Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.682-683

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$In_{0.49}GaP/Al_{0.45}GaAs$ E-pHEMT with High Gate Forward Turn-on Voltage & High Transconductance Linearity

Kyoungchul Jang, Juyong Lee, Jaehak Lee, Kwangseok Seo

Seoul National Univ., School Of Electrical Engineering and Computer Science
San 56-1, Shillim-dong, Kwanak-ku, Seoul 151-744, Korea
Phone: +82-2-877-0298 E-mail: liberty@snu.ac.kr

Abstract
We present $In_{0.49}Gap/Al_{0.45}GaAs$ Enhancement-mode pseudomorphic HEMT (E-pHEMT) with high gate forward turn-on voltage and high transconductance linearity. E-pHEMT's with high gate forward turn-on voltage usually suffer from severe transconductance reduction at high Vgs. The low electron carrier density of ungated region of E-pHEMT, especially of gate side recess region, is closely related to that transconductance reduction. We adopted $Al_{0.45}GaAs$ as a barrier for higher gate forward turn-on voltage and $In_{0.49}Gap$ as an etch stop, which causes less deep levels, for higher transconductance at high gate bias. The gate forward turn-on voltage was around 1.1V. The transconductance of 0.5μm E-pHEMT was over 90% of gm.max for the gate voltage swing of 0.65V.

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 a narrower gate voltage swing. There have been many researches to obtain high gate forward turn-on voltage(Vg.on) for larger gate swing range. [1] But E-pHEMT with high Vg.on usually suffers from current saturation at high gate bias. [2] Thus efforts for higher Vg.on were not so fruitful due to severe gm reduction at high gate bias.

Our device simulation shows that this current saturation is closely related to the gate side recess region. According to our simulation the channel carrier density under the gate is a linear function of gate bias. But the channel electron carrier density of ungated region is not a function of gate bias. Especially the low channel carrier density of side recess region can be the bottleneck for the current increase.

We present $In_{0.49}GaP/Al_{0.45}GaAs$ E-pHEMT with high Vg.on and high transconductance linearity. We adopted $Al_{0.45}GaAs$ as a barrier layer for higher Vg.on. We adopted $In_{0.49}Gap$ as a etch stop layer of E-pHEMT. InGaP etch stop layer not only offers good etch selectivity but also causes less deep level defects than AlGaAs etch stop.[3] We can expect that InGaP etch stop will have less surface trap density than AlGaAs. We fabricated 0.15μm and 0.5μm gate E-pHEMT. The fabricated E-pHEMT's were fully passivated using Si_3N_4 in RPECVD.

2. Transconductance at high gate bias and Lateral Carrier Distribution

In previous research we found out that an origin of gm reduction of E-pHEMT is low and finite carrier density of channel layer of ungated area.[4] E-pHEMT has rather low sheet carrier density for positive threshold voltage. Especially the low channel electron density of gate side recess region can be a bottleneck for current increase. We performed 2D device simulation to see the effects of surface trap in side recess region. We assumed the side recess length of 50nm and the surface trap density of $1x10^{12}cm^{-2}$. Figure 1 shows the estimated IV curve of E-pHEMT for various surface trap density of the gate side recess region. It tells us that a barrier layer with low surface trap density is essential for high transconductance at high Vgs.

3. Epi strucure

Figure 2 shows the epi structure of E-pHEMT. As we wanted fairly high Vg.on, wide band-gap material of $Al_{0.45}GaAs$ is inserted into the barrier. According to the device simulation result of figure 1 an etch stop layer with low trap density is required for high current density E-pHEMT. InGap is a good candidate for that purpose. InGap not only offers excellent etch selectivity but also causes less deep level defects.[3]

4. Measurement

Table I summarizes the performances of the E-pHEMT's. Figure 3 shows the transfer curves of the 0.15μm and 0.5μm E-pHEMTs before and after passivation. At the gate bias of 0V and the drain bias of 3V, drain leakage current (Idss) was 0.0026mA/mm for 0.5μm E-pHEMT, 0.048mA/mm for 0.15μm E-pHEMT. At the gate bias of 1.5V, very high current densities of 480mA/mm and 440mA/mm are achieved for 0.15μm and 0.5μm E-pHEMTs.

6. Discussion

The comparison of the 0.15μm and 0.5μm devices before and after passivation shows that the side recess region is closely related to the performance of E-pHEMT. The maximum transconductance of the unpassivated 0.15μm and 0.5μm devices are 440mS/mm and 430mS/mm respectively. The maximum transconductance of the both devices are almost same. However the maximum transconductance of the passivated 0.15μm and 0.5μm devices are 520mS/mm and 470mS/mm respectively. The maximum transconductance of the 0.15μm device got much higher than that of 0.5μm device after passivation. After the passivation the drain current at the gate bias above 0.8V increases for both 0.15μm and 0.5μm devices. It is noticeable that the drain current increase of 0.15μm device exceeds that of 0.5μm device.

The fabricated 0.5μm E-pHEMT had fairly wide and flat transconductance maximum. Its transconductance was over 90% of gm.max for the gate voltage swing of 0.65V. The transconductance of $In_{0.49}GaP/Al_{0.25}GaAs$ E-pHEMT was over 90% of gm.max for the gate voltage swing of 0.35V due to low Vg.on. [3] The transconductance of $Al_{0.25}GaAs/Al_{0.5}GaAs$ E-pHEMT was over 90% of gm.max for the gate voltage swing of 0.5V. [2] Wide transconductance maximum of $In_{0.49}GaP/Al_{0.45}GaAs$ E-pHEMT is due to high Vg.on and low surface trap density of $In_{0.49}GaP$.

5. Conclusion

We fabricated $In_{0.49}GaP/Al_{0.45}GaAs$ E-pHEMT with high Vg.on and high transconductance linearity. An origin of severe transconductance reduction of conventional E-pHEMT at high Vgs is ungated area, especially gate side recess region. $Al_{0.45}GaAs$ barrier offers high Vg.on. $In_{0.49}GaP$ etch stop layer, which causes less surface trap density , is helpful for achieving higher current density at high Vgs. The transconductance of 0.15μm and 0.5μm E-pHEMT's was over 90% of gm.max for the gate swing of 0.5V and 0.65V repectively.The comparison of 0.15μm E-pHEMT and 0.5μm E-pHEMT, before and after passivation, tells us that the side recess region is closely related to the performance of E-pHEMT.

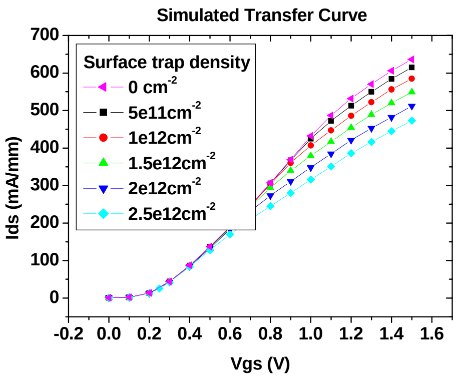


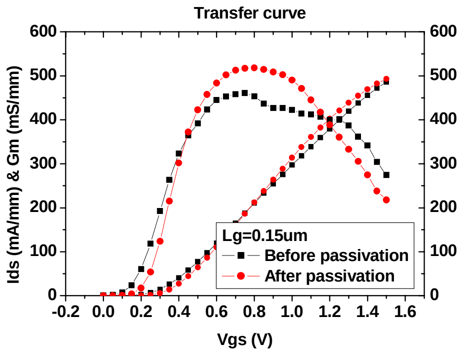
Fig. 1 Simulated transfer curves of E-pHEMT for various trap density of side recess region

Layer	Material
Cap	GaAs
Barrier	In0.49GaP
	Al0.45GaAs
	Al0.22GaAs
Channel	In0.22Ga0.78As
Barrier	Al0.22Ga0.78As
Buffer & Substrate	

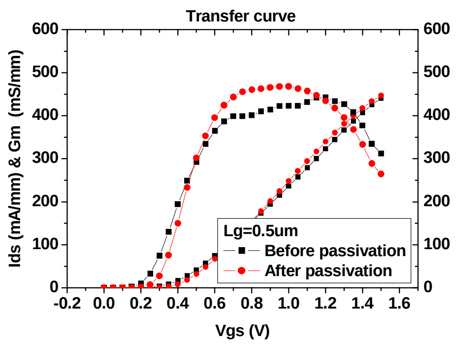
Fig. 2 Epi structure of $In_{0.49}GaP/Al_{0.45}GaAs$ E-pHEMT

Table I. Summary of E-pHEMT performance

	Lg (μm)	Vth (V)	Gm.max (mS/mm)	Vg.on (V)	BV_{DG} (V)
Unpassivated	0.15	0.18	440	1.2	10
	0.5	0.25	430	1.1	12
passivated	0.15	0.25	520	1.1	6.5
	0.5	0.3	470	1.05	7.5



(a)



(b)

Figure 3. Transfer curves of E-pHEMT before and after passivation (a) Lg=0.15μm (b) Lg=0.5μm

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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