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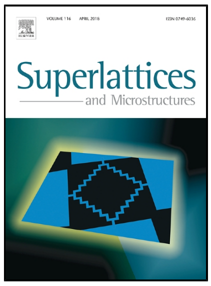

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Sumit Verma, Sajad A. Loan, Abdullah G. Alharbi

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Polarization Engineered Enhancement Mode GaN HEMT: Design and Investigation

Sumit Verma[1], Sajad A. Loan*[1] and Abdullah G. Alharbi[2]
[1]Department of Electronics and Communication Engineering, Jamia Millia Islamia
(Central University) New Delhi, *sloan@jmi.ac.in
[2]Jouf University Sakaka Saudi Arabia

***Abstract*—: In this paper, we propose and perform the experimentally calibrated simulation of a novel structure of a GaN/AlGaN high electron mobility transistor (HEMT). The novelty of the structure is the realization of enhancement mode operation by employing polarization engineering approach. In the proposed polarization engineered HEMT (PE-HEMT) a buried Aluminum Nitride (AlN) box is employed in the GaN layer just below the gate. The AlN box creates a two-dimensional hole gas (2DHG) at the GaN/AlN interface, which creates a conduction band barrier in the path of the already existing two-dimensional electron gas (2DEG) at GaN/AlGaN. Therefore, there is no direct path between the source and drain regions at zero gate voltage due to the barrier created by AIN and the device is initially OFF, an enhancement mode operation. A two dimensional (2D) calibrated simulation study of proposed PE-HEMT shows that the device has a threshold voltage (V_{th}) of 2.3V. The PE-HEMT also reduces the electron spillover and thus improves the breakdown voltage by 108% as compared to conventional HEMT. The thermal analysis of the GaN PE-HEMT shows that a hot zone occurs on the drain side gate edge. It has been observed that the drain current in the PE-HEMT structure can be improved by 157% by using AlN heat sink.**

***Index Terms*— GaN, HEMT, AlN, Polarization Engineering, enhancement mode, thermal analysis**

I. INTRODUCTION

Gallium Nitride (GaN), a Group III nitride, is acknowledged a promising candidate with a strong potential to replace silicon devices in power electronics applications. The GaN devices are superior to silicon devices due to some unique properties, like large band gap material (3.4 eV), high breakdown field (~3 MV/cm), large electron saturation velocity (2.5 ×10^7 cm/s) and high operating temperature. Further, GaN/AlGaN devices realize two-dimension electron gas (2DEG) with sheet charge concentration of more than 10^{13}/cm^2 and electron mobility of around 2000 cm^2/V^{-s}. These properties of GaN devices make them attractive for high performance power switching, optoelectronics and other radio frequency (RF) applications [1-6]. GaN based power devices have low gate capacitance, low ON resistance and permit energy efficient high frequency switching operations than the silicon counterpart. The conventional GaN/AlGaN based high electron mobility transistors (HEMT) are depletion mode type (initially ON), which actually limit their operation domain. The depletion mode HEMT devices are less reliable, have safety issues due to inverse piezoelectric effects and have high dislocation and defect densities [3-4, 8-9]. On the other hand, normally OFF or enhancement mode GaN (E-GaN) based HEMTs are desirable for simple circuit designing, energy and power efficiency, safe mode of operation in power electronics domain, better reliability etc. However, realizing an enhancement mode GaN based HEMT is difficult due to strong polarization effects. The various approaches used to realize the E-GaN HEMTs include recessed gate structures [7-8], cap layer structures [3, 10], fluorine treatment method, use of high k dielectrics and multi-cap layers, p-type gate devices [11-12]. However, these devices are complex and costly structures and are difficult to fabricate. Besides, the recessed gate and the fluorine treatment structures degrade the mobility and transconductance properties of the HEMT [6-7]. Recently, a comparative simple and better E-GaN MOSFET has been proposed using the charge plasma (CP) concept [3], however, realizing ohmic contacts in such a structure is challenging.

Herein, we propose a novel structure of a polarization engineered based normally OFF/enhancement mode GaN/AlGaN HEMT. The proposed polarization engineered HEMT (PE-HEMT) device exhibits enhancement mode operation by employing Aluminum Nitride (AlN) box buried in the GaN layer just below the gate. The AlN box creates 2DHG at the GaN/AlN interface, which creates a conduction band barrier in the path of the already existing 2DEG at the GaN/AlGaN interface. Therefore, the direct conduction path between the source and drain regions at zero gate voltage breaks by the barrier created by the AIN layer and hence the device remains OFF. Thus, the gate electrode needs to be properly biased to lower this barrier and to start the conduction again. Therefore, the proposed PE-HEMT device exhibits the enhancement mode operation in a comparatively simple way. A 2D experimentally calibrated simulation using Atlas simulator has shown that the proposed device exhibits a threshold voltage of 2.3 volts. The PE-HEMT structure also reduces the electron spill over and thus improves the breakdown voltage compared to conventional HEMT. The thermal analysis shows that in presence of lattice heating drain current gets reduced because of phonon scattering. However, the use of AlN heat sink helps in reducing the self-heating effects and improves the drain current by 157%.