# Hybrid normally-off AlGaN/GaN HEMT using GIT technique with a p-region below the channel

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***Abstract*— Gallium nitride based High Electron Mobility Transistors (HEMT) are powerful candidates for high frequency and high power applications. Unfortunately, while switching applications demand normally-off operation, these devices are normally-on. In this paper, after calibrating the simulator using experimental data, we address the advantages and drawbacks of two normally-off HEMT devices: the previously proposed Gate Injection Transistor (GIT) and our newly proposed HEMT with a p-GaN region below the channel. Afterwards, an hybrid normally-off HEMT is proposed, combining both techniques, aiming to merge their advantages and remedying their drawbacks.**

## I. Introduction

GaN HEMT seems to be a very promising candidate for future power applications. Thanks to the GaN properties and the HEMT's topology, AlGaN/GaN HEMTs are now potential candidates for high frequency applications with high power and low noise, such as microwave and millimeter wave communications, imaging and radars. While power switching applications strongly demand normally-off operation [1], conventional HEMTs are normally-on. Several normally-off structures have been proposed such as recessed gate structure [2], fluorine ion treatment device [3] and Gate Injection Transistor (GIT) [4].

## II. Simulation Strategy

In this work, we will start by simulating two normally-off HEMTs: HEMT with a p-GaN region directly below the gate (gate injection transistor - GIT) (figure 1b) and our newly proposed HEMT with a p-GaN region below the AlGaN/GaN interface (figure 1c). After pointing the advantages and drawbacks of these structures, a new design combining the two techniques (two p-GaN regions: one below the channel and another above it) (figure 1c) is studied. All the device parameters remain constant throughout the simulation, except for the doping concentration and the position of the p-GaN region. To do this study, ATLAS, a physically-based TCAD simulation tool from Silvaco is used. Physical models used in the simulation include Shockley-Read Hall recombination, Fermi-Dirac statistics and field-dependent mobility. The simulator was calibrated by using real parameters of a normally-on HEMT device.

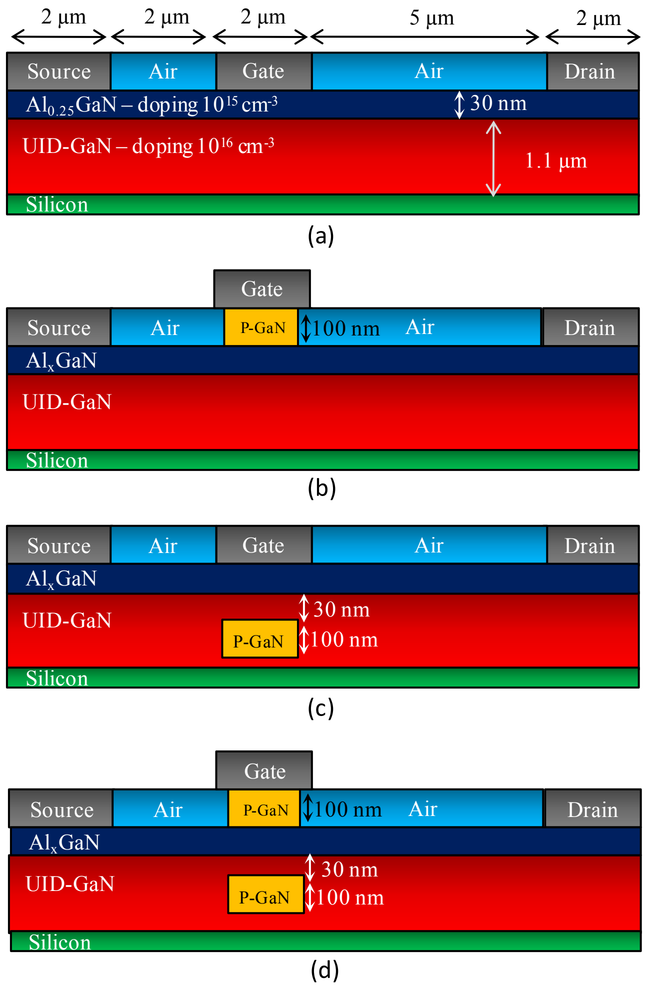


*Figure 1. Schematic cross section of the (a) conventional HEMT used for calibration, (b) GIT transistor, (c) our proposed HEMT with a p-GaN region below the channel and (d) GIT with p-GaN region below the gate.*

*In the 3 figures, you should replace "Silicon" by "Transition layers / Silicon"*

## III. Results and Discussion

Figure 2 shows the simulated transfer characteristics of the conventional normally-on HEMT and GIT both with x-mole fraction of 0.15. In the GIT, two different p-doping concentrations were used: $10^{18}$ cm$^{-3}$ and $4\times10^{18}$ cm$^{-3}$. The thickness and the width of the p-GaN region is 100 nm and

1 µm respectively. It can be seen that the introduced p-GaN region, above the AlGaN layer, increases the threshold voltage. Moreover, the shift in the threshold voltage increases with increasing the doping concentration. At a doping concentration of $4\times10^{18}$ $cm^{-3}$, the threshold voltage increases from -1.1 V to 0.6 V as well as the forward gate voltage which increases from 3.2 V to 7 V.

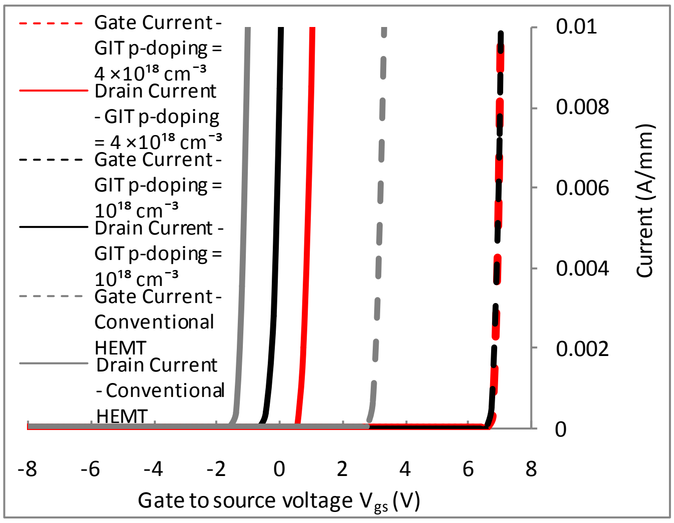


*Figure 2. Simulated transfer characteristics of the conventional normally-on HEMT and GIT with p-GaN doping concentrations of $10^{18}$ $cm^{-3}$ and $4\times10^{18}$ $cm^{-3}$*

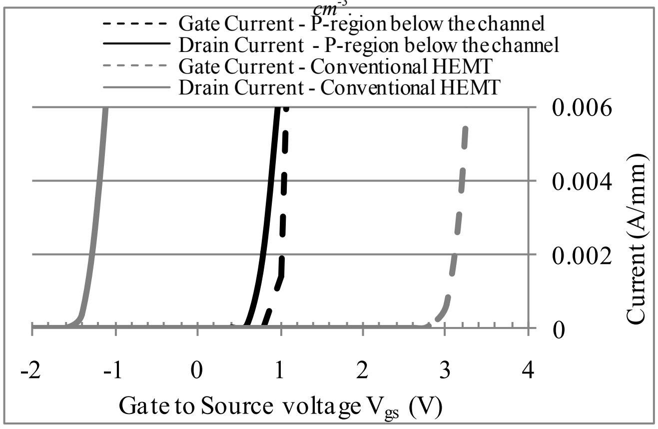


*Figure 3. Simulated transfer characteristics of the conventional normally-on HEMT and HEMT with a p-GaN region below the channel. The p-doping concentration is $10^{18}$ $cm^{-3}$.*

Figure 3 shows the simulated transfer characteristics of the conventional normally-on HEMT and HEMT with a p-GaN region below the channel. The x-mole fraction in the two structures is equal to 0.15. The doping concentration, thickness and width of the p-GaN region are $10^{18}$ $cm^{-3}$, 100 nm and 1 µm respectively. The distance between the p-GaN region and the AlGaN/GaN interface is equal to 30 nm. It can be seen that the introduced p-GaN region below the channel increases the threshold voltage from -2 V to 0.6 V. However, it decreases the forward gate voltage from 3.2 V to 0.9 V.

It is clear from figures 2 and 3 that although the same threshold voltage (0.6 V) was achieved after introducing the p-GaN region, the doping concentration required to achieve this threshold voltage is lower ($10^{18} < 4\times 10^{18}$ $cm^{-3}$) when the p-GaN region is introduced below the channel rather than above it. On the other hand, the forward gate voltage is much higher when the p-GaN region is introduced above the channel. To achieve normally-off HEMT with relatively low p-doping concentrations and high forward voltage, a design combining the above mentioned techniques is proposed. Figure 4 shows the simulated transfer characteristics of an hybrid normally-off HEMT, with a threshold voltage of 2.5 V and a forward gate voltage of 3.8 V, using the GIT technique with a p-region below the channel. The doping concentration, thickness andwidth of the p-GaN region are $5\times10^{17}$ $cm^{-3}$, 100 nm and 1 µm respectively. The distance between the p-GaN region and the AlGaN/GaN interface is 30 nm.

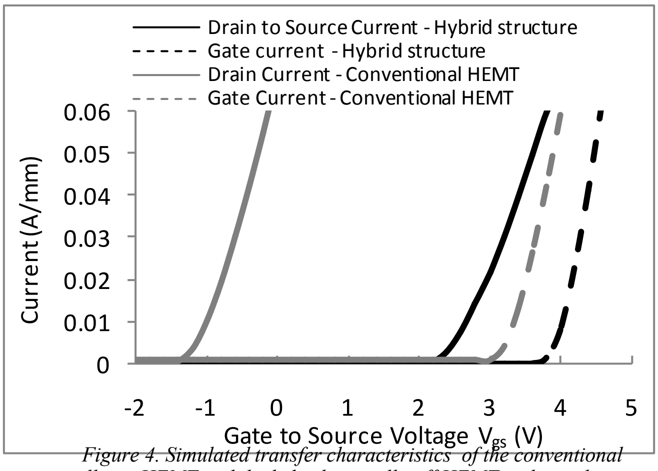


*Figure 4. Simulated transfer characteristics of the conventional normally-on HEMT and the hybrid normally-off HEMT with a p-doping concentration of $5\times10^{17}$ $cm^{-3}$.*

## IV. Conculusion

In this work, we address an advantage and a drawback of the two normally-off HEMT devices: the previously proposed Gate Injection Transistor (GIT) and our newly proposed HEMT with p-GaN region below the channel. Simulation results have shown that the doping concentration required to achieve the desired threshold voltage is lower when the p-GaN region is introduced below the channel rather than above it. On the other hand, the forward gate voltage is much higher when the p-GaN region is introduced above the channel. To achieve a normally-off HEMT with high forward gate voltage, using a relatively low p-doping concentration, an hybrid normally-off HEMT was proposed using two p-GaN regions, one above the channel and another below it.

## References

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