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/AlN/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 selfheating 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 $In_xAl_{1-x}N$/AlN/GaN and $Al_xGa_{1-x}N$/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 $In_xAl_{1-x}N$ or $Al_xGa_{1-x}N$, and a 2 nm GaN cap layer on the top. The $In_xAl_{1-x}N$ barrier layers were grown with In compositions x ($x = 0.2$ for sample group A and $x = 0.16$ for sample group B). The $Al_xGa_{1-x}N$ 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 $n_s = 1.3*10^{13}$ cm^{-2}, $n_s = 3*10^{13}$ cm^{-2}, and $n_s = 1.23*10^{13}$ 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 Microtech 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 I_d in the device with $n_s = 3*10^{13}$ 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, $I_d = 264$ mA/mm, is higher than that for group A devices and C, $I_d = 118$ mA/mm and $I_d = 111$ mA/mm, respectively. The maximum transconductance is observed at a higher negative gate voltages V_{gs} for group B devices $g_m = 156$ mS/mm at $V_{gs} = -9$ V as compared with device groups A and C, $g_m = 162$ mS/mm at $V_{gs} = -1.8$ V and $g_m = 117$ mS/mm $V_{gs} = -1.2$ V, respectively. Correspondingly, the higher negative gate voltage is required to terminate the drain current in the channel with higher pristine 2DEG density.

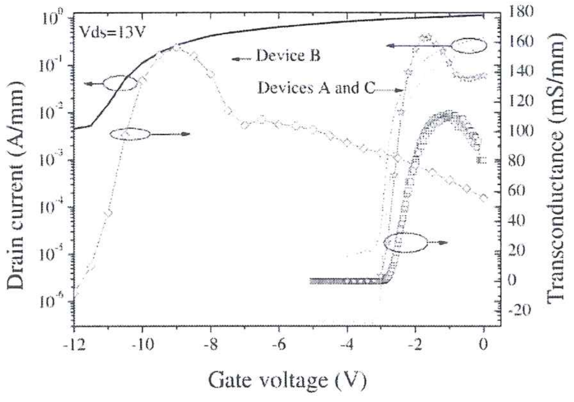

Fig. 1: Transfer and transconductance characteristics of HFETs for device A (dashed line, stars), device B (solid line, diamonds), and device C (dotted line, squares).

Meanwhile, the maximum cut-off frequency f_T is $f_T = 3.5$ GHz at $V_{gs} = -1.6$ V for device A, $f_T = 6.9$ GHz at $V_{gs} = -8.5$ V for device group B, and $f_T = 3.7$ GHz at $V_{gs} = -1.3$ V for device C in **Fig. 2**.