transfer from the channel layer to the ohmic contact.

3-1. Epi Structure

To improve the transconductance linearity, epi structure which facilitates current flow between channel and cap was devised. This epi uses the concept of conduction band lowering.[3] Delta doped AlGaAs cap layer between n+ GaAs and InGaP etch stop layer, lowers conduction band of barrier. This layer lowers electron barrier between channel and ohmic contact but doesn't reduce gate forward turn-on voltage. Fig. 2 shows the epi structure. n+ InGaAs cap is also adopted for better ohmic contact resistance [4].

3-2. Self Align Gate process

Self Align Gate (SAG) process can reduce gate-to-source spacing. Device simulation showed that smaller L_{SD} leads to more linear transfer curve in Fig. 3. Fig. 4 shows the cross section of fabricated SAG E-pHEMT. L_{SD} was reduced to 0.2um

4. Measurement

Fig. 5 shows measured transfer curves of E-pHEMT. Newly devised E-pHEMT epi fabricated in SAG process showed more linear transfer curve. Device had the DC characteristics of Vth=-0.1, Gm.max = 400mS/mm, Vg.on=1.3V and BV_{DG} = 5V.

5. Conclusion

The major source of severe transconductance reduction of E-pHEMT at high Vgs is ungated area. Low and finite channel carrier density of ungated area, incorporated with wide bandgap barrier that prohibits electron flow between channel layer and ohmic contact, is a bottleneck for current increase. New epi structure and SAG process which reduce the access resistance of ungated area leaded to more linear transfer curve.

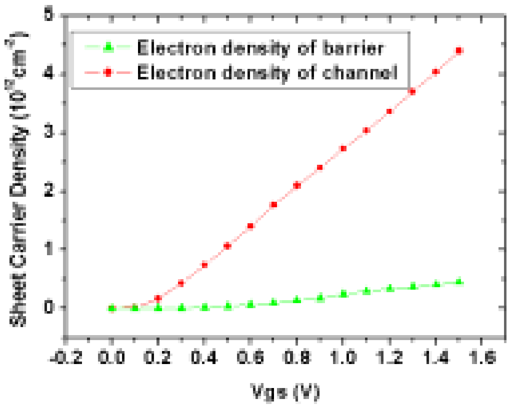

Fig. 1 Carrier dependence on gate bias: Electron carrier density of channel doesn't saturate. Electron carrier density of barrier is less than 10% of that of channel.

Table. 1 Electron carrier density at Vgs=1.2V

		Channel electron carrier density
Ungated region	As grown	2.0E12cm^{-2}
	Wide recess	1.5E12cm^{-2}
Gated region		3E12cm^{-2}

Layer	Material	Thickness
Cap	In0.22GaAs	100Å
	GaAs	200Å
	3X Al0.22GaAs/ δ-doping	3X 15 Å
Barrier	In0.49GaP	25 Å
	Al0.45GaAs	60 Å
	Al0.22GaAs	55 Å
Channel	In0.22Ga0.78As	110Å
	In0.30Ga0.78As	
	In0.22Ga0.78As	
Barrier	Al0.22Ga0.78As	750Å
Buffer & Substrate		

Fig. 2 Newly devised E-pHEMT epi structure. Delta doped AlGaAs layer in the cap lowers conduction band of barrier. InGaAs cap lowers ohmic contact resistance.

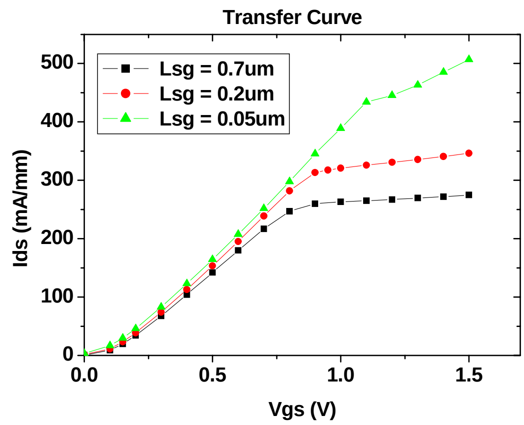

Fig. 3 Simulated transfer curves for various Lsg

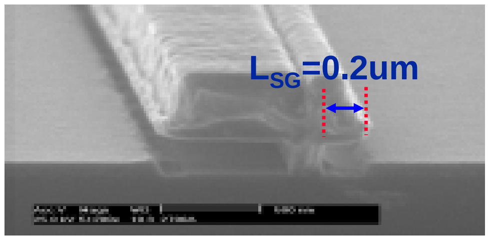

Fig. 4 SEM image of SAG E-pHEMT

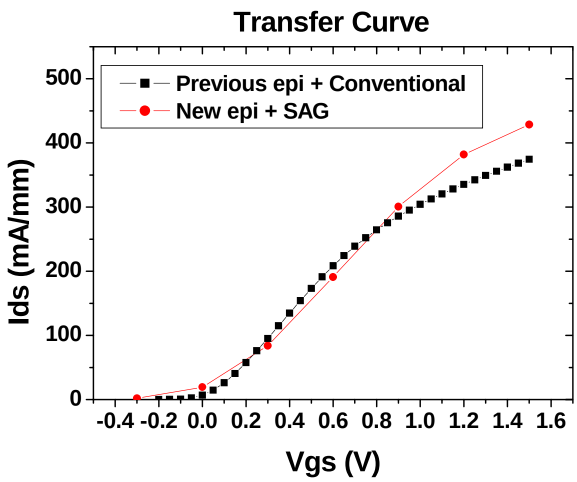

Fig. 5 Measured transfer curve of E-pHEMT

Acknowledgements

This work was financially supported by the National program for Tera-HZ Level Integrated Circuits of the Minister of Science and Technology as one of the 21st Century Frontier program

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