OPTIMUM GATE BIAS OF GAN HETEROSTRUCTURE FETS

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ABSTRACT

Electron density dependent dc (direct current) and rf (radio frequency) characteristics of InAlN/AIN/GaN and AlGaN/AlN/GaN Heterostructure Field Effect Transistors (HFETs) are compared. The optimum gate bias is found within the same window determined by the resonance plasmon-assisted decay of non-equilibrium longitudinal optical phonons [1-3] which is in good agreement with the data for the short-gate devices with the best frequency performance [4-12].

1. INTRODUCTION

Gallium nitride based HFETs are promising for microwave power applications. High power is achieved by inducing a high density two-dimensional electron gas (2DEG) in an undoped GaN channel. However, device performance is limited by channel self-heating aggravated by accumulation of non-equilibrium optical phonons (hot phonons) [13]. The hot phonons reduce the frequency of HFET operation and enhance device degradation [3]. The optimal conditions for performance of the GaN channels have been associated with the experimentally resolved plasmon-assisted ultrafast decay of hot phonons at the resonance 2DEG density of ~1*10^13 cm^-2 [3].

2. DEVICES AND EXPERIMENTAL SETUP

The InAlN/AlN/GaN and AlGaN/AlN/GaN heterostructures were grown on sapphire substrates in a low-pressure custom designed organometallic vapour phase epitaxy system. The structures consisted of a 250 nm AlN initiation layer, the 3 μm of undoped GaN, the 1 nm AlN spacer layer, a 20 nm barrier layer of either In0.2Ga0.8N or Al0.2Ga0.8N, and a 2 nm GaN cap layer on the top. The InAlN/AlN barrier layers were grown with In compositions x (x = 0.2 for sample group A) and x = 0.16 for sample group B). The AlGaN/AlN barrier layer was grown with Al composition x = 0.3 for sample C. The ohmic contacts for HFETs and gated Hall bars consisted of Ti/Al/Ni/Au, while Pt/Au (thickness 30/50 nm, length/width 2 μm/90 nm) was used for the gate electrodes. The devices were mesa isolated in a SAMCO inductively coupled plasma etcher based on chlorine chemistry. The devices were not passivated. The Hall effect measurements yielded the pristine 2DEG density of n0 = 1.3*10^13 cm^-2, n1 = 3*10^13 cm^-2, and n2 = 1.23*10^13 cm^-2 for the samples A, B, and C, respectively.

On wafer dc and rf characteristics were measured at the ambient temperature of 25 °C with Agilent PNA E8364B Network Analyzer, Agilent E5270B Precision Measurement Mainframe, and Süss Michecy probe station, PM8. The s-parameters were measured in the frequency range from 0.25 to 26 GHz.

3. RESULTS AND DISCUSSION

The transfer characteristics are represented in Fig. 1. The higher 2DEG density supports an order of magnitude higher open channel drain current I0 in the device with n0 = 3*10^13 cm^-2 as compared with those for the devices with 2.3 - 2.4 times lower density. The drain current of device B at the maximum transconductance, Ig = 264 mA/mm, is higher than that for group A devices and C, I0 = 118 mA/mm and Ig = 111 mA/mm, respectively. The maximum transconductance is observed at a higher negative gate voltages Vgs for group B devices gA = 156 mS/mm at Vgs = -9 V as compared with device groups A and C, gA = 162 mS/mm at Vgs = -1.8 V and gA = 117 mS/mm Vgs = -1.2 V, respectively. Correspondingly, the higher negative gate voltage is required to terminate the drain current in the channel with higher pristine 2DEG density.

![Fig. 1: Transfer and transconductance characteristics of HFETs for device A (dashed line, stars), device B (solid line, diamonds), and device C (dotted line, squares).](image-url)

Meanwhile, the maximum cut-off frequency fT is fT = 3.5 GHz at Vgs = -1.6 V for device A, fT = 6.9 GHz at Vgs = -8.5 V for device group B, and fT = 3.7 GHz at Vgs = -1.3 V for device C in Fig. 2.
4. SUMMARY

The performance of HFETs is strongly affected by accumulation of non-equilibrium optical phonons especially at high 2DEG densities. The plasmonic-controlled resonance has a strong effect on heat dissipation and power conversion: the negative gate bias reduces the electron sheet density under the gate, and the optimum bias is reached near the resonance value $n_s = 1 \times 10^{13}$ cm$^{-2}$. The optimum gate voltage is predictable with the simple linear dependence if the pristine 2DEG density in as-grown channels is higher than the resonance value.

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