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Studies on the DC Characteristics of Microelectronic AlGaN/GaN HEMTs

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Abstract
In this work, total 3752 individual simulation-outputs are reported. Total 25 individual microelectronic single-heterojunction AlGaN/GaN high electron mobility transistor (HEMT) structures are designed and simulated in this work using the SILVACO-ATLAS software tool. In this work, drain voltage and gate voltage are electrical parameters to determine the DC characteristics of HEMTs. Aluminium mole fraction is the structural parameter in this purpose. The effects of drain voltage and gate voltage on drain current are studied for different combinations of AlGaN thickness and gate length. Also, the effect of aluminium mole fraction on drain current is studied for these combinations. This work will be helpful to experimentally fabricate the microelectronic HEMT structures.

Keywords: *Drain voltage, gate voltage, mole fraction, drain current*

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INTRODUCTION

Recently, Mukhopadhyay has established many characteristics of high electron mobility transistors (HEMTs) [1–3]. Charfeddine *et al*. have also realized the DC characteristics of HEMTs [4]. Many other authors have reported the physics of HEMTs analytically [5–12]. In the work of Charfeddine *et al.*, the effect of gate length and kink effect are studied in DC characteristics [4]. Chattopadhyay *et al*. have presented the thermal model for DC characteristics, analytical model for gate capacitance, analytical charge-control model, and analytical transconductance model [5–8].

Also, Khandelwal *et al*. have reported the analytical model for 2DEG charge density, analytical model of surface potential, robust surface potential based compact model, and compact model of I-V with C-V characteristics [9–12]. In this work, author has studied the effect of drain voltage on drain current in the AlGaN/GaN HEMTs. Also, the effect of gate voltage on drain current is studied. Finally, the effect of aluminium mole fraction on drain current is studied. These studies will be helpful to fabricate the AlGaN/GaN HEMTs experimentally.

DESIGNS OF SIMULATED STRUCTURES

In this work, a representative cross-sectional view of the microelectronic single-heterojunction AlGaN/GaN HEMT structure is shown in Figure 1. The cross-sectional dimensions of different portions of these designed HEMT-structures are given below: (A) Source dimensions are: 500 nm (length)×100 nm (height); (B) Drain dimensions are: 500 nm (length)×100 nm (height); (C) Gate dimensions are: L_G (length)×500 nm (height); (D) Total horizontal length of the device is 9500 nm; (E) GaN thickness is 500 nm; (F) Sapphire thickness is 1000 nm; and (G) Source to gate fixed distance is 3000 nm. In this work, the gate length (L_G) is varied with the following lengths as 1.5, 2.0, 2.5, 3.0, and 3.5 µm. With the variation in gate length, the source to gate distance is fixed (3000 nm), but the gate to drain distance is variable. The selected thicknesses of AlGaN nano-layers are 30, 32, 33, 34, and 35 nm. The selected aluminium mole fractions (x) are 0.10, 0.15, 0.20, 0.25, and 0.30. In this work, total 25 individual HEMT-structures are designed and simulated according to the selected combinations of structural parameters. GaN and sapphire are chosen as the materials to design the HEMT structures according to the already reported comparative material properties with respect to other materials [1, 2]. In this work, the AlGaN doping concentration is maintained as 1×10^{18} cm^{-3} in each HEMT structure.

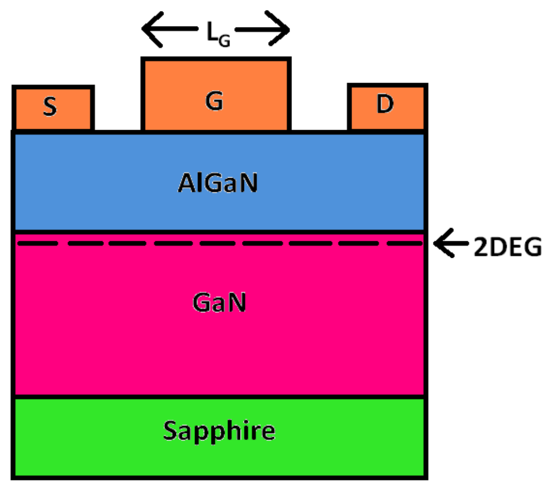

Fig. 1: *Representative Schematic Diagram of the Microelectronic Single-Heterojunction AlGaN/GaN HEMT Structures is Shown.*

RESULTS AND DISCUSSION

From the Figures 2–6, the effects of drain voltage (V_D) and gate voltage (V_G) on drain current are shown corresponding to the AlGaN thickness (T) of 30 nm and gate length (L_G) of 1.5 µm. According to the Figure 2, the drain current increases with drain voltage at any particular aluminium mole fraction (x) corresponding to the gate voltage (V_G) of 0 V [1–3]. According to the Figure 3, the drain current increases with drain voltage at any particular mole fraction (x) corresponding to the gate voltage (V_G) of –1 V [1–3]. According to the Figure 4, the drain current increases with drain voltage at the mole fractions (x) of 0.25 and 0.30, but no significant change in drain current is observed at the mole fractions (x) of 0.10, 0.15, and 0.20, corresponding to the gate voltage (V_G) of –2 V [1–3]. According to the Figure 5, the drain current increases with drain voltage at the mole fraction (x) of 0.30, but no significant change in drain current is observed at the mole fractions (x) of 0.10, 0.15, 0.20, and 0.25, corresponding to the gate voltage (V_G) of –3 V [1–3]. According to the Figure 6, the drain current increases with increasing gate voltage at any particular mole fraction (x) corresponding to the drain voltage (V_D) of 1 V [1–3].

According to the Figures 7–11, the effects of drain voltage and gate voltage on drain current are shown corresponding to the AlGaN thickness (T) of 32 nm and gate length (L_G) of 2.0 µm. According to the Figure 7, the drain current increases with drain voltage at any mole fraction (x) corresponding to the gate voltage (V_G) of 0 V [1–3]. According to the Figure 8, the drain current increases with drain voltage at any particular mole fraction (x) corresponding to the gate voltage (V_G) of –1 V [1–3]. According to the Figure 9, the drain current increases with drain voltage at any particular mole fraction (x) corresponding to the gate voltage (V_G) of –2 V [1–3]. According to the Figure 10, the drain current increases with drain voltage at any particular mole fraction (x) corresponding to the gate voltage (V_G) of –3 V [1–3]. According to the Figure 11, the drain current increases with gate voltage at any particular mole fraction (x) corresponding to the drain voltage (V_D) of 1 V [1–3].

According to the Figures 12–16, similar effects of drain voltage and gate voltage on drain current are observed corresponding to the AlGaN thickness (T) of 33 nm and gate length (L_G) of 2.5 µm. Again, according to the Figures 17–21, similar effects of drain voltage and gate voltage on drain current are observed corresponding to the AlGaN thickness (T) of 34 nm and gate length (L_G) of 3.0 µm [1–3]. Finally, according to the Figures 22–26, similar effects of drain voltage and gate voltage on drain current are observed corresponding to the AlGaN thickness (T) of 35 nm and gate length (L_G) of 3.5 µm [1–3]. In this work, the drain current increases at higher aluminium mole fraction (x) for any particular combination of drain voltage (V_D), gate voltage (V_G), AlGaN thickness (T), and gate length (L_G) [1–3]. The simulation results of this work are completely matching with the trends obtained by Charfeddine *et al.* [4].

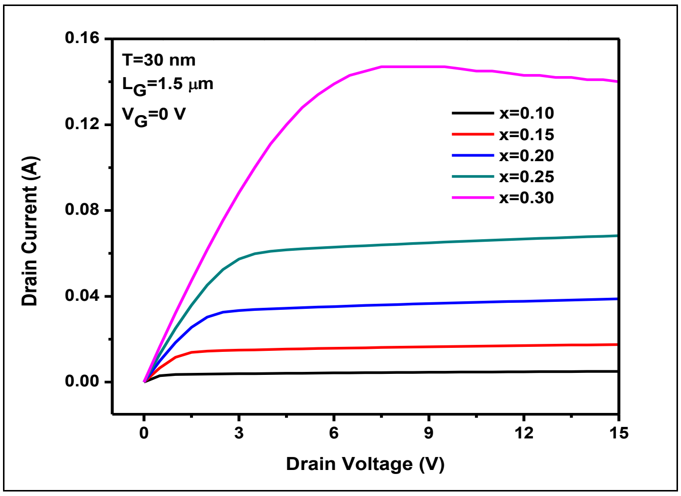

Fig. 2: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of 0 V, Gate Length (L_G) of 1.5 µm and AlGaN Thickness (T) of 30 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

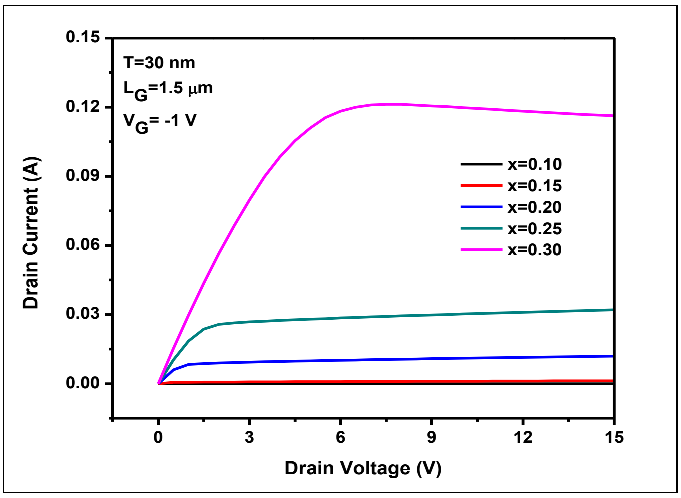

Fig. 3: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –1 V, Gate Length (L_G) of 1.5 µm and AlGaN Thickness (T) of 30 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

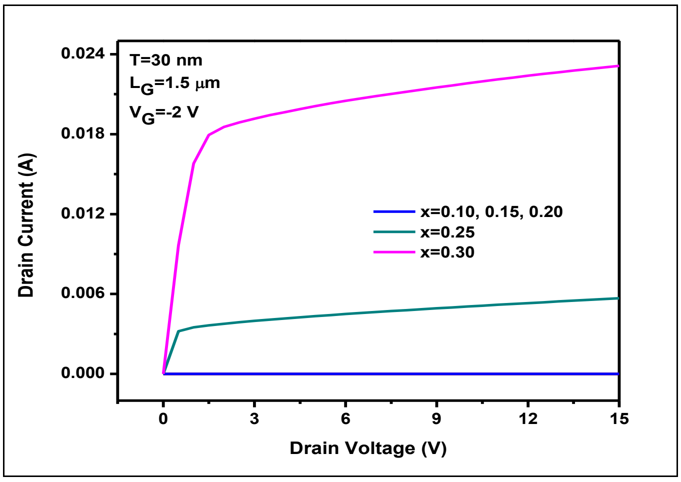

Fig. 4: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –2 V, Gate Length (L_G) of 1.5 µm and AlGaN Thickness (T) of 30 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

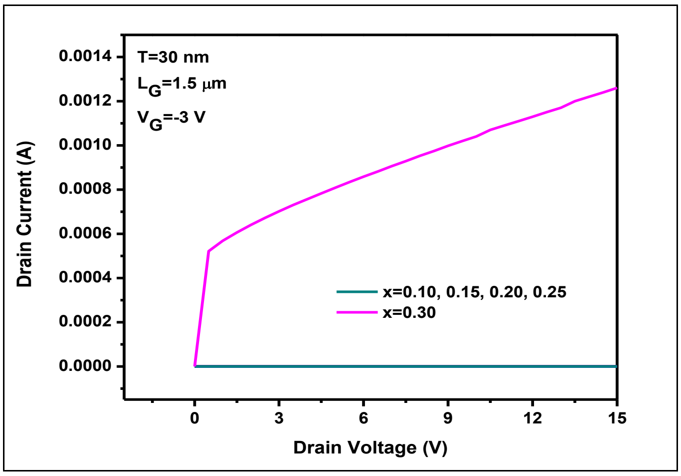

Fig. 5: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –3 V, Gate Length (L_G) of 1.5 µm and AlGaN Thickness (T) of 30 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

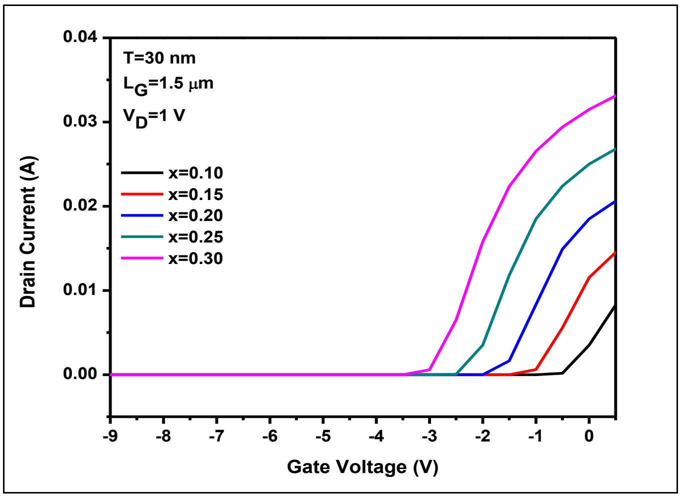

Fig. 6: *The Variation of Drain Current with Respect to Gate Voltage is Shown Corresponding to the Drain Voltage (V_D) of 1 V, Gate Length (L_G) of 1.5 µm and AlGaN Thickness (T) of 30 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

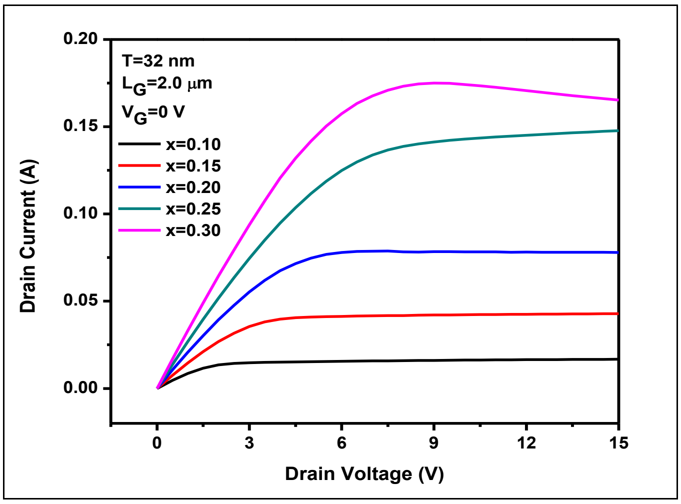

Fig. 7: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of 0 V, Gate Length (L_G) of 2.0 µm and AlGaN Thickness (T) of 32 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

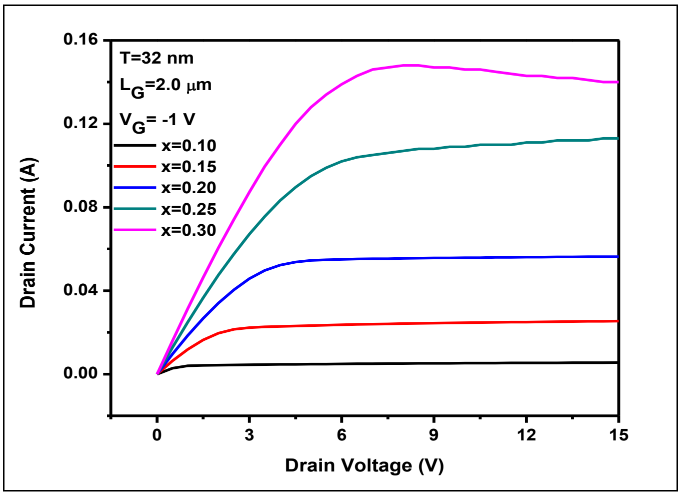

Fig. 8: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –1 V, Gate Length (L_G) of 2.0 µm and AlGaN Thickness (T) of 32 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

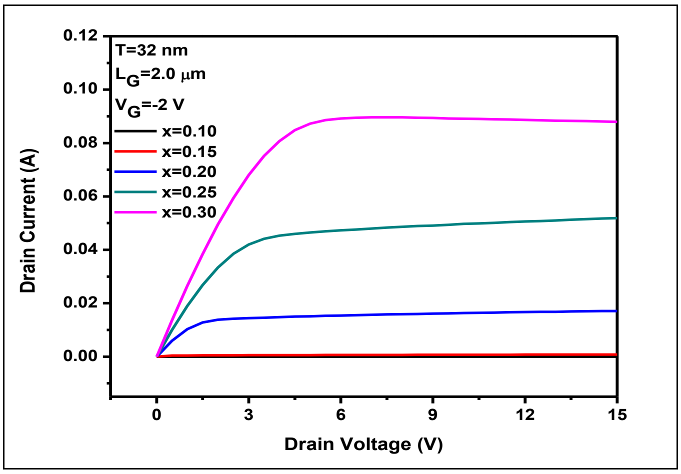

Fig. 9: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –2 V, Gate Length (L_G) of 2.0 µm and AlGaN Thickness (T) of 32 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

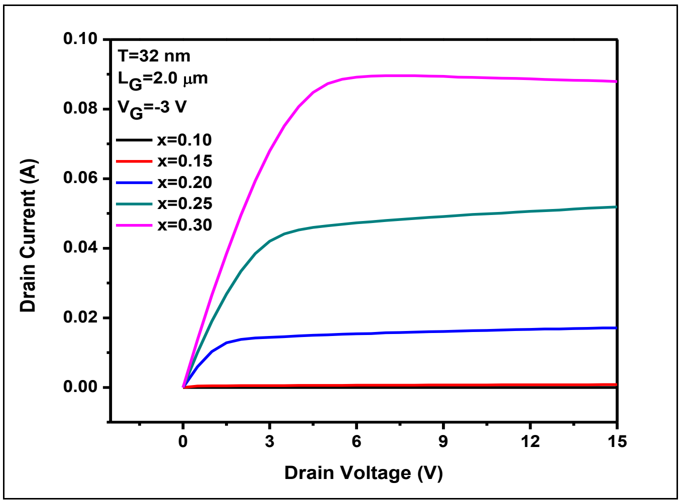

Fig. 10: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –3 V, Gate Length (L_G) of 2.0 µm and AlGaN Thickness (T) of 32 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

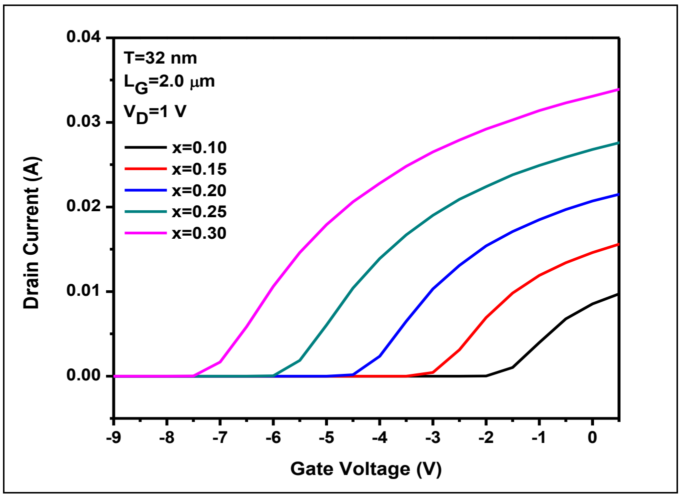

Fig. 11: *The Variation of Drain Current with Respect to Gate Voltage is Shown Corresponding to the Drain Voltage (V_D) of 1 V, Gate Length (L_G) of 2.0 µm and AlGaN Thickness (T) of 32 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

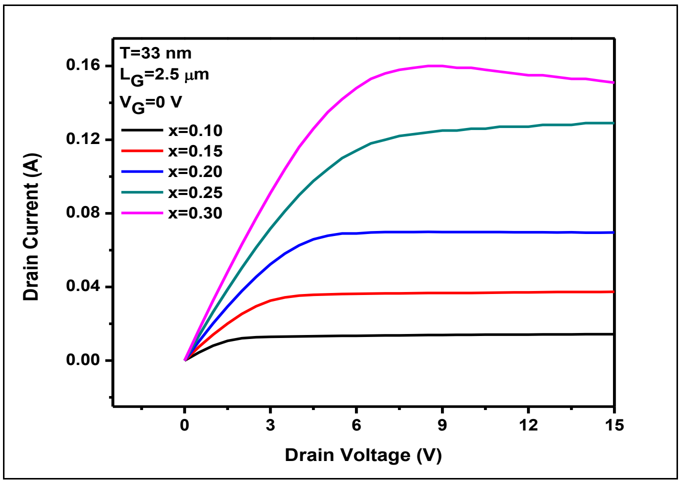

Fig. 12: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of 0 V, Gate Length (L_G) of 2.5 µm and AlGaN Thickness (T) of 33 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

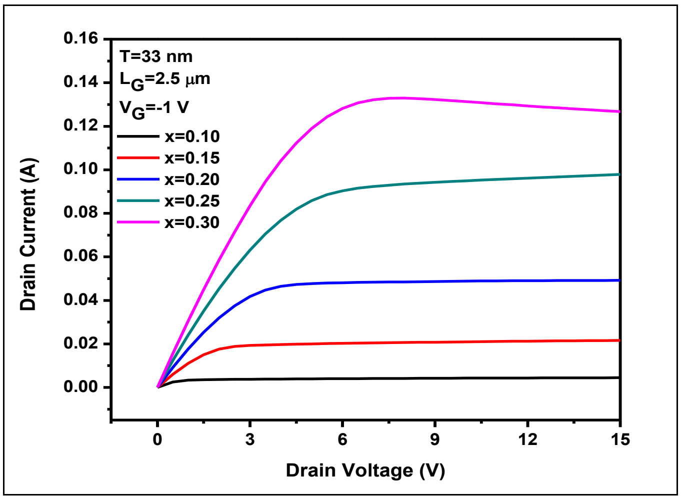

Fig. 13: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –1 V, Gate Length (L_G) of 2.5 µm and AlGaN Thickness (T) of 33 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

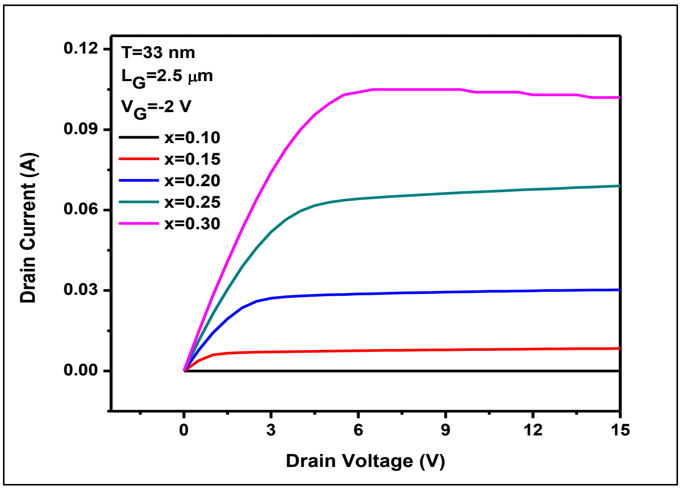

Fig. 14: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –2 V, Gate Length (L_G) of 2.5 μm and AlGaN Thickness (T) of 33 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

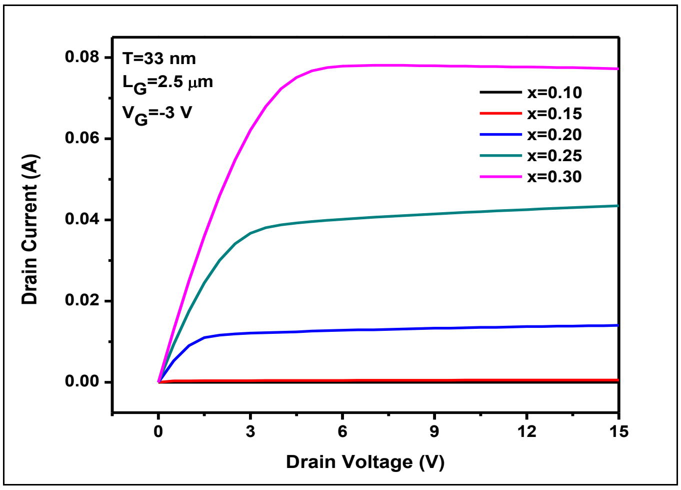

Fig. 15: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –3 V, Gate Length (L_G) of 2.5 μm and AlGaN Thickness (T) of 33 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

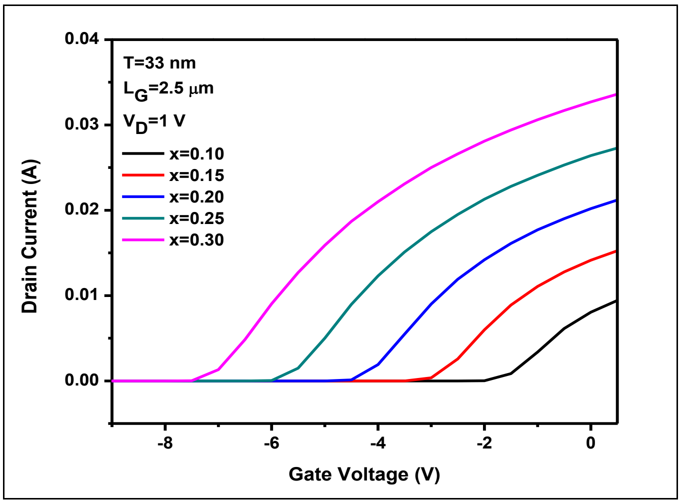

Fig. 16: *The Variation of Drain Current with Respect to Gate Voltage is Shown Corresponding to the Drain Voltage (V_D) of 1 V, Gate Length (L_G) of 2.5 μm and AlGaN Thickness (T) of 33 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

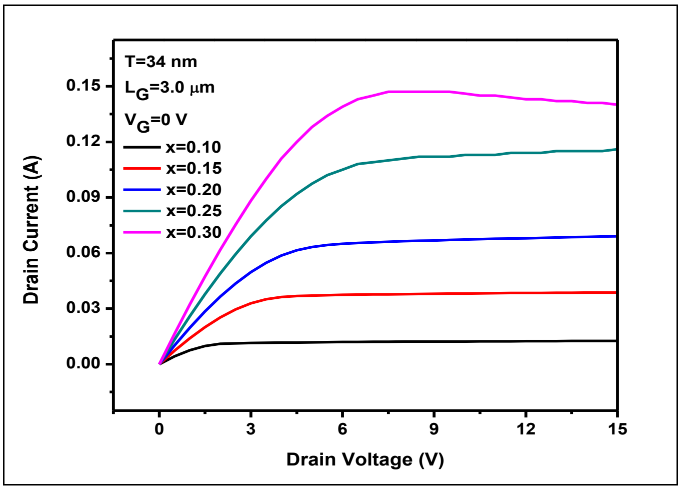

Fig. 17: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of 0 V, Gate Length (L_G) of 3.0 µm and AlGaN Thickness (T) of 34 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

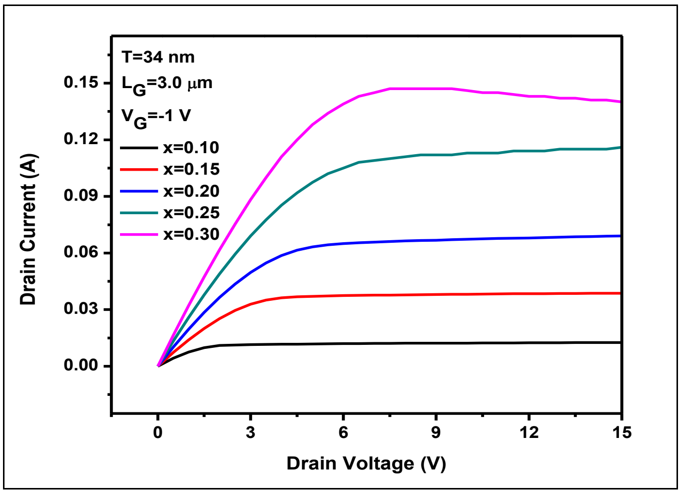

Fig. 18: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –1 V, Gate Length (L_G) of 3.0 µm and AlGaN Thickness (T) of 34 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

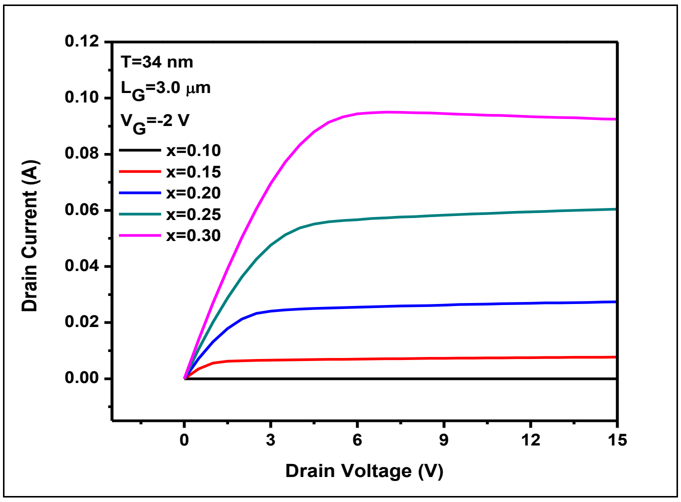

Fig. 19: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –2 V, Gate Length (L_G) of 3.0 µm and AlGaN Thickness (T) of 34 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

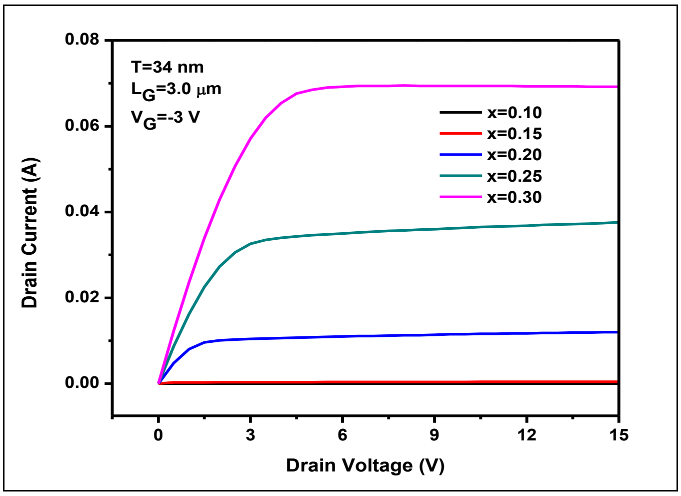

Fig. 20: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –3 V, Gate Length (L_G) of 3.0 µm and AlGaN Thickness (T) of 34 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

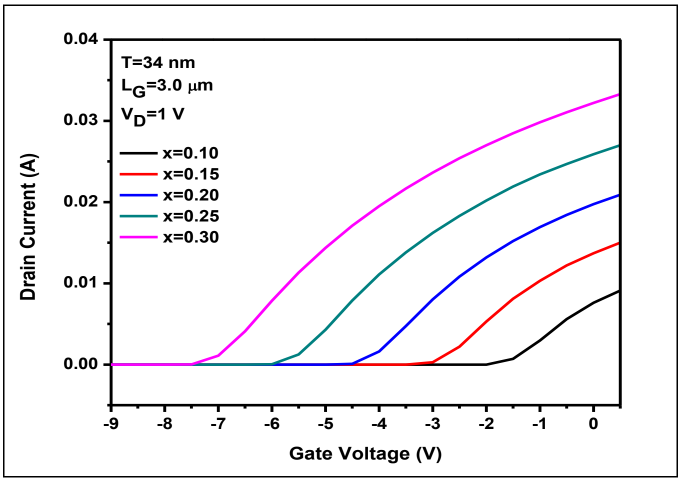

Fig. 21: *The Variation of Drain Current with Respect to Gate Voltage is Shown Corresponding to the Drain Voltage (V_D) of 1 V, Gate Length (L_G) of 3.0 µm and AlGaN Thickness (T) of 34 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

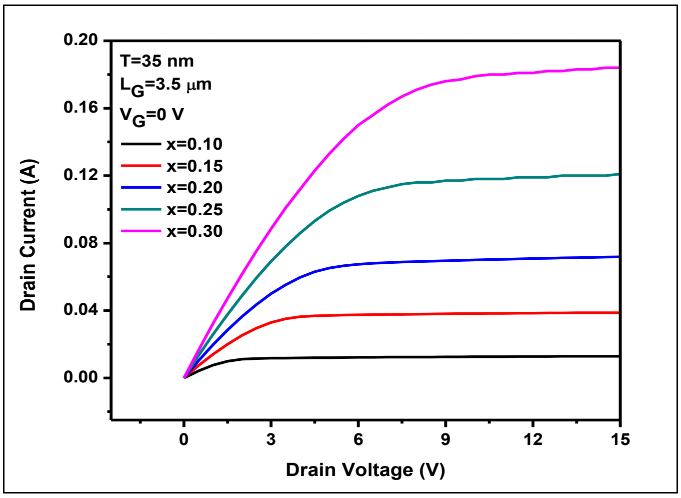

Fig. 22: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of 0 V, Gate Length (L_G) of 3.5 µm and AlGaN Thickness (T) of 35 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

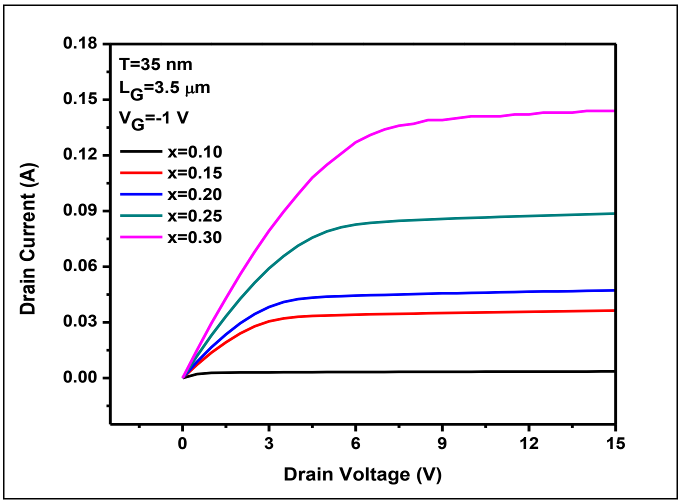

Fig. 23: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –1 V, Gate Length (L_G) of 3.5 µm and AlGaN Thickness (T) of 35 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

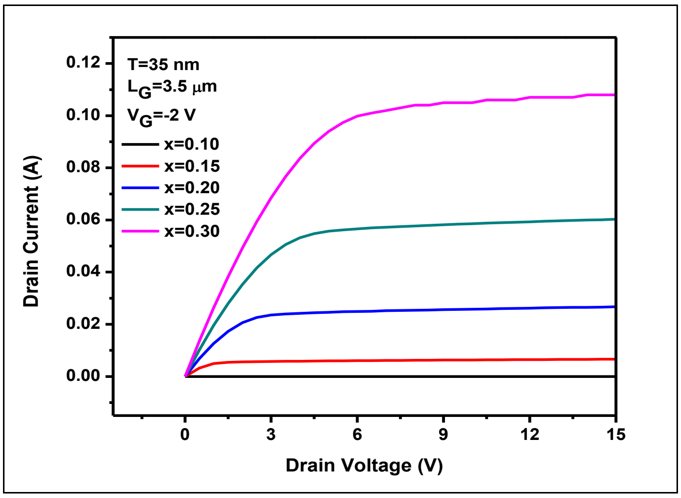

Fig. 24: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –2 V, Gate Length (L_G) of 3.5 µm and AlGaN Thickness (T) of 35 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

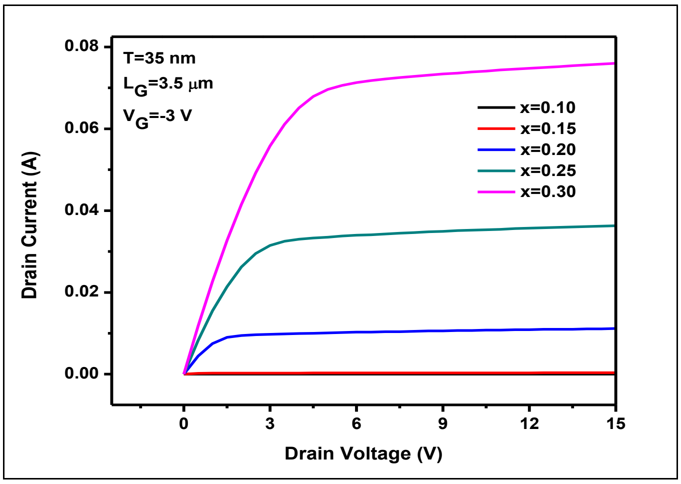

Fig. 25: *The Variation of Drain Current with Respect to Drain Voltage is Shown Corresponding to the Gate Voltage (V_G) of –3 V, Gate Length (L_G) of 3.5 µm and AlGaN Thickness (T) of 35 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

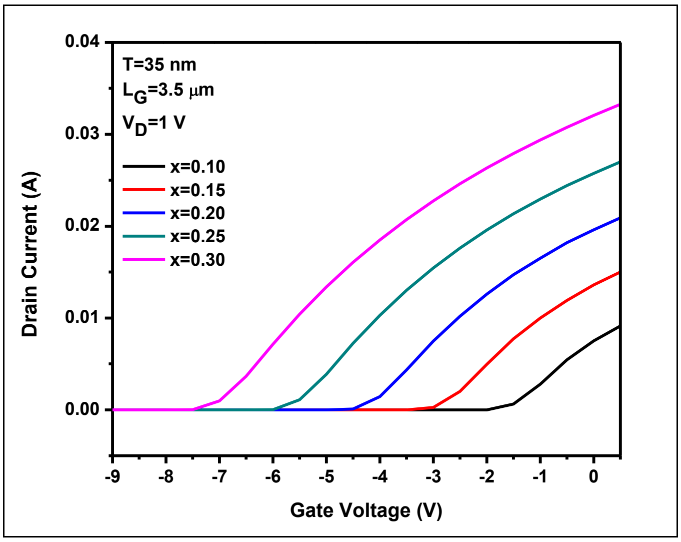

Fig. 26: *The Variation of Drain Current with Respect to Gate Voltage is Shown Corresponding to the Drain Voltage (V_D) of 1 V, Gate Length (L_G) of 3.5 µm and AlGaN Thickness (T) of 35 nm. The Variation of Drain Current is Also Shown with Respect to Aluminium Mole Fraction (x).*

CONCLUSIONS

Total 3752 individual simulation-outputs are reported in this work. Total 25 individual microelectronic single-heterojunction AlGaN/GaN HEMT structures are designed and simulated in this work using the SILVACO-ATLAS software tool. According to the simulation results, the drain current increases with increasing drain voltage for different combinations of AlGaN thickness and gate length. The drain current increases with increasing gate voltage for these combinations. The drain current increases at higher aluminium mole fraction in AlGaN nano-layer for these combinations. This work will be helpful to fabricate the microelectronic AlGaN/GaN HEMT structures experimentally.

REFERENCES

1. Mukhopadhyay S, Kalita S. Report on the Effects of Mole Fraction, Doping Concentration, Gate Length and Nano-Layer Thickness to Control the Device Engineering in the Nanoelectronic AlGaN/GaN HEMTs at 300K to Enhance the Reputation of the National Institute of Technology Arunachal Pradesh. *Nano Trends*. 2017; 19: 15–47p.
2. Mukhopadhyay S. Report on the Novel Electrical Characteristics of Microelectronic High Electron Mobility Transistors to Establish a Low-Cost Microelectronics Laboratory in the National Institute of Technology Arunachal Pradesh. *Journal of Semiconductor Devices and Circuits (JoSDC)*. 2017; 4(2): 6–28p.
3. Mukhopadhyay S, Kalita S. Novel Effect of Gate Length on the Electrical Characteristics of Nanoelectronic Double-Heterojunction HEMTs with the Circuit Symbols and Load Line to Configure the Common-Source Amplifiers in Analog Electronics. *Research & Reviews: A Journal of Embedded System & Applications (RRJoESA)*. 2017; 5(2): 8–18p.
4. Charfeddine M, Belmabrouk H, Zaidi MA, *et al.* 2-D Theoretical Model for Current-Voltage Characteristics in AlGaN/GaN HEMTs. *Journal of Modern Physics (JMP)*. 2012; 3(8): 881–886p.
5. Chattopadhyay MK, Tokekar S. Thermal Model for DC Characteristics of AlGaN/GaN HEMTs Including Self-Heating Effect and Non-Linear Polarization. *Microelectron J*. 2008; 39(10): 1181–1188p.
6. Chattopadhyay MK, Tokekar S. Temperature and Polarization Dependent Polynomial Based Non-Linear Analytical Model for Gate Capacitance of $Al_mGa_{1-m}N/GaN$ MODFET. *Solid-State Electron*. 2006; 50(2): 220–227p.
7. Korwal M, Haldar S, Gupta M, *et al.* Parasitic Resistance and Polarization-

Dependent Polynomial-Based Non-Linear Analytical Charge-Control Model for AlGaN/GaN MODFET for Microwave Frequency Applications. *Microw Opt Technol Lett*. 2003; 38(5): 371–378p.
8. Chattopadhyay MK, Tokekar S. Analytical Model for the Transconductance of Microwave $Al_mGa_{1-m}N/GaN$ HEMTs including nonlinear Macroscopic Polarization and Parasitic MESFET Conduction. *Microw Opt Technol Lett*. 2007; 49: 382–389p.
9. Khandelwal S, Goyal N, Fjeldly TA. A Physics-based Analytical Model for 2DEG Charge Density in AlGaN/GaN HEMT Devices. *IEEE Trans Electron Devices*. 2011; 58(10): 3622–3625p.
10. Khandelwal S, Chauhan YS, Fjeldly TA. Analytical Modeling of Surface-Potential and Intrinsic Charges in AlGaN/GaN HEMT Devices. *IEEE Trans Electron Devices*. 2012; 59(10): 2856–2860p.
11. Khandelwal S, Yadav C, Agnihotri S, *et al.* Robust Surface-Potential-Based Compact Model for GaN HEMT IC Design. *IEEE Trans Electron Devices*. 2013; 60(10): 3216–3222p.
12. Khandelwal S, Fjeldly TA. A Physics Based Compact Model of I-V and C-V Characteristics in AlGaN/GaN HEMT Devices. *Solid-State Electron*. 2012; 76: 60–66p.

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