

Design and Fabrication of Multi-finger Field Plate for Enhancement of AlGaIn/GaN HEMT Breakdown Voltage

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ABSTRACT

The design and fabrication of gate/source connected multi-finger field plate structures using TCAD ATLAS simulation software is presented. The designed field plate structures are fabricated on indigenous AlGaIn/GaN HEMT devices. AlGaIn/GaN HEMT devices with field plate structures exhibit about three times improvement in breakdown voltage of device and are in close agreement with the simulation results. Integration of field plates in device have resulted in higher V_{DS} (drain to source voltage) operation and improvement in output power of AlGaIn/GaN HEMT devices. Incorporation of field plates also decrease the reverse leakage current of HEMT devices.

Keywords: GaN; HEMT; Field plate; ATLAS; Breakdown voltage

1. INTRODUCTION

Recent advances in gallium nitride (GaN) technology have significantly increased power densities for high electron mobility transistor (HEMT) over previous technologies, such as gallium arsenide (GaAs) and other III/V devices¹. This allows not only the production of smaller device with same output power, but also provides much higher device impedance. Higher impedance makes RF matching much easier, eliminating the extra cost and complexity needed for other conventional elements such as based on GaAs. In addition to this, high-voltage property of GaN reduce the need of voltage conversion, leading to higher efficiency operation which in return results in power saving and reduced costs for cooling the system. These characteristics make GaN technology, a highly desirable component for RADAR and military communication systems. Therefore GaN based devices are of strategic importance to defence RF and electronic warfare systems for providing electronic counter measure (ECM) capabilities especially for RF jammer applications.

Field plate structures in AlGaIn/GaN HEMT devices are very important for high frequency and high output power operation. Field plates enhance the breakdown voltage of device by decreasing the peak of electric field near gate edge towards drain²⁻⁹. Field plates also help in reducing the extent of virtual gate formation and thus improve the transient operation of the device¹⁰. AlGaIn/GaN HEMTs with gate Field plate have shown reduced current collapse characteristics^{11,12}. Use of field

plates in AlGaIn/GaN HEMT improve the low frequency noise of the device but adversely affects the frequency response and power added efficiency performance¹³. Properly designed Field plates enhance the device performance in thermal aspects by reducing the thermal resistance and channel temperature of transistor¹⁴. The effect of Field plates depends on the quality (stoichiometry) of the passivation film underneath the Field plates structures¹⁵. In this work we designed and fabricated the source connected and gate connected field plate structures for high power AlGaIn/GaN HEMT devices for up to C-band applications. The output power of AlGaIn/GaN HEMT devices is proportional to V_{DS} (source to drain voltage) applied during biasing. The highest V_{DS} which can be applied safely to the device depends upon the breakdown voltage of the device. So to achieve high output power we need to maximise the breakdown voltage of the device. One of the most popular and important way of enhancing the breakdown voltage of AlGaIn/GaN HEMT device is to reduce peak electric field between gate and drain, using properly designed source and gate connected field plate structures.

2. DESIGNING OF FIELD PLATES

Multi-finger field plates have been designed using TCAD ATLAS software. We have used two field plate structures that is source connected and gate connected field plates. Field plate schematics are as shown in Fig. 1. ATLAS software is calibrated to match our indigenously fabricated HEMT experimental results. Two dimensional electron gas (2DEG) is generated using interface statement and is set equal to the experimentally measured sheet carrier concentration. Contact resistances of

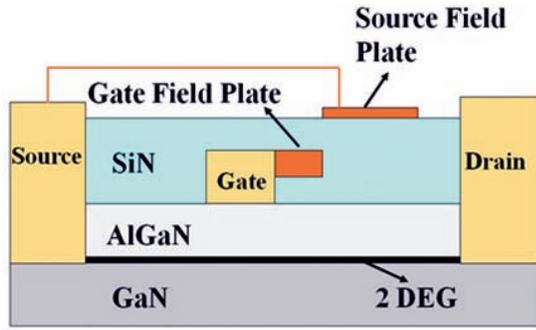


Figure 1. Schematics of gate connected and source connected field plates.

ohmic contacts, Schottky barrier height of gate contact, low field mobility are set equal to the experimentally measured values of these parameters. Low $V_{DS} = I_D - V_{GS}$ (source to gate voltage) characteristics are simulated and matched with measured $I_D - V_{GS}$ characteristics. The off-state gate and drain leakage currents can significantly affect the breakdown phenomenon in device. So simulated off-state gate and drain leakage currents are matched to experimentally measured leakage currents. Selberherr’s Impact Ionisation model is used to simulate breakdown phenomenon.

To optimise the gate connected field plate length, breakdown characteristics and F_T (cut-off frequency) are simulated for different L_{GFP} (gate field plate length). L_{GFP} is varied from 0.2 μm in steps of 0.1 μm till the breakdown voltage value saturates. The L_{GFP} optimisation results are as shown in Fig. 2.

Optimised L_{GFP} is 0.6 μm and breakdown voltage is more than doubled after using gate connected field plate. Gate connected field plate increases the gate capacitance thereby reducing the F_T of the HEMT device.

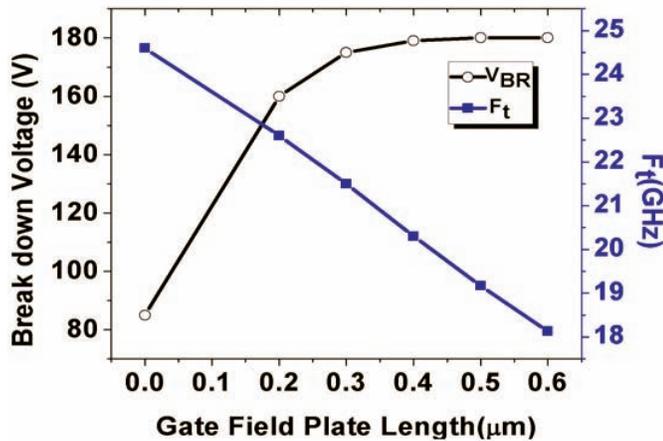


Figure 2. Optimisation of gate connected field plate at $V_{GS} = -7\text{V}$. No source field plate is considered in gate connected field plate optimisation.

SiN layer of fixed thickness is deposited over the gate connected field plate by plasma enhanced chemical vapour deposition system (PECVD). Source connected field plate is then optimised using 0.6 μm gate connected field plate and SiN layer thickness between these two field plates. Results of Source field plate optimisation are as shown in Fig. 3.

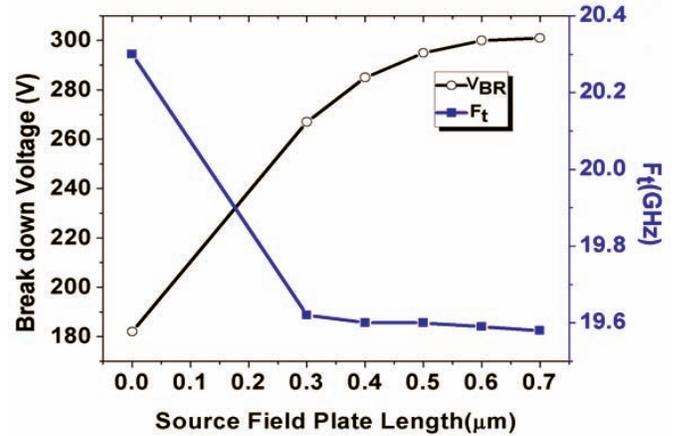


Figure 3. Optimisation of source connected field plate at $V_{GS} = -7\text{V}$. The length of gate field plate is 0.6 μm .

Simulation results show that by using both gate connected and source connected filed plates the breakdown voltage is enhanced by more than three times. Fig. 4 shows the distribution of lateral electric field in HEMT device channel with distance from the gate edge towards drain contact at $V_{DS} = 85\text{V}$.

Field Plates have decreased the peak value of electric field in channel by dividing it in three peaks. This leads to enhancement in breakdown voltage of the AlGaN/GaN HEMT devices.

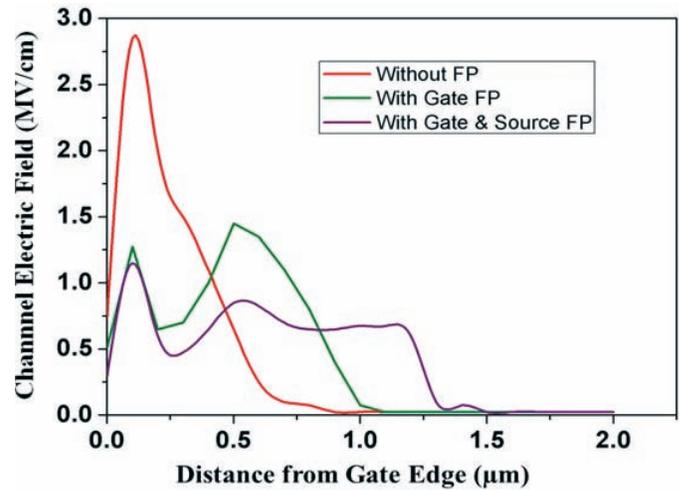


Figure 4. Channel electric field distribution with and without field plates.

3. FABRICATION AND MEASUREMENTS

The typical MOCVD grown HEMT structure used for device fabrication is consists of a GaN buffer layer, AlN spacer layer, AlGaN barrier layer and thin GaN cap layer. Hall-effect measurements showed a two-dimensional electron gas (2DEG) density of $\sim 1.0 \times 10^{13} \text{ cm}^{-2}$ and an electron mobility of $\sim 1800 \text{ cm}^2/\text{Vs}$. The device fabrication starts with source and drain ohmic contacts formation by e-beam evaporation followed by device isolation using BCl_3/Cl_2 based inductively coupled plasma reactive ion etching (ICP-RIE) for dry etching. This is followed by formation of Ni/Au gate Schottky contacts $\sim 0.7 \mu\text{m}$

gate length. Devices are then passivated by a thin SiN layer using PECVD process.

Designed Field Plates are then fabricated on AlGaIn/GaN HEMT by formulating a compatible process flow incorporating steps for gate and source connected field plates as described. Contact Windows are opened in SiN passivation layer by using CF_4/O_2 based dry etching. Bi-layer resist process is used for gate field plate lithography followed by Ti/Au metal deposition in e-beam metal deposition system. Finally Lift-off is done to remove unwanted metal. Similarly Source connected field plates are fabricated after deposition of SiN layer by PECVD process. The complete process flow is as depicted in Fig. 5. DC and pulse IV characteristics, before/after SiN passivation, are measured using Agilent B1500 parametric analyser and GaAscode pulse IV system respectively. FESEM characterisation is used to ensure the proper field plates placement over the gate.

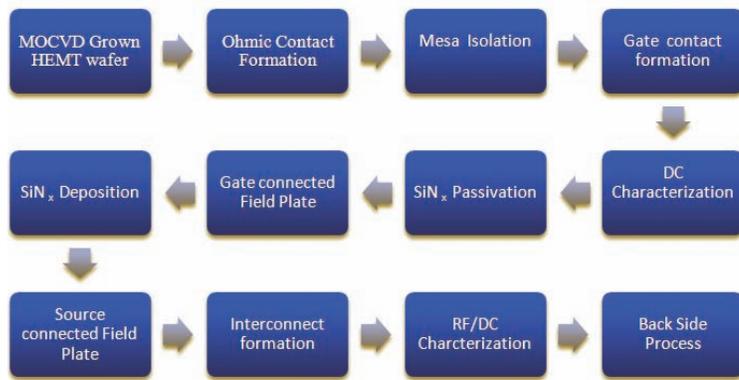


Figure 5. Complete process flow sequence for the fabrication of HEMT with multi-finger field plates.

FE-SEM image of fabricated gate connected and source connected field plate is shown in Fig. 6. The fabricated field plates are exactly as per the designed structures. Three different devices including AlGaIn/GaN HEMT without field plates, with gate connected field plates and with both Gate and source connected field plates are fabricated on single wafer. Comparison of breakdown characteristics with field plates is as shown in Fig. 7. AlGaIn/GaN HEMT devices with both Gate and Source connected field plates exhibit breakdown voltage of about 150 V whereas the breakdown voltage before without field plates is about 40 V (breakdown voltage is the voltage measured @ leakage current 1mA/mm). HEMT devices with only Gate connected Field Plate have breakdown voltage

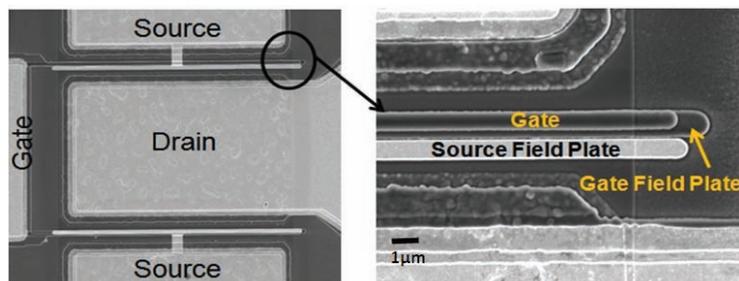


Figure 6. FE-SEM image of fabricated gate and source field plates.

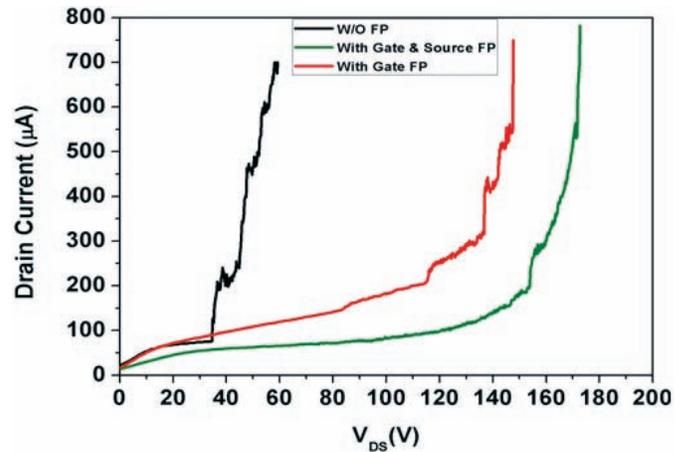


Figure 7. Breakdown characteristics of fabricated AlGaIn/GaN HEMT devices at $V_{GS}=-7V$.

of about 130 V. The enhancement in breakdown voltage with Field plates is more than three times. Breakdown characteristics are in trend with prediction of simulation results, although there is a difference in simulated and experimentally measured initial breakdown voltage values without field plates. This may be due to the process issues difficult to include in simulation. The enhancement of breakdown voltage by incorporating field plates, increased the device operating voltage suitability up to 50 V operation. Also with field plates, due to reduction in peak electric field, the availability of active electron taps between gate and drain reduces drastically that results in minimum current collapse and knee walkout.

Hence the incorporation of multi finger field plate is increasing the device breakdown voltage in addition to reduction in current collapse, thus enhancing the total power output of the HEMT device. In other words, field plated device structure enhanced the operating voltage range from 28 V to 50 V without significant reduction in source drain current. The power output increased by ~60 per cent at 50 V in comparison to 28 V of operation for 1mm gate width of HEMT device at 3.0 GHz.

4. CONCLUSIONS

Multi-finger field plates are very much effective in enhancing the breakdown voltage and hence output power of AlGaIn/GaN HEMT devices. The designed Gate connected and Source connected Field Plates increased the breakdown voltage by more than three times, making HEMT device suitable for 50 V V_{DS} operation. The designed field plates are successfully implemented on AlGaIn/GaN HEMTs through a well formulated process sequence. The simulated results of breakdown voltage are in very good agreement with the experimental results of GaN HEMT fabricated with field plates and therefore validated the multi-finger field plate design and fabrication process of Field Plates structures. Also the RF power output with field plate increased by ~60 per cent at 50 V for 1mm gate width of HEMT device at 3.0 GHz.

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