Device Simulation of P-InAlN-Gate AlGaN/GaN High Electron Mobility Transistor

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ABSTRACT

We simulate a p-InAlN gate AlGaN/GaN high electron mobility transistor (HEM). The studied HEMT is operated at an enhancement mode (e-mode) with positive threshold voltage and low gate leakage current at high gate voltage. The sub-threshold swing and drain induced barrier lowing of the new HEMT are superior to the conventional one owing to the p-InAlN gate.

1. INTRODUCTION

AlGaN/GaN HEMT is known as alternative for high-power and high-frequency electronic systems. Conventional HEMT operates at depletion-mode resulting from high-density 2DEG induced by spontaneous and piezoelectric polarization. Owing to a normally-on behavior, it is difficult for power-electronic applications because of safe operation and system cost concern. Threshold voltage (V_{th}) of AlGaN/GaN HEMT depends on Al composition, doping concentration, and the thickness of the AlGaN barrier. To design a normally off device, various techniques, such as the gate recess, the thin barrier layer, the cap layer, and the fluorine incorporation have been reported [1-5].

In this work, P-type InAlN is used as gate in AlGaN/GaN HEMT is numerically studied. Large band gap of this material results in relatively higher threshold voltage than other commonly used p-type material gate device. And, injection of hole to channel at high gate bias results in high current.

2. THE SIMULATION METHOD

Conventional AlGaN/GaN HEMT is shown in Fig. 1(a). Device parameters of conventional and purposed AlGaN/GaN HEMT devices are listed in Table I. For device simulation, a set of quantum mechanically corrected transport equations was solved. Together with the transport model, recombination-generation model, lattice heating model, low field mobility model, and special high field mobility model for nitride are considered. The mobility for the alloy scattering is

$$\mu_n(N_D,T)=\mu_{\min}\times\left(\frac{T}{300}\right)^{\beta_1}+\frac{(\mu_{\max}-\mu_{\min})\times\left(\frac{T}{300}\right)^{\beta_2}}{1+\left(\frac{N_D}{10^{17}}\times\left(\frac{300}{T}\right)^{\beta_3}\right)^{\gamma(T/300)^{\beta_4}}}$$

where $\mu_{\min}$ and $\mu_{\max}$ are the minimum and maximum mobility for the materials. The mobility for the interface roughness scattering is

$$\frac{1}{\mu_0^I(N_D,T)}=a\left(\frac{N_D}{10^{17}}\right)\frac{\ln\left(1+\beta_{cw}^2\right)}{\left(\frac{T}{300}\right)^{1.5}}+b\left(\frac{T}{300}\right)^{1.5}+\frac{c}{e^{\left(\frac{\Theta}{T}-1\right)}}$$

where $\Theta=\hbar\omega_{LO}/k_B$, $\beta_{cw}^2=3(T/300)^2(N_D/10^{17})^{-2/3}$, N_D (cm^{-3}) is ionized donor concentration, and T is absolute temperature. Simulation models are calibrated with the experimental results of conventional AlGaN/GaN HEMT. Fig. 1(b) shows the simulation results are exactly fitted with experimental results. Using these calibrated simulation models; electrical properties of purposed device are studied.

3. RESULTS AND DISCUSSION

The proposed enhancement mode HEMT is shown in Fig. 2(a). Estimated band diagram of the p-InAlN gate HEMT with $Al_{0.08}Ga_{0.92}N$ backbarrier is plotted in Fig. 2(b). P-InAlN increase the channel potential and channel beneath the gate is totally depleted in unbiased condition. So the purposed device is normally off device. Electron distribution in the p-InAlN gate HEMT, as shown in Fig. 3, shows that concentration of electron inside the channel below the gate is almost depleted when the gate bias is 1 V and is gradually increased when the gate bias is increased. Notably, to make equilibrium, holes are generated so that the drain current varies with the gate bias. Normalized I_d-V_g curve obtained for the conventional and purposed p-InAlN HEMT devices at the drain bias is 10 V are plotted in Fig. 4. If V_{th} is defined as the gate voltage at which the drain current becomes 1 mA/mm, the value of V_{th} of the p-InAlN gate HEMT is equal to 1.15 V which is almost 4.15 V larger than the conventional HEMT (it is -3.2 V). Not shown here, the sub-threshold swing and drain induced barrier lowing of the new HEMT are superior to the conventional one owing to the p-InAlN gate. The new device is at very low gate leakage current operated at high gate voltage

4. CONCLUSIONS

The proposed P-InAlN-gate enhancement mode HEMT has been numerically studied. Threshold voltage obtained at the drain bias 10 V is 1.15 V which is the highest threshold voltage, to the best of our knowledge. The maximum drain current obtained is 261 mA/mm at the gate bias is 3.5 V and the purposed device is e-mode device with very low gate leakage current.

5. ACKNOWLEDGEMENTS

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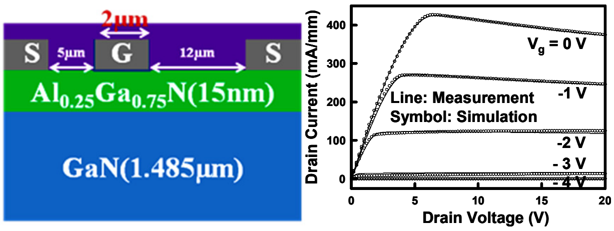
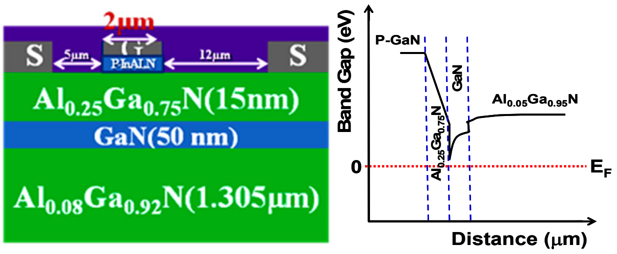


(a) (b)

Fig.1. (a) Conventional HEMT. (b) The calibration results of the conventional HEMT. The calibrated parameters are used for new device simulation.

Table I. The adopted device parameters for the conventional and the p-InAlN gate HEMT devices.

	Conventional HEMT	p-InAlN gate HEMT
AlGaN barrier thickness (nm)	15	15
Al composition (%)	25	25
GaN channel thickness	1.485 μm	50nm
Gate length (μm)	2	2
Gate width (μm)	100	100
Source-drain distance (μm)	21	21
p-AlInN layer thickness (nm)	-	200
Hole concentration	-	1×10^{18}
AlGaN buffer layer thickness (μm)	-	1.305
Al composition (buffer) (%)	-	8
In composition (%)	-	17



(a) (b)

Fig. 2. (a) The proposed HEMT for enhancement mode operation. (b) The energy band diagram of the purposed HEMT.

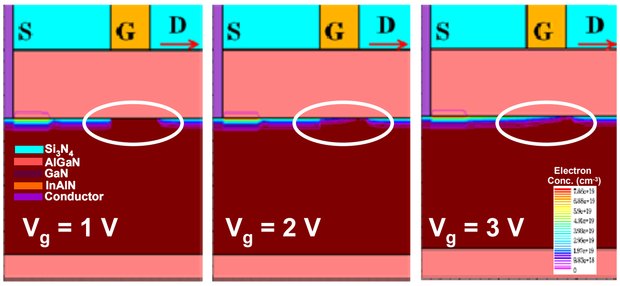


Fig. 3. Plots of electron concentration distribution of the proposed p-InAlN-gate AlGaN/GaN HEMT device under different gate bias V_g = 1, 2, and 3 V. The electron concentration inside the channel below the gate is almost depleted when the gate bias is 1V which is gradually increase when the gate bias is increased, as circled above.

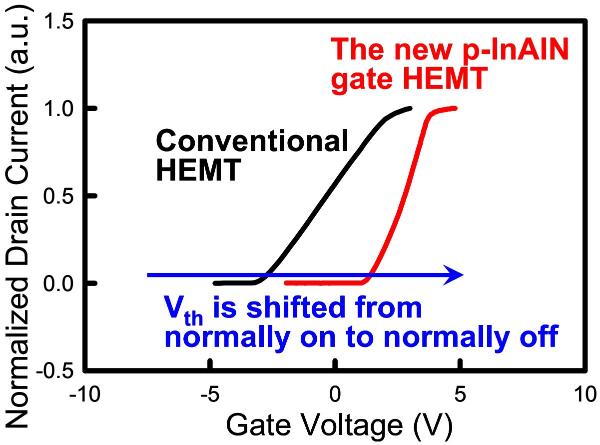


Fig. 4. Plots of normalized I_d-V_g between the conventional HEMT and the proposed p-InAlN-gate AlGaN/GaN HEMT devices. It is clearly shown that the new structure is at enhancement mode which is different from the conventional depletion mode.

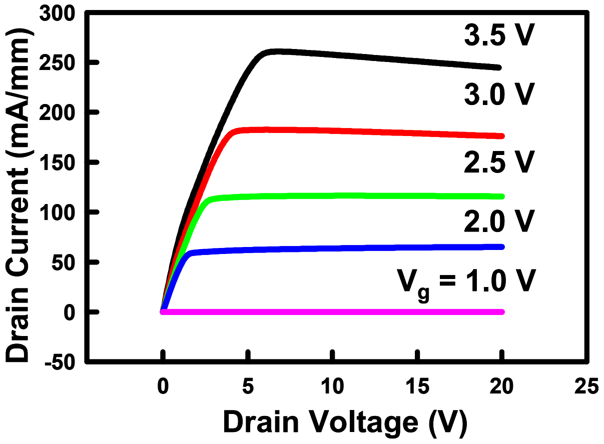


Fig. 5. The simulated I_d-V_d curves of the proposed p-InAlN-gate AlGaN/GaN HEMT device.