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Performance Analysis of GaN/AlGaN HEMTs Passivation using Inductively Coupled Plasma Chemical Vapour Deposition and Plasma Enhanced Chemical Vapour Deposition Techniques

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ABSTRACT

In the present paper SiN thin film has been studied as a passivation layer and its effect on AlGaN/GaN HEMTs is investigated using two different deposition techniques i.e PECVD and ICPCVD. AlGaN/GaN HEMTs devices passivated with optimised SiN film have delivered lower gate leakage current (from µA to nA). Device source drain saturation current (I_{ds}) increased from 400mA/mm to ~550 A/mm and the peak extrinsic trans-conductance increased from 100 mS/mm to 170 mS/mm for a 0.8 µm HEMT device. The optimised SiN passivation process has resulted in reduced current collapse and increased breakdown voltage for HEMT devices.

Keywords: GaN; Passivation; SiN; Plasma enhanced chemical vapour deposition; PECVD; Inductively coupled plasma chemical vapor deposition; ICPCVD

1. INTRODUCTION

GaN based high electron mobility transistors (HEMTs) on SiC substrate have shown potential electrical characteristics that make them suitable candidate for high frequency, high power and high temperature applications. These devices are of tremendous interest in high power applications at microwave frequencies. These devices are known for better IV characteristics and record high output power at RF frequencies. However, GaN HEMTs suffer from current collapse and frequency dispersion mainly due to trapping of electron in the active channel region[1-18]. The trapping effect is mainly due to defects, dislocations which might have incorporated during HEMT structure growth. A lot of work has been carried out to investigate and understand the effect of frequency dependent behaviour and reduction in drain current which degrades the device performance. Passivation by suitable dielectrics generally leads to mitigate the current collapse and increases off state break down voltage. People have presented work on SiN passivation layer for AlGaN/GaN HEMTs which has shown an increase in output power and breakdown voltage[4,8,9].

In the present paper we have studied the SiN passivation of GaN HEMTs carried out by two different techniques i.e. plasma enhanced chemical vapour deposition (PECVD) and inductively coupled plasma chemical vapour deposition (ICPCVD). A comparative study of passivated and unpassivated AlGaN/GaN HEMTs with a gate-length of 0.8 µm has been presented for both deposition techniques as shown in Fig. 1. The effect of silicon nitride passivation on device DC characterisation has been compared. We have observed significant increase in saturation current and breakdown voltage for both the silicon nitride deposition process.

2. EXPERIMENTAL WORK

The study is carried out on AlGaN/GaN HEMTs device fabricated on metal organic chemical vapour deposition (MOCVD) on silicon carbide (SiC) substrate. The HEMT structure consists of undoped GaN buffer and 25 nm - 27 nm AlGaN. Hall measurements showed a sheet carrier concentration of 1e13 cm^{-2} and an electron mobility of 1600 cm^2/Vs at room temperature. The device isolation is achieved by mesa etching using BCl_3/Cl_2 plasma etching in inductively coupled plasma reactive ion etching (ICPRIE) system.

After source, drain and gate formation the devices have been processed for passivation, One half of the wafer is passivated by SiN film deposited by PECVD method and other half of the wafer is passivated using SiN film deposited by ICPCVD technique. This methodology is adopted to study the effect of both passivation techniques on same HEMT structure and device geometry before and after passivation[16-18.]

In PECVD[11-13] method we have used silane (SiH_4), ammonia (NH_3) and nitrogen (N_2) gases for deposition of silicon nitride film. The process parameters used for PECVD method are, RF power 250 W, temperature 300 °C while in ICPCVD process silane (SiH_4) and nitrogen (N_2) gases are used at 100 °C temperature for silicon nitride deposition.

We have kept the silicon nitride film thickness ~1000A in both the cases to avoid any variation in 2DEG due to

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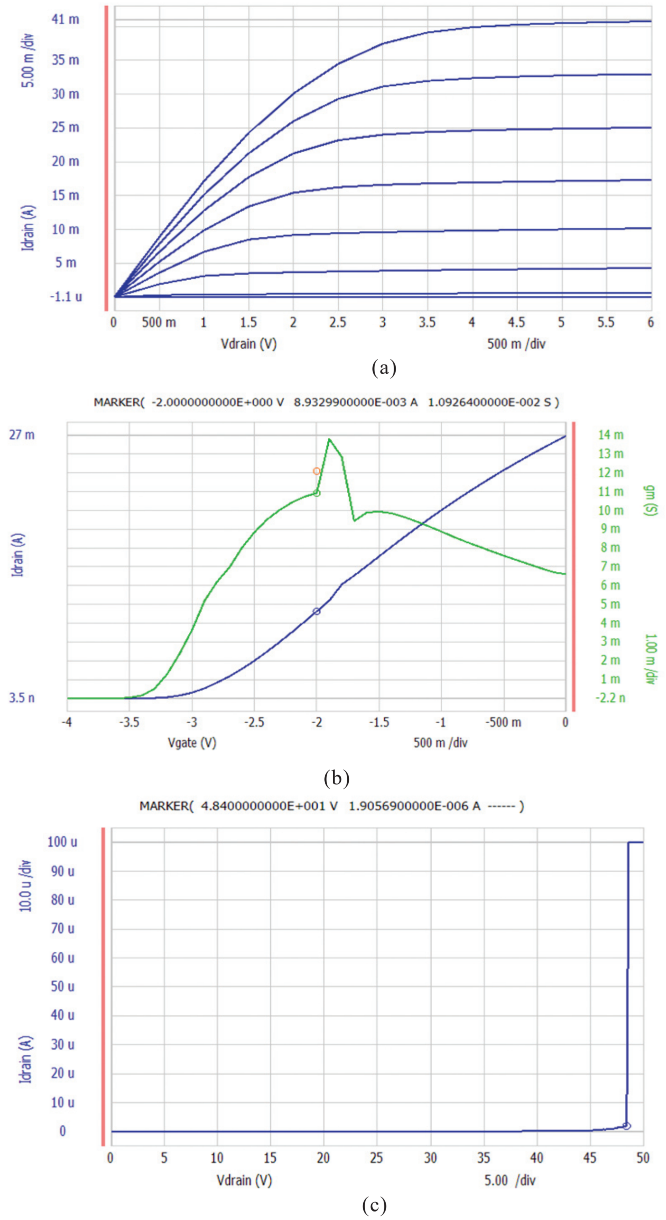

Figure 1. (a)-(b) I-V and Transconductance (c) Breakdown voltage characteristics before passivation.

SiN thickness. To evaluate device performance devices are characterised before and after the passivation using parametric analyser B1500A for IV characteristics.

3. RESULTS AND DISCUSSIONS

We have observed increase in source drain saturation current in both type of passivation techniques. In PECVD passivation the HEMT devices has shown increase in drain current from 400 mA/mm to 480 mA/mm as shown in Figs. 2(a) and 2(b), whereas in ICPCVD passivation the current has increased to 550 mA/mm as shown in Figs. 3(a) and 3(b). Breakdown voltage measured is 50 V for PECVD passivation as shown in Fig. 2(c). In case of ICPCVD passivation the breakdown voltage is increased to 75 V on the same device structure as shown in Fig. 3(c). The passivated HEMT devices by ICPCVD method have shown significant increase in performance compare to PECVD passivation.

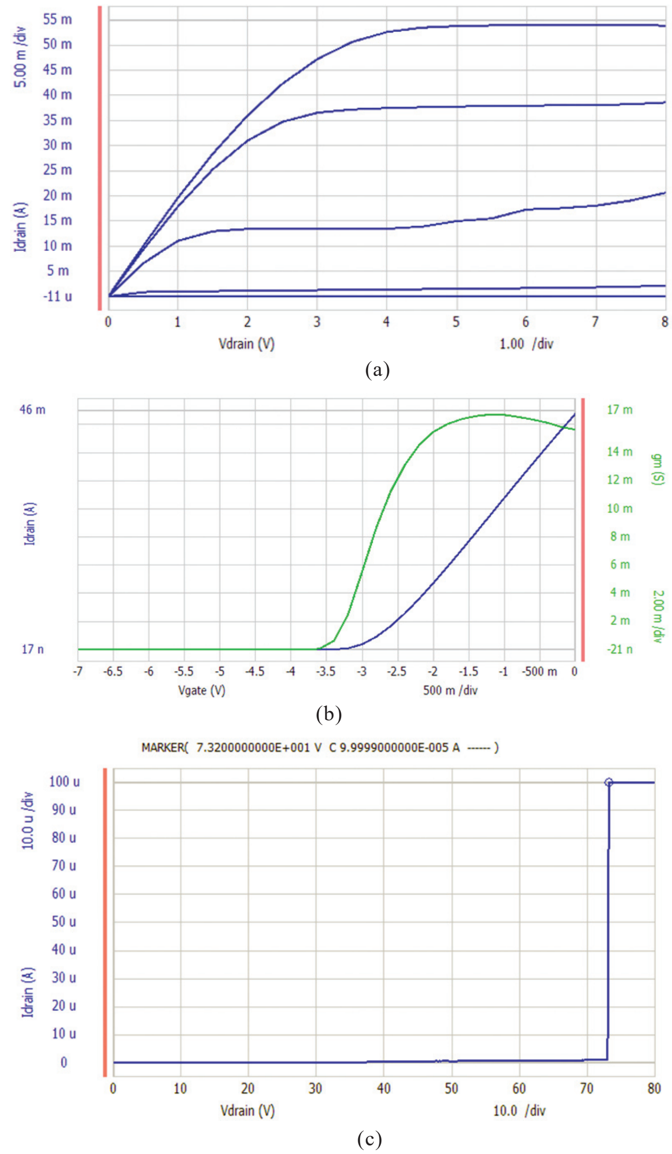

Figure 2. (a)-(b) I-V and Transconductance (c) Breakdown voltage characteristics after ICPCVD passivation.

Drain current collapse occurs during high frequency operation in GaN devices. This is due to trapping effects caused by surface states and considered to be responsible to this depression in current. This is mainly caused by existence of a 'virtual gate', which might have depleted the transistor access regions. The virtual gate is formed between the gate and drain electrodes. Traps in either the GaN buffer or AlGaN barrier layers also lead to the poor performance of device as they act as source for leakage current. Surface passivation by a suitable dielectric film is essential to mitigate the current collapse effect[1,2,6,16]. Number of people have suggested that in SiN passivation Si incorporation at the AlGaN surface as shallow donor and helps in reducing surface traps and hence the current collapse.

We have observed a much higher increase in breakdown voltage in ICPCVD process in comparison to PECVD process. This may be due to the quality of silicon nitride. The PECVD silicon nitride film is less dense as compared to ICPCVD silicon nitride as the etch rate is higher for the PECVD deposited

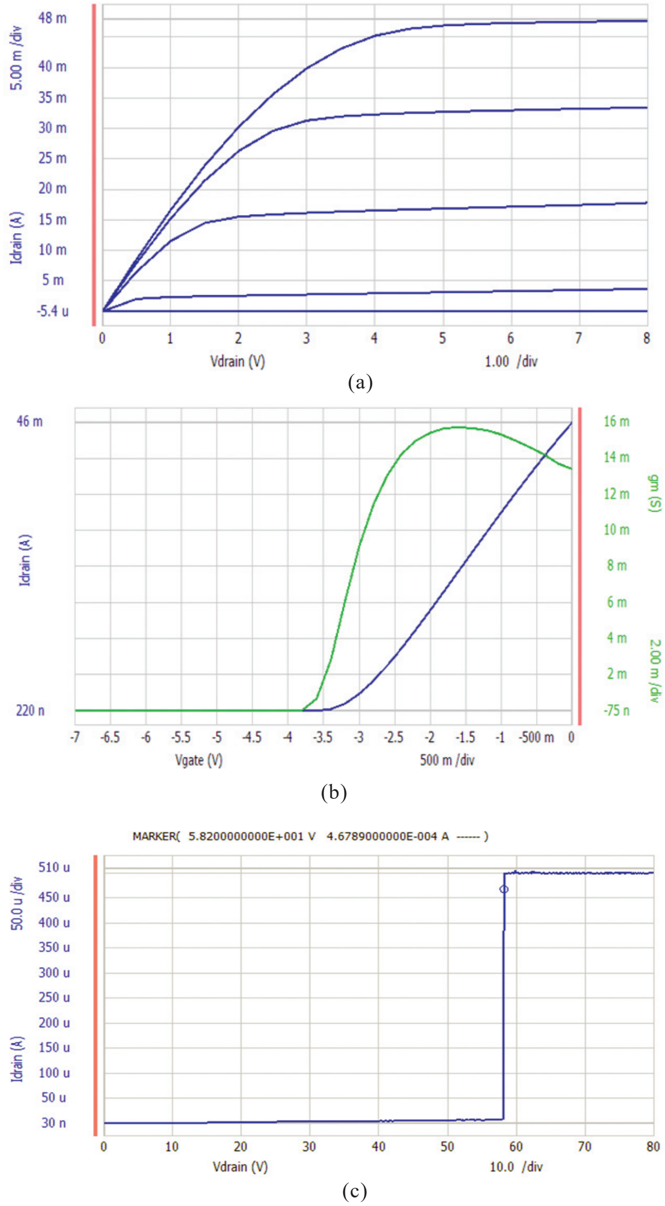

Figure 3. (a)-(b) I-V and Transconductance, (c) breakdown voltage characteristics after PECVD passivation.

silicon nitride films in comparison to ICPCVD deposited nitride film. FTIR also has shown more hydrogen contents in PECVD silicon nitride than ICPCVD silicon nitride films. A comparison of source drain DC current for both ICPCVD and PECVD passivation process on HEMTs device performance is as shown in Fig. 4.

The increase in breakdown voltage can be attributed to the distribution of high field region through silicon nitride film used for passivation. Silicon nitride surface passivation film leads to suppression of surface states probably, which are trapping the electrons coming from gate. A comparison for breakdown voltage has shown in Fig. 5[9,13].

Both type of passivation have resulted in improvement of the device performance. The channel conductivity was increased, and consequently the drain current and transconductance were also increased. The improvement observed with the passivation layer mainly due to induced variable stress from compressive

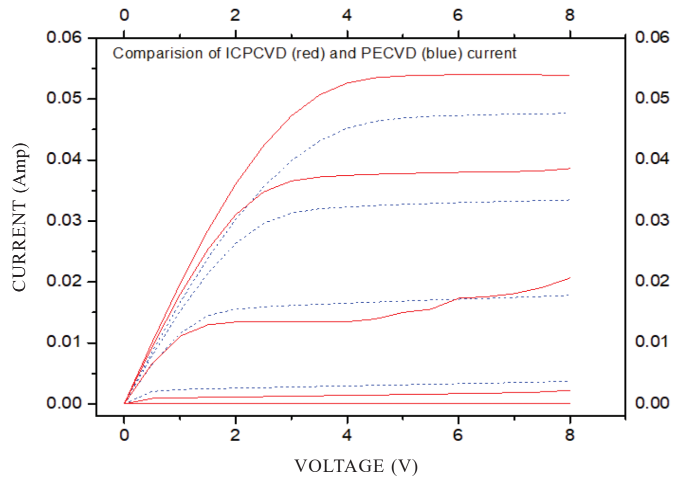

Figure 4. Comparison of I-V characteristics of HEMT devices after ICPCVD and PECVD passivation.

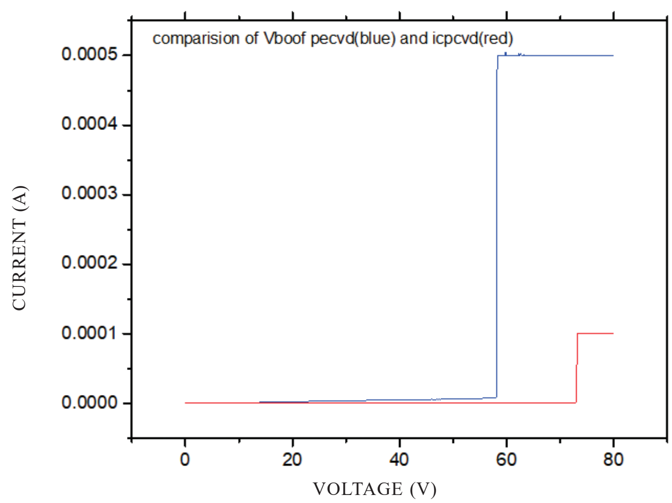

Figure 5. Comparison breakdown voltage (V_{boff}) of HEMT device after ICPCVD and PECVD passivation.

PECVD nitride (−125 MPa) to tensile ICPCVD nitride (~50MPa)[12-14]. It is clearly evident that the devices with tensile passivation-induced stress exhibited the better performance.

The FTIR spectra for silicon nitride films for both PECVD and ICPCVD processes is as shown in Fig. 6. The FTIR spectrum is showing more hydrogen percentage (more N-H and Si-H bond compare to Si-N) in PECVD than ICPCVD grown films clearly indicating the better quality of ICPCVD films. The refractive index measurement and etch rate also confirming the same.

4. CONCLUSIONS

The effect of SiN thin film passivation on AlGaN/GaN HEMT device is analysed using two different techniques namely PECVD and ICPCVD. Carrier (electron) trapping at the SiN/GaN interface is considered to be mainly responsible for the behavior observed. Analysis of the device IV characteristics under pulsed regime with variable pulse width may reveal more information. SiN passivated HEMT devices with a gate-length of ~ 0.8 μm have shown better electrical (DC) characteristics with lower gate leakage current. Also the device breakdown

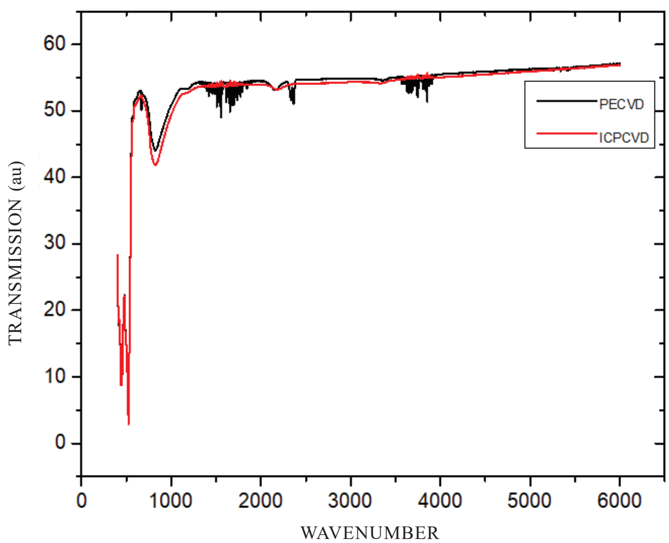

Figure 6. FTIR spectra for PECVD and ICPCVD grown silicon nitride showing Si-N, Si-H and N-H absorption peaks.

voltage increased significantly after passivation in comparison to un-passivated devices. For our HEMT devices, ICPCVD silicon nitride passivation exhibits better performance than PECVD passivation method, though both the techniques are suitable for passivation of GaN based HEMTs devices.

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