Current Collapse reduction technique using N–doped buffer layer into the bulk region of a Gate Injection Transistor

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***Abstract*—GaN based transistors are subjected to current collapse. In this work a unique solution to this issue is presented by using a buried n-type doped region in the bulk region below the 2DEG channel. The proposed structure is named as "Buried n-doped Gate Injection Transistor (BNGIT)". TCAD simulation of the structure shows that this added layer increases the electron density in the channel just above it. Hence the loss of electrons due to traps can be compensated which results in current collapse free operation.**

***Index Terms*—BNGIT, GIT, HEMT, TCAD**

I. Introduction

The Gate injection transistors (GIT) designed using GaN/AlGaN operates as an Enhancement-mode high electron mobility transistor (HEMT). When a GaN/AlGaN HEMT is operated for longer duration at high drain bias, its ON resistance (R_{ON}) increases. This phenomenon is also known as current collapse in GaN based devices. Many solutions have been proposed to eliminate this issue but complete removal of current collapse has not yet been achieved. So far the best solution to this issue is given by HDGIT [1]. Our work mainly focuses on reducing the current collapse by introducing a n-type buried region in the GaN bulk. Two dimensional structures have been simulated using Sentaurus TCAD [2].

II. Device Structure and principle of operation

A. Structure

The cross section schematic of a the proposed BNGIT is shown in Fig. 1. The dimensions, mole fraction and doping of the layered materials and contacts used in the device have been shown in Fig. 1. A n-type buried region is introduced in the GaN bulk region with a doping of $1e19\ \mathrm{cm}^{-3}$ (represented as green box). Source and drain contacts have been considered as ohmic. A Schottky gate is used with a work function of 4.6 eV.

B. Operating Principle

Current collapse is observed due loss of electrons in the channel because of the presence of traps. When an electron gets trapped it they become immobile and do not conduct [3],

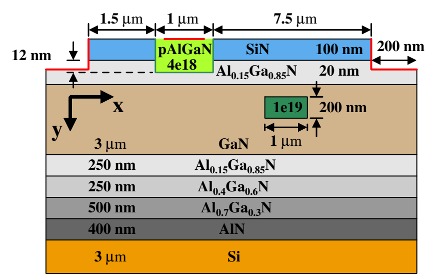

Fig. 1: Proposed structure of BNGIT

[4]. A solution to this problem has been provided by HDGIT in which a virtual drain is introduced. This additional drain is externally connected to the drain terminal and upon the application of drain voltage, it facilitates the accumulation of electrons in the channel. And thus the current collapse is reduced [5]. But the virtual drain reduces the channel length and hence the breakdown voltage (BV) is reduced. In this work BNGIT tries to achieve this same current collapse reduction but with a different approach. Here a n-doped region is placed below the channel in GaN bulk which increases the electron density just above it. This buried region region helps in compensating the loss of electrons to traps by contributing electrons to the channel.

III. Results and Discussions

A Y-cut has been taken to observe the concentration of electrons in the channel just above the buried n-doped region. It can be seen from Fig. 2(a) that electron density is higher in this region as compared to the rest of the 2DEG channel.

On comparison we can see in Fig. 2(b) that the GIT shows current collapse but BNGIT is free from such an effect. The BV of BNGIT is also evaluated and compared with other transistors and has been shown in Fig. 3(a). The BV of BNGIT is also evaluated by varying the depth of the buried n-doped layer into the bulk region. It can be seen from Fig. 3(b) that the BV increases with the increase in depth of the n-buried layer and saturates after a certain depth.

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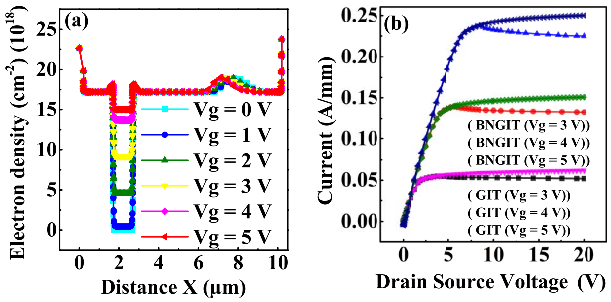

Fig. 2: (a) Electron density (BNGIT) and (b) I–V characteristics of BNGIT and GIT for different gate bias, V_g.

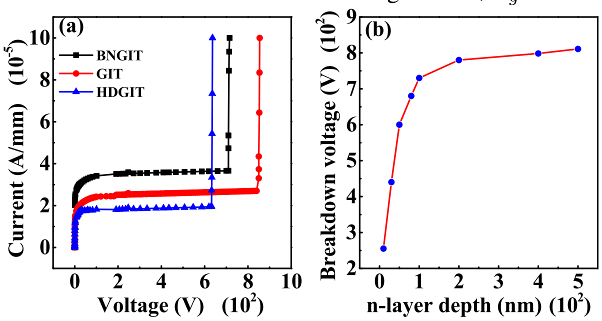

Fig. 3: Breakdown voltage: (a) comparison for GIT, BNGIT and HDGIT and (b) at different depths of buried n-doped region for BNGIT.

IV. Model for Sheet Density of 2DEG

Guang et.al [6] proposed an expression for the sheet density of 2DEG. This equation needs modification for our proposed device as it has a buried n–doped region. Simulation experiments are performed to evaluate the modification needed. First, by varying the doping (conc.) with the position (depth) of the n–doped region fixed (at 100 nm) and secondly, by varying the position of the n–doped region with doping fixed at $1\mathrm{e}19\ \mathrm{cm}^{-3}$, results are represented in Fig. 4 and peak values thereof are tabulated in table I & II. Hence, the expression for the sheet density of 2DEG for the proposed structure is:

$$n_s = \frac{k.n}{q.D.(d_{GaN} + d_{AlGaN})} \times \left[d_{AlGaN}.\sigma_{AlGaN} + d_{GaN}.\sigma_{GaN} - \frac{\epsilon}{q}(q.\phi_b + E_f) \right] \quad (1)$$

here, k is the proportionality constant, n is doping concentration of the buried layer and D is the depth of the buried layer from the 2DEG channel.

TABLE I: Peak 2DEG with change in doping concentration of the buried layer for fixed depth (at 100nm from channel)

Doping Concentration (cm^{-3})	Peak electron density (cm^{-2})
1e17	1.73e19
5e17	1.78e19
1e18	1.82e19
5e18	1.86e19
1e19	1.92e19

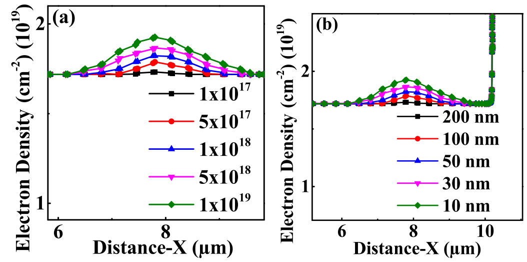

Fig. 4: 2DEG density variation: (a) for change in doping concentration and (b) for change in depth of n–doped buried layer.

TABLE II: Peak 2DEG with change in depth of the buried layer from channel for fixed doping conc. ($1\mathrm{e}19\ \mathrm{cm}^{-3}$)

Depth from channel (nm)	Peak electron density (cm^{-2})
10	2.2e19
30	2.12e19
50	2.02e19
100	1.92e19
200	1.72e19

V. Summary and Conclusion

The proposed structure has shown higher breakdown voltage than a HDGIT and is free from current collapse. Breakdown voltage is dependent on the depth and doping of the buried n-doped layer. Further an expression to calculate the sheet density of the 2DEG for the proposed structure is stated.

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