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Review of AlGaN/GaN HEMTs Based Devices

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Abstract This paper presents a review of the recent advances of the AlGaN/GaN high-electron-mobility transistors (HEMTs) based devices. The AlGaN/GaN HEMTs have attracted potential for high frequency, voltage, power, temperature, and low noise applications. This is due to the superior electrical, electronic properties, high electron velocity of the GaN. These properties include the GaN wide band gap energy, electrical, optical and structural properties. The based structures of GaN such as AlGaN/GaN are driving the interest in the research areas of GaN HEMTs. Recently, the AlGaN/GaN HEMTs have gained a great potential in radio frequency (RF) and power electronics (PE) based devices and applications. The recent aspects of the AlGaN/GaN HEMTs devices are presented and discussed. The performance of different device demonstrated based on AlGaN/GaN HEMTs are reviewed. The structural, electrical, and optical properties of these devices are also reviewed.

Keywords: *Gallium Nitride (GaN), HEMTs, Traps, Defects, Aluminum gallium nitride/gallium nitride (AlGaN/GaN), Aluminum Nitride (AlN)*

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1. Introduction

GaN is one of the group III-nitride family. It has unique electrical, electronic and optical properties. These properties include the direct wide bandgap. These unique properties make the GaN materiel as one of the key materials for high frequency, large bandwidth, high power based devices. GaN is a very hard, chemically and mechanically stable material. It has a high heat capacity and thermal conductivity [1,2].

AlGaN/GaN HEMTs have a high performance at high powers and frequencies [3,4]. This is due to the high critical break down fields, electron mobility and concentration [5]. The GaN thermal conductivity enhances the channels heat reduction in the AlGaN/GaN HEMTs based devices. The heat reduction is an important for devices with high reliable and performance [6,7]. The AlGaN/GaN HEMTs devices also have been used as switching devices [8,9]. These devices have a high breakdown field, high voltage [10], and high electron velocity [11,12]. The high electric field and high electron velocity of the AlGaN/GaN HEMTs devices allows the fabrication of low ON resistance, high breakdown voltage, and high switching frequency [13,14]. On the other hand, the AlGaN/GaN heterostructures HEMTs based devices have a great performance comparing with typical HEMTs devices [15,16,17]. Moreover, most of the AlGaN/GaN HEMTs are depletion type [18,19].

The AlGaN/GaN HEMTs have been the driving tool for many research investigations in the recent years. The AlGaN/GaN HEMTs are very promising devices for high frequency, voltage, power, and temperature applications [20,21]. This is due to the excellent material's properties of GaN. These properties include the wide band gap energy of 3.4 eV, the high electron mobility of 2000 cm^2/Vs, the thermal conductivity of 160 W/Km, and the high breakdown field of 3.3 MV/cm [22,23,24]. The GaN properties plays an important role in improving the saturated drain current and the DC transconductance of these devices [25]. The AlGaN/GaN based HEMTs are also attractive for microwave wave applications leading to a high power density performance, as well as the electron saturation velocity [26]. These devices have other applications including the cellular handset, high broadband [27,28]. They are considered the best candidates for wireless communication system applications. On the other hand, The AlGaN/GaN HEMTs have becoming a very attractive some advanced application [29]. These applications include the satellite communications, weather forecasting, and military systems [30,31,32]. The AlGaN/GaN HEMTs have recently used for biosensing based devices [33]. These devices require a high sensitivity for certain applications [34]. Recently, the AlGaN/GaN HEMTs devices are becoming very essential for wireless, radars, and power amplifiers applications [35].

2. AlGaN/GaN HEMTs Challenging Issues

The GaN based HEMTs devices have several structures including AlGaN and InGaN. These HEMTs can be made with heterostructures including different material and different band gap energies. In these structures, buffered layers are being used in the structure of GaN based HEMTs for the reduction of the lattice mismatch between the crystalline structures [35,36,37]. Some of the challenges in the AlGaN/GaN HEMTs device are the reduction of the gate leakage current and the reduction of the noise, and the improving of the drain current. The high quality, resistive substrates, and high thermal conductivity are the most important requirments for high performance AlGaN/GaN HEMTs devices [38,39]. Despite of their properties, these devices have other critical problems. In these devices, the existence of defects and traps in the structure effecting the commercial usage and reproducibility. Other issues like the trapping are affecting the device reliability and cause the reduction of the drain current, light sensitivity [40] and reducing the output power [24,41]. There are several methods for investigating the effect of the traps in the AlGaN/GaN HEMTs devices. These methods include the interconnection between the output power and the traps [24,42]. However, these defects result in the electron trapping leads to the reduction of the device performance [43]. Recently, several techniques are being used to investigate the trapping effect in the AlGaN/GaN HEMTs. These techniques include the transient spectroscopy method [44], the gate to drain conductance method [45], the high to low frequency method [46,47], the capacitance and conductance method [48,49,50]. Moreover, the AlGaN/GaN HEMTs devices suffers from the self heating in the conducting channel [7,51]. This heating effect increases with the increase the power density [7,52] and thus results in a degradation of device performance [38,39]. The self heating results in activating the different degradation mechanisms including the mechanical, electrical, and material [7]. Thus, controlling the device temperature is one of the key issues in achieving the device stability and reliability in AlGaN/GaN HEMTs [7,53]. The self heating effect in the AlGaN/GaN HEMTs, also causes the channel temperature to increase and directly effects the transport properties [54,55,56].

One of the challenging issues of the AlGaN/GaN HEMTs is the normally ON behavior of the device [21,57,58]. Some of the proposed solutions for this issue including using different structures for the device gate [59,60]. Other solutions include the usage a thin barrier layer of AlGaN [61] and *p*-type GaN [21,62]. Furthermore, these devices have an additional challenging issue of a limited gate voltage [21]. The gate voltage is limited to 6 volts. This is due to the device gate contact resistive behavior. Other issues of the AlGaN/GaN based HEMT is that the gate contacts required a minimum current to keep the transistor ON [21,63]. The AlGaN/GaN HEMTs have some other serious issues that degrades their performance. These includes the gate leakage current [64] and the drain current collapsing [65,66,67,68]. The gate leakage current reduces the power efficiency, the breakdown voltage, and increases the noise [69]. Moreover, the gate leakage current of the device increases with the increasing of the device temperature. This is due to the surface traps [70,71].

3. Fabrication of AlGaN/GaN HEMTs

The AlGaN/GaN HEMTs devices can be fabricated on different types of substrates. These substrates include the silicon (Si), silicon carbide (SiC), and sapphire (Al_2O_3). Among these substrates, the SiC substrates are the most sufficient substrates for the production of high quality AlGaN/GaN HEMTs devices [72,73]. On the other hand, the contact of the AlGaN/GaN HEMTs devices can be fabricated in two types, ohmic and Schottky. The ohmic contacts can be fabricated to the AlGaN/GaN HEMTs devices source and drain using many methods. These methods include the induced trap assisted tunneling [74], the microwave and rapid thermal annealing [75,76,77,78]. Moreover, the Schottky contacts in the AlGaN/GaN HEMTs are the vital process. The disadvantage of the Schottky contacts in the AlGaN/GaN HEMTs is the large reverse leakage current, which makes the device difficult to work efficiently. The reduction of the reverse gate leakage current of the AlGaN/GaN HEMTs is essential for the device high performance [79,80,81].

4. AlGaN/GaN Based HEMT Devices

The optimization of the performance for the AlGaN/GaN HEMTs has been reported by Sun et al. [82]. In that study, the reduction of the AlGaN/GaN HEMTs gate leakage current was achieved [82]. The study showed the effect of the gate structure and etching process on the device leakage current [82]. The device in that study delivered a drain current of 533 mA/mm at gate length of 0.5µm [82]. The gate leakage current of 20 nA/mm was measured at a drain voltage of 200 V [82]. Furthermore, the study's result showed that the forward voltage of device could be improved by reducing the edge's dimensions [82]. Moreover, the study showed that the forward voltage would be also improved by scaling down the gate length (L_G) [82]. Figure 1 shows the proposed structure of the AlGaN/GaN HEMTs [82]. Figure 2 shows the I-V measurements on the AlGaN/GaN HEMTs with different L_G varies from 0.5 µm to 2.0 µm [82].

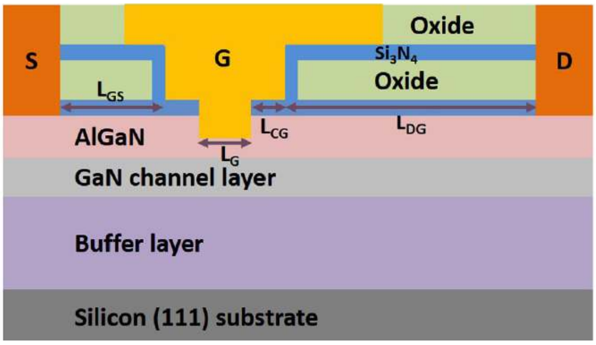

Figure 1. Schematic cross section of AlGaN/GaN HEMTs [82]

The characterization of AlGaN/GaN HEMTs using GRT was reported by Pavlidis et al. [83]. In that work, the performance of the AlGaN/GaN on SiC was investigated using two thermal methods [83]. These methods are the gate resistance thermometry (GRT) and the Raman thermometry (RT) [83]. In that study, the GRT was used to determine the channel temperature of the AlGaN/GaN [83]. While, the RT was used to verify the GRT by comparing the channel temperatures measured by both techniques under various biasing conditions [83]. The study's result showed that the GRT method showed a lower peak temperature comparing with the RT method [83]. In that study, it was also found that the GRT and the RT results were comparable for the open channel and normal bias conditions at low power densities [83]. It was also found that the RT measures a higher temperature comparing with the GRT at higher power densities [83]. This is could be due to the large peak temperature in the center of the device [83]. Figure 3 shows the device structure of four terminal sensing to measure the gate resistance over a single finger for six finger devices used in that study [83]. Figure 4 shows the power densities versus RT and GRT [83].

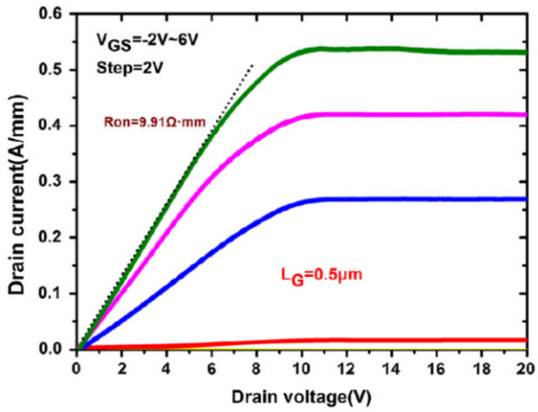

Figure 2. I-V measurements of AlGaN/GaN HEMTs with different L_G [82]

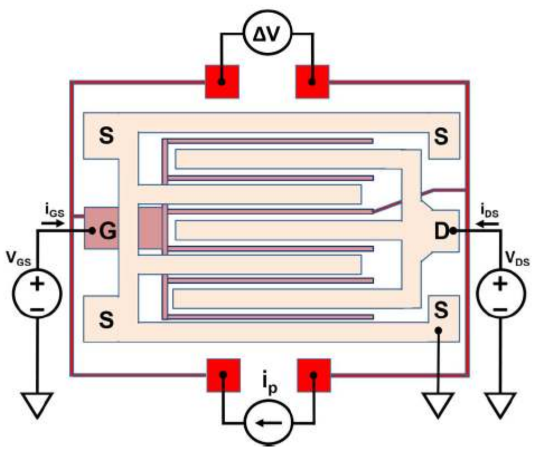

Figure 3. Device layout and configuration of four-terminal sensing to measure the gate resistance over a single finger for six finger devices [83]

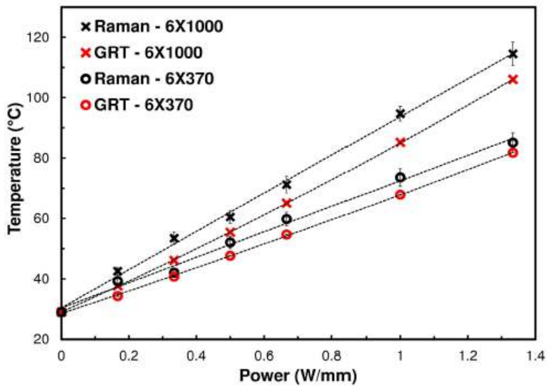

Figure 4. Raman and GRT measured temperatures at power densities up to 3.5 W/mm [83]

The thermal stability and the failure mechanism of Schottky gate based AlGaN/GaN HEMTs was reported by Mocanu et al. [29]. In that study, the electrothermal stability behavior of the depletion mode stability and the predominant defect mechanism of the Schottky gate AlGaN/GaN HEMTs was investigated [29]. In that study, the temperature measurements were conducted at different operating points [29]. The aim was to determine the thermal limits of the safe operating area [29]. The temperature measurements confirmed the observed failure patterns [29]. The study's results showed that the failure mechanism was caused by the additional power dissipation [29]. This was resulting from the drain gate current leakage of the Schottky gate [29]. The study's result helps to understand the electrothermal behavior of the AlGaN/GaN HEMTs [29]. It is they also can be bases for safe operating area thermal limits and thus to avoid device failures [29]. Figure 5 shows a cross section (a) and top view (b) of the AlGaN/GaN HEMTs device [29]. Figure 6 shows the I-V characteristics for the device in temperatures ranging from 27 up to 440℃ [29].

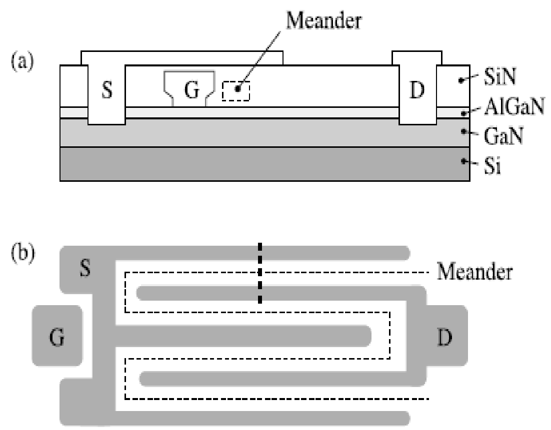

Figure 5. Cross section of AlGaN/GaN HEMTs device (a) and top view of the investigated device (b) [29]

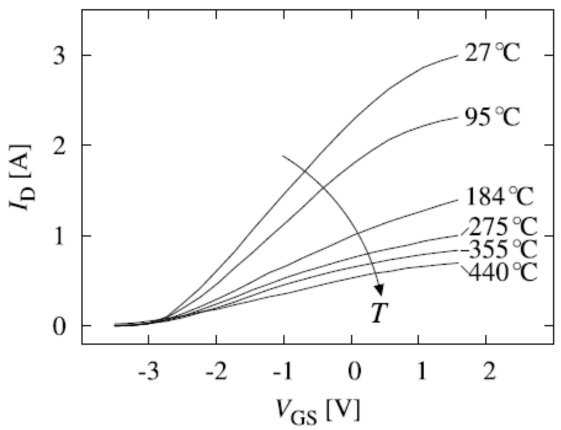

Figure 6. I-V characteristics for the device in temperatures ranging from 27 to 440℃ [29]

The effect of the hydrogen on the defects of the AlGaN/GaN HEMTs characterized by low frequency noise was reported by Chen et al. [84]. The low frequency noise method was used to investigate the effect of the hydrogen on defects [84]. The study's result showed that the drain current (I_D) of the AlGaN/GaN HEMTs increased after the hydrogen treatment [84]. The maximum I_D was measured to be 80 mA at the gate to source voltage (V_{gs}) of 0 V and drain to source voltage (V_{ds}) of 5 V [84]. The hydrogen treatment resulted in improving the suppression of the current collapsing [84]. It was also found that the trap density decreased by about one order of magnitude after the hydrogen treatment [84]. The study's result also showed that the trap's reduction was due to the hydrogen defects at the AlGaN layer [84]. It was also due to the AlGaN barrier layer and the heterostructure interface [84]. In that study, the electrical properties of the AlGaN/GaN device were tested before and after the treatment with the hydrogen [84]. The study's results showed that the I-V properties were affected by the hydrogen treatment [84]. The drain current of AlGaN/GaN HEMTs increased to 917 mA [84]. The results also showed that the trap density decreased to 5.1×1016 $cm^{-13}eV^{-1}$ for the AlGaN/GaN HEMTs after the treatment [84]. This behavior was due to the reduction of electron trap levels at different interfaces [84]. Figure 7 shows the I-V characteristics of the AlGaN/GaN HEMTs before and after hydrogen treatment [84]. Figure 8 shows the pulsed I-V characteristics of AlGaN/GaN HEMTs with V_{gs} ranging from -3.0 to 0 V at 0.5 V step before hydrogen treatment (a) and after hydrogen treatment (b) [84].

The fabrication the AlGaN/GaN HEMTs on patterned resistive/conductive SiC templates was reported by Prystawko et al. [85]. In that study, a high performance AlGaN/GaN HEMTs was fabricated on resistive substrates of SiC [85]. The SiC layer was used to grow a thick resistive SiC epitaxial layer on conductive SiC substrate [85]. In that study, a patterned SiC templates were fabricated on smooth AlGaN/GaN HEMTs with width of flat regions 100 µm [85]. The study's results showed that the fabricated AlGaN/GaN HEMTs had a good electrical performance [85]. Figure 9 shows the optical image of the AlGaN/GaN HEMTs structure [85]. Figure 10 shows the I-V characteristics of AlGaN/GaN HEMTs [85].

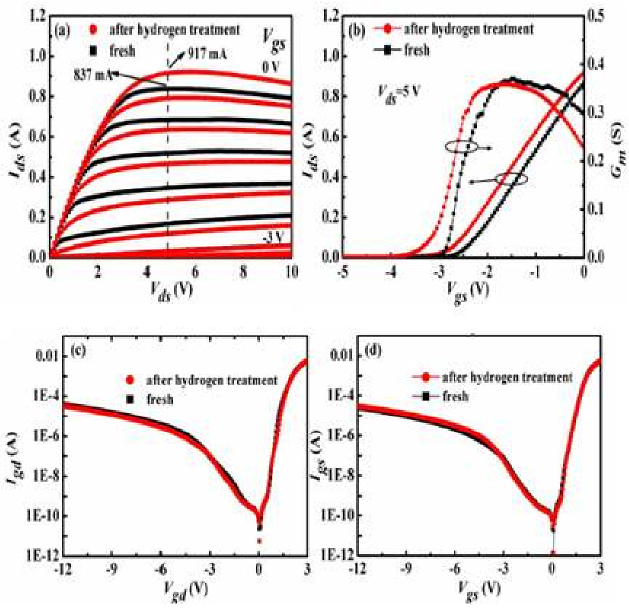

Figure 7. I-V characteristics of AlGaN/GaN HEMTs before/after hydrogen treatment (a) Output characteristics with V_{gs} ranging from -3.0 to 0 V at 0.5 Vstep (b) Transfer characteristics and transconductance at V_{ds} = 5 V (c) V_{gd} characteristics (d) V_{gs} characteristics [84]

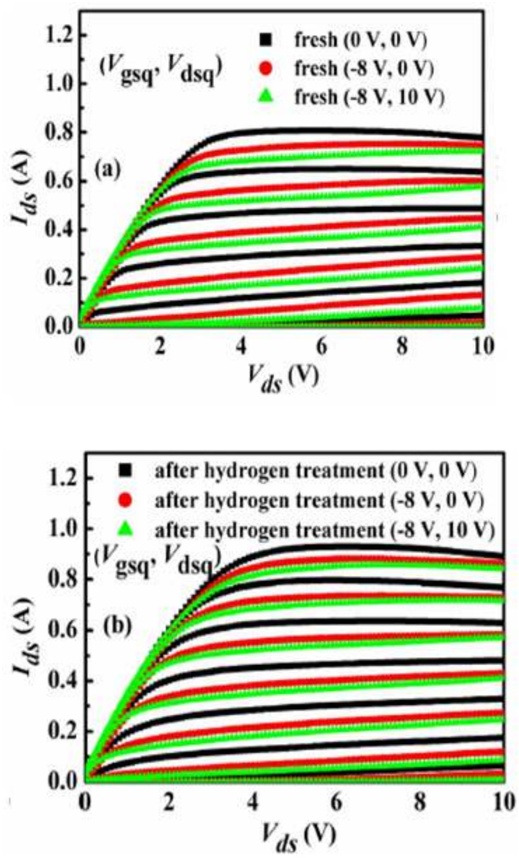

Figure 8. Pulsed I-V characteristics of AlGaN/GaN HEMTs with V_{gs} ranging from -3.0 to 0 V at 0.5 V step before hydrogen treatment (a) and after hydrogen treatment (b) [84]

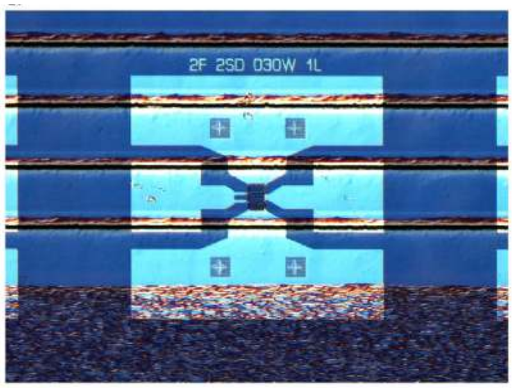

Figure 9. Optical image of AlGaN/GaN HEMT structure [85]

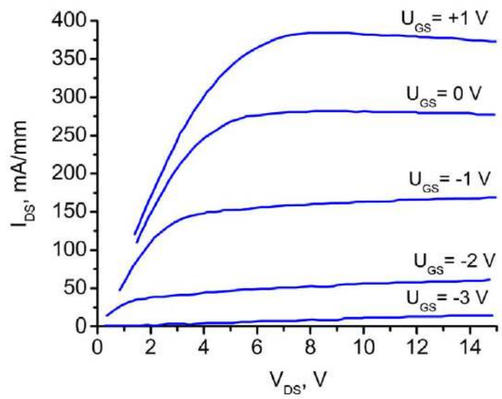

Figure 10. I-V characteristics of AlGaN/GaN HEMTs [85]

The effects of the polycrystalline AlN on the performance of the AlGaN/GaN HEMTs was reported by Zhang et al. [86]. In that study, the AlGaN/GaN HEMTs was fabricated by the plasma enhanced chemical vapor deposition (PECVD) [86]. This fabrication method causes some surface damage at the resulted device [86]. In that study, the AlN films grown by plasma enhanced atom layer deposition (PEALD) [86]. The resulted device had a peak transconductance of 38.6% and a saturation I_D of 26.3% with 50 V [86]. The resulted AlN film polycrystalline in the device was annealed at 850 °C [86]. The annealing process resulted in reducing the trap charging effect [86]. Figure 11 shows the device structure of the AlGaN/GaN HEMTs [86]. Figure 12 shows the double directional C-V characteristics (a) and the extracted carrier concentration distribution at different depths (b) [86].

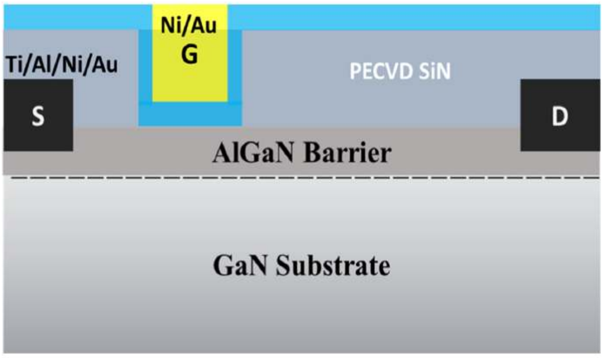

Figure 11. Device structure of AlGaN/GaN HEMTs [86]

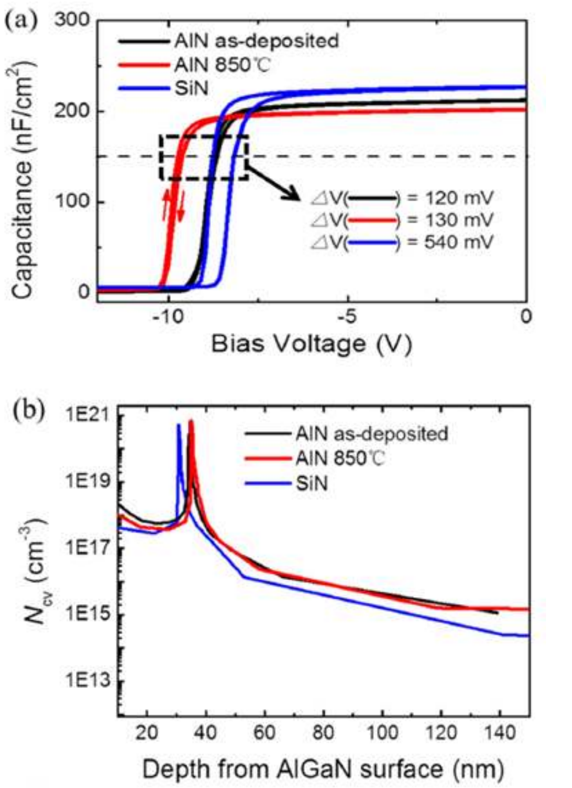

Figure 12. Double directional C-V characteristics (a) extracted carrier concentration distribution at different depths (b) [86]

The high temperature carrier density and mobility enhancements in the AlGaN/GaN HEMTs using AlN layer was reported Ko et al. [87]. In that study, the effect of the AlN layer on the optical and electrical properties of AlGaN/GaN HEMTs was investigated [87]. The AlGaN layer in HEMTs structure layer was grown using grown by metal organic chemical vapor deposition method (MOCVD) [87]. Several measuring methods were used to examine the properties of the resulted structure including the x-ray diffraction (XRD) and the photoluminescence (PL), the electrolyte electro reflectance (EER) [87]. The study's result showed an improvement of the electric field from 430 to 621 kV/cm with the use of the AlN layer [87]. Also, the results also showed that the temperature resulted in decreasing the device's mobility and the carrier concentrations for the AlGaN/GaN HEMTs [87]. This was due to the phonon scattering and carrier thermal escaping [87]. Figure 13 shows the AlGaN/GaN HEMTs device's structure with and without the AlN [87]. Figure 14 shows the room temperature (RT) PL spectra of the AlGaN/GaN HEMTs device structure with and without the AlN [87].

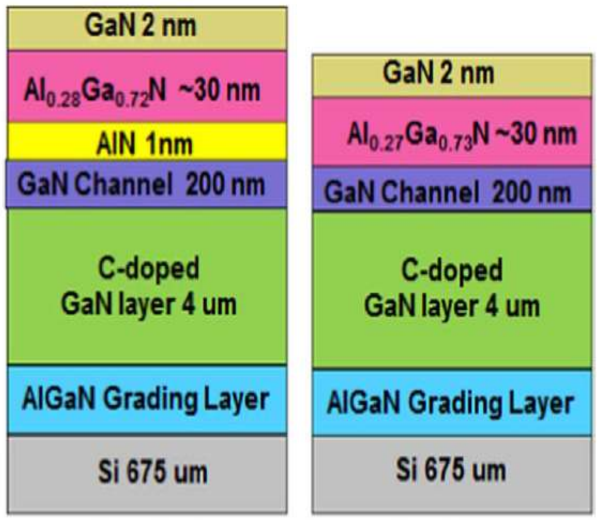

Figure 13. Device structure of AlGaN/GaN HEMTs with/without AlN [87]

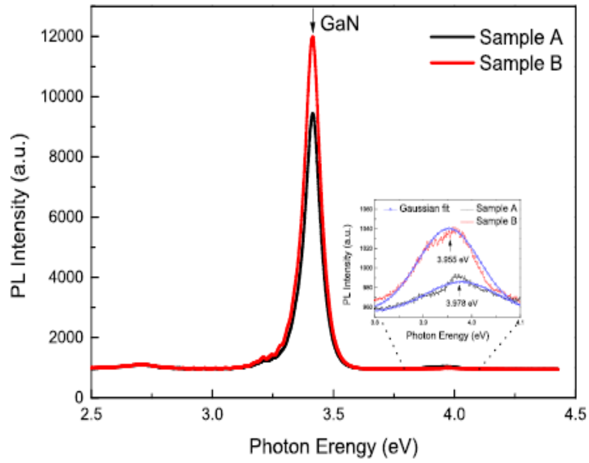

Figure 14. PL spectra of AlGaN/GaN HEMTs structure with/without AlN [87]

The improved reliability of AlGaN/GaN-on-Si HEMTs with high density SiN passivation was reported by Sasangka et al. [88]. In that study, the effect of the physical degradation in the AlGaN/GaN HEMTs was investigated. The study's result provided an evidence that pre-existing oxygen was detrimental to device reliability [88]. It decreased the device lifetime. One solution to that problem is the optimization of the device fabrication processes [88]. It was also found that the SiN degrades under the high temperature reverse bias [88]. That resulted in causing the oxygen from the ambient diffuses through the passivation to electrochemically oxidize the AlGaN surface to form pits at the gate edge [88]. Figure 15 shows the device structure of the AlGaN/GaN-on-Si HEMTs [88]. Figure 16 shows the I-V characteristics for AlGaN/GaN-on-Si HEMTs [88].

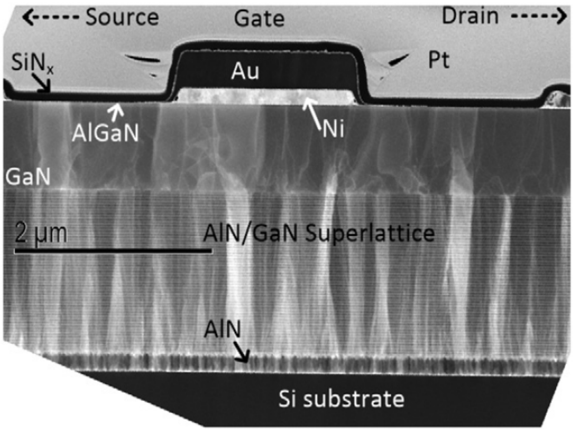

Figure 15. Device structure of AlGaN/GaN-on-Si HEMTs [88]

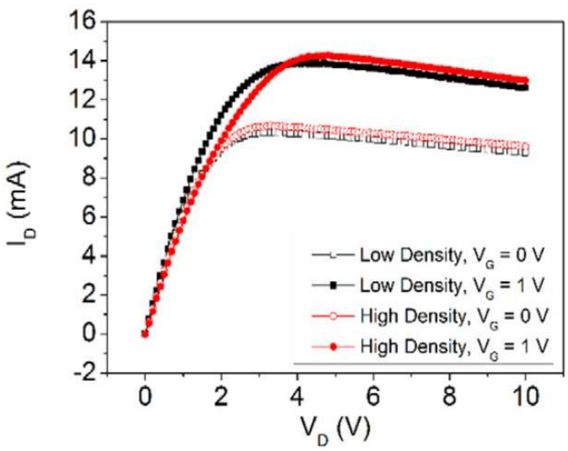

Figure 16. I-V characteristics for AlGaN/GaN-on-Si HEMTs [88]

The performance enhancement of the gate annealed AlGaN/GaN HEMTs have been reported by Mahajan et al. [89]. In that work, the effect of the unannealed and post gate annealed electrical performances of the AlGaN/GaN HEMTs was investigated [89]. In that work, the effects of the gate annealing on the DC parameters of the AlGaN/GaN HEMTs were investigated [89]. It was found that the post gate annealing significantly improved the performance of the AlGaN/GaN HEMT device parameters [89]. The study's result showed that the improvement in the device parameters was correlated with the electron mobility and the removal of interface in the gated region after gate annealing [89]. The study's result showed that a significant improvement in the electrical characteristics of the devices was observed for an optimal annealing of 300℃ [89]. It was also found that the annealing also resulted in a decreasing in the Schottky reverse leakage current and an improving the off-state device breakdown voltage [89]. Figure 17 shows the I-V characteristics for AlGaN/GaN HEMTs before and after gate annealing [89]. Figure 18 shows the C-V characteristics for AlGaN/GaN HEMTs before and after gate annealing [89].

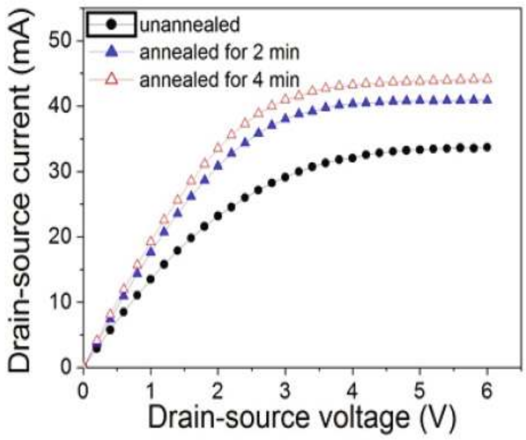

Figure 17. I-V characteristics for AlGaN/GaN HEMTs before/after gate annealing [89]

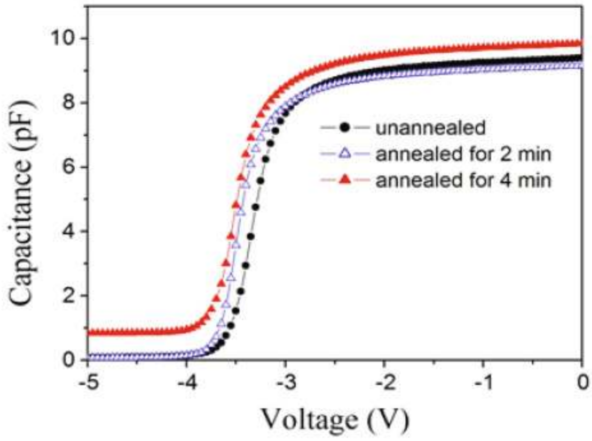

Figure 18. C-V characteristics for AlGaN/GaN HEMTs before/after gate annealing [89]

The optimization of the ohmic contacts on the thin/thick AlGaN/GaN HEMTs devices was reported by Dhakad et al. [90]. In that study, the effect of different thickness of ohmic contacts on the device performance was investigated [90]. In that study, three different materials were used for the ohmic contacts [90]. These materials include the Ti/Al/Cr/Au, Ti/Al/Pt/Au and Ti/Al/Ni/Au metal [90]. The study's result showed that the Ni based metal had the best morphology [90]. The Ni showed the highest specific contact resistance [90]. The study showed that low contact resistance values of 0.8 × 10^5 Ω-cm^2 were achieved [90]. It was also found that the contact resistance increased dramatically for thin AlGaN/GaN HEMTs [90]. Figure 19 shows the ohmic contact (Ti/Al/x/Au) surface morphology images where x metal layer is replaced by Cr, Pt, and Ni metals fabricated over thick AlGaN (25 nm) structures [90]. Figure 20 shows a comparison of specific contact resistance for different ratio of Ni-based ohmic contacts (1:5:4:3, 1:5:2:3 and 1:7.5:2:2.5) over thin and thick AlGaN [90].

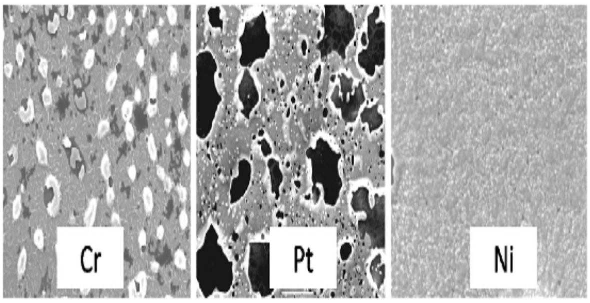

Figure 19. Surface morphology images of ohmic contact (Ti/Al/ Cr /Au), (Ti/Al/ Pt /Au), (Ti/Al/ Ni /Au) [90]

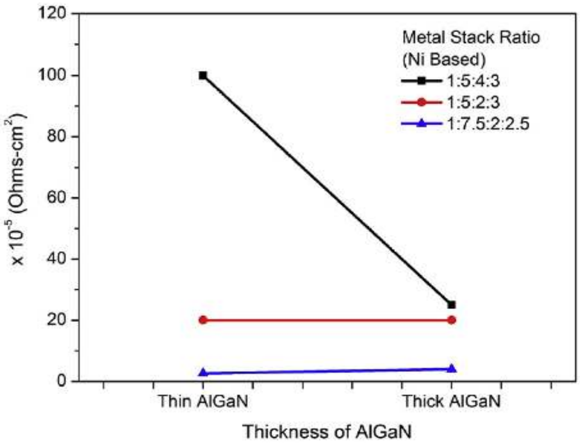

Figure 20. Specific contact resistance for different ratio of Ni-based ohmic contacts (1:5:4:3, 1:5:2:3, 1:7.5:2:2.5) over thin/thick AlGaN [90]

The performance improvement and scalability of the AlGaN/GaN HEMTs have been investigated by Takhar et al. [91]. In that study, two types processes were used including the wet-recessed and the wet-oxidized [91]. In that study, a thin layer of Al_2O_3 was grown in the AlGaN/GaN heterostructure [91]. That study showed that the wet etching resulting in a damage free recession of the gate region and compensating for the decreased gate capacitance and increased the gate leakage [91]. The study also showed that the performance improvement of the AlGaN/GaN HEMTs was manifested as an increase in the saturation drain current, transconductance, and unity current gain frequency [91]. This is due to the decrease in the subthreshold current [91]. The study showed that the performance improvement was primarily due to the increase in the effective velocity which make the wet-recessed gate oxide AlGaN/GaN HEMTs much more scalable [91]. Figure 21 shows a schematic of the AlGaN/GaN HEMTs with and without Al_2O_3 below the Schottky gate [91]. Figure 22 shows the C-V characteristics for the AlGaN/GaN HEMTs [91].

The role of interface traps on the negative threshold voltage (V_T) shift in the AlGaN/GaN HEMTs have been studied by Malik et al. [92]. In that study, the negative shift in the V_T in AlGaN/GaN HEMTs with application of reverse gate bias stress was investigated [92]. In that study, the measurements were applied to the device after biasing in strong pinch-off and a low drain to source voltage condition for a fixed time duration [92]. The results showed that the negative V_T shift after application of reverse gate bias stress [92]. The results indicated that the presence of more carriers in channel as compared to the unstressed condition [92]. The study's results also showed that the presence of the AlGaN/GaN interface states was the reason of negative V_T shift [92]. Figure 23 shows the I-V characteristics of the AlGaN/GaN HEMTs device measured before and after the reverse gate [92]. Figure 24 shows the buffer leakage current measured at V_{GS} =-7V [92]. Figure 25 shows the I-V of device with long (5 ms), medium (3.3 ms) and short (2.5 ms) integration time after application of reverse gate voltage stress [92].

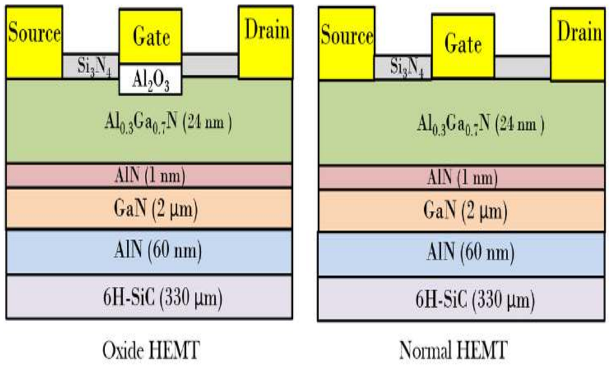

Figure 21. Schematic of AlGaN/GaN HEMTs with/without Al_2O_3 below Schottky gate [91]

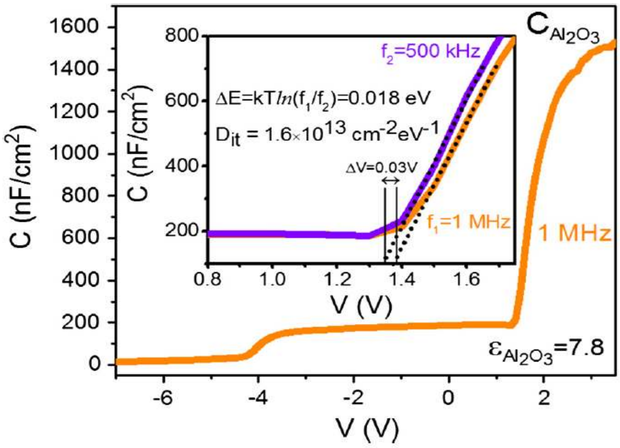

Figure 22. C-V characteristics for AlGaN/GaN HEMTs [91]

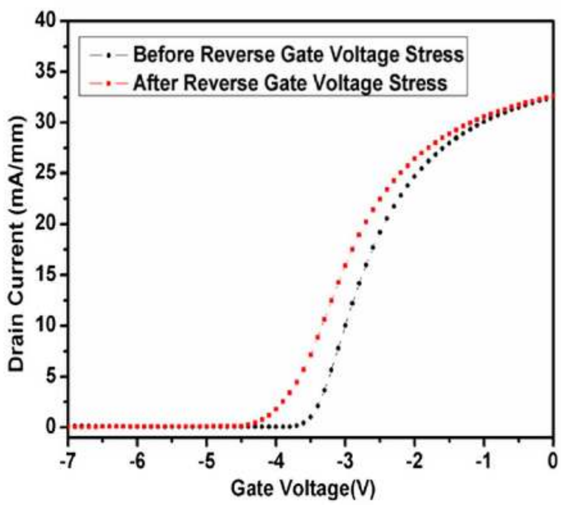

Figure 23. I-V characteristics of device measured before/after reverse gate bias state stress at V_{GS} =-7 V and V_{DS} =100 mV for a time duration of 15 s [92]

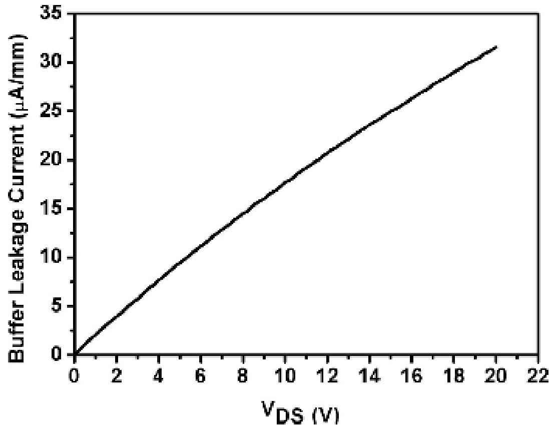

Figure 24. Buffer leakage current measured at V_{GS} =-7V (off-state condition) [92]

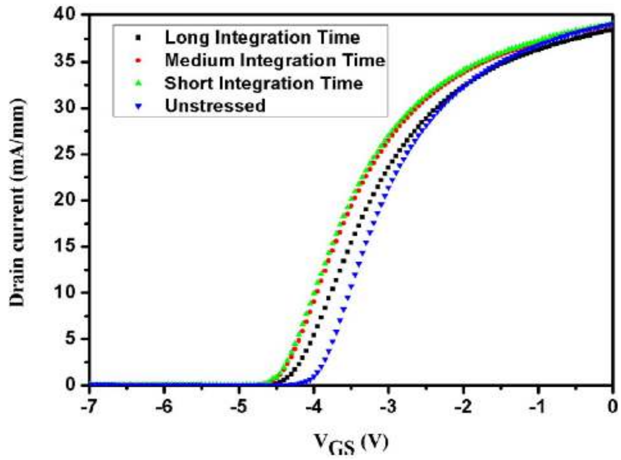

Figure 25. I-V characteristics of device with long (5 ms), medium (3.3 ms) and short (2.5 ms) integration time after application of reverse gate voltage stress [92]

The electrical degradation of the AlGaN/GaN HEMTs induced by residual stress of SiN was reported by Bai et al. [93]. In that study, the traps characteristics of the AlGaN/GaN interface was reported [93]. In that study, several types of measurements were used. These measurements include the DC measurement, frequency dependent C-V measurements [93]. The study's results showed that the stress may induced a decrease in the I_D, and increased on-resistance [93]. It was also found that the SiN/GaN interface traps with energy 0.42 eV to 0.45 eV was obtained after passivation [93]. The results showed that the formation of the acceptor-like traps under the gate on AlGaN barrier side was the reason for the degradation [93]. Figure 26 shows a schematic of AlGaN/GaN HEMTs [93]. Figure 27 shows the C-V characteristics of un-passivated and passivated AlGaN/GaN HEMTs [93].

The ultra-high voltage electron microscopy investigation of the irradiation induced displacement defects on the AlGaN/GaN HEMTs was reported by Sasaki et al. [94]. In that study, the irradiation effect on the AlGaN/GaN HEMTs was investigated [94]. Several techniques were used to examine the irradiation effect including the ultra-high voltage electron microscopy (HVEM) and the optical measurements [94]. The study's results showed that the dislocation loop on created on a 1.5 µm device irradiated by 18 MeV (Nickel) Ni ions [94]. The results also showed that none line-type tracking defect was created by the heavy ion irradiation [94]. The results showed that the device characteristics remained stable, and no increasing in the leakage current [94]. Figure 28 shows the AlGaN/GaN HEMTs before irradiation (a) and after irradiation 18 MeV Ni ions at 2.8 × 10^{13} ion/cm^2(b) [94]. Figure 29 shows the reverse (a) and forward (b) Schottky contact I-V characteristics before and after the 18 MeV Ni ions irradiation [94].

The surface stoichiometry modification and the improved DC/RF characteristics of the AlGaN/GaN HEMTs were reported by Upadhyay et al. [95]. That study showed that the plasma treatment with nitrogen (N_2) and oxygen (O_2) followed with thermal annealing improved the surface morphology of the AlGaN/GaN HEMTs [95]. The study also shows an improvement in the transistor characteristics including the source/drain access and gate regions after treatment [95]. The treatment with N_2 helped in the reduction of the N-vacancy [95]. On the other hand, the formation of oxides leads to the reduction of the gate leakage current [95]. The study's results showed that an increasing of the device transconductance, the saturation drain current, the ON/OFF current ratio were observed [95]. The results also showed an increasing the current gain frequency by a factor of 1.7 for a channel length of 500 nm [95]. Figure 30 shows the schematic of the AlGaN/GaN HEMTs [95]. Figure 31 shows I-V of the AlGaN/GaN HEMTs [95].

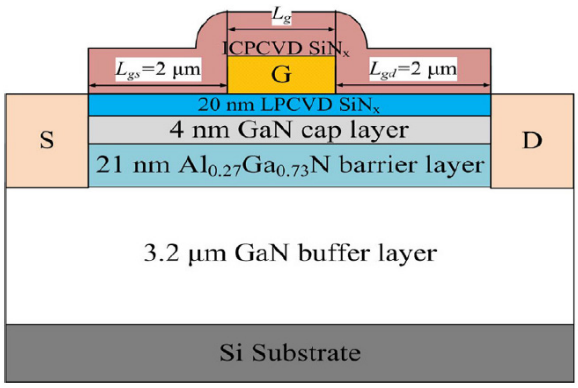

Figure 26. Schematic of AlGaN/GaN HEMTs [93]

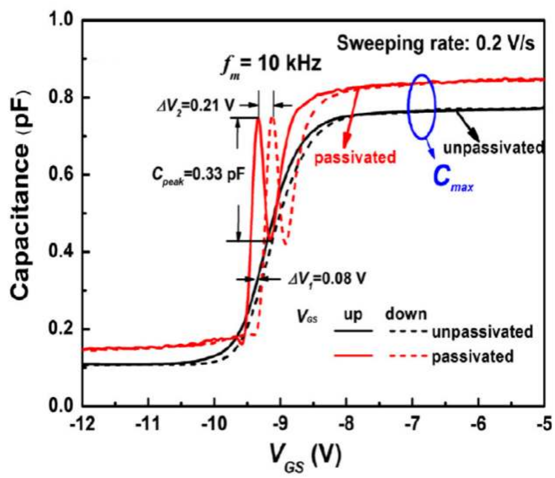

Figure 27. C-V characteristics of un-passivated/passivated AlGaN/GaN HEMTs with L_g = 2 µm at f_m = 10 kHz [93]

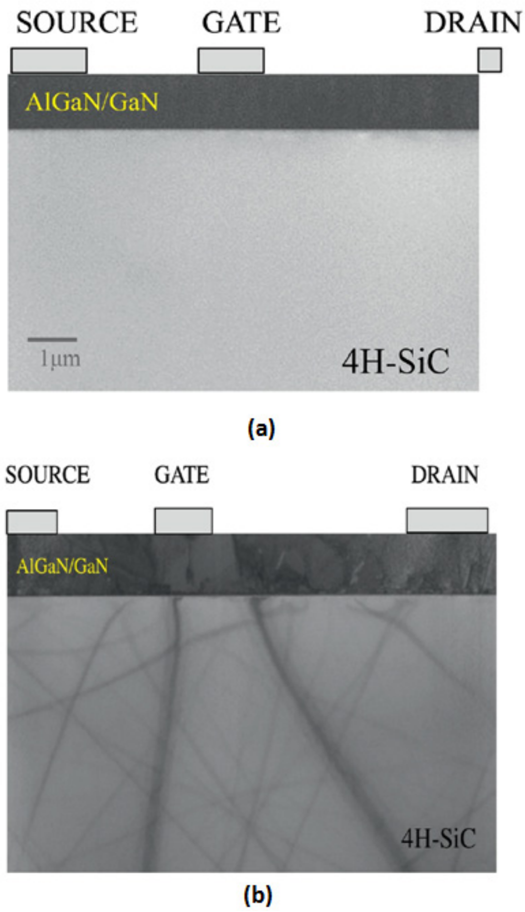

Figure 28. AlGaN/GaN HEMTs before irradiation (a) and after irradiation 18 MeV Ni ions at 2.8×10^{13} ion/cm^2 (b) [94]

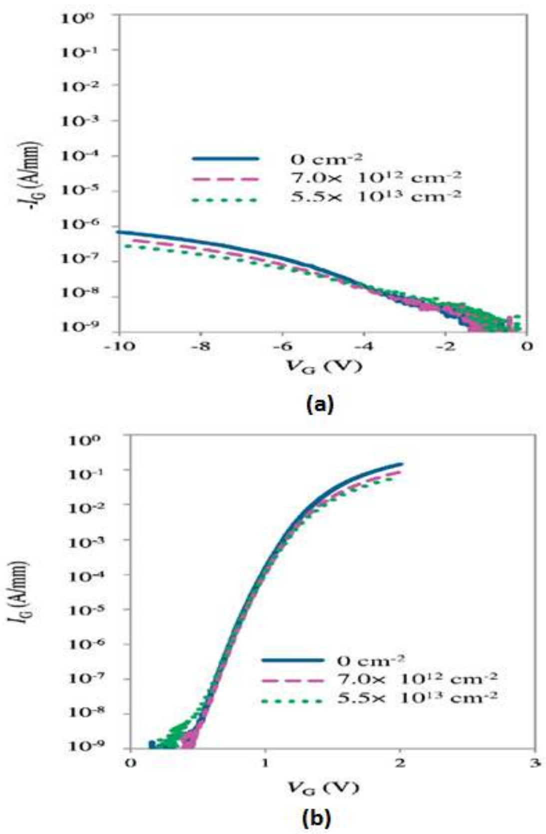

Figure 29. I-V characteristics of Schottky contact for AlGaN/GaN HEMTs (a) reverse (b) forward before and after the 18 MeV Ni ions irradiation [94]

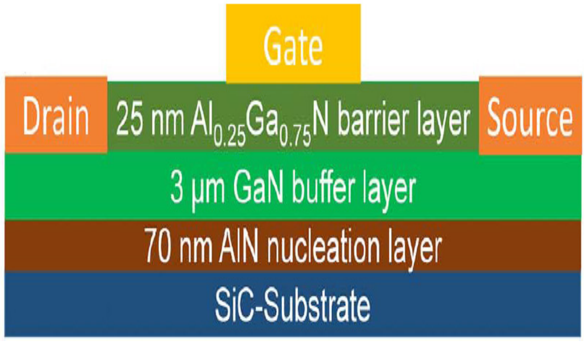

Figure 30. Schematic of AlGaN/GaN HEMTs [95]

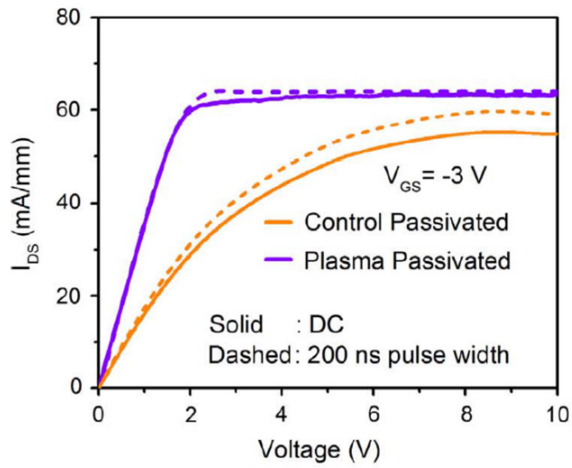

Figure 31. I-V characteristics of AlGaN/GaN HEMTs [95]

5. Conclusions

In this paper, a review of the recent advances of the AlGaN/GaN HEMTs based devices have been presented. Several structures of the AlGaN/GaN HEMTs were explained and discussed. The effect of different parameters on the performance of the AlGaN/GaN HEMTs was discussed. In this paper, some of the most important technological issues related to the fabrication of AlGaN/GaN HEMTs have been reviewed. Despite of the progress in the development of the AlGaN/GaN HEMTs based devices, these devices still have several critical problems. These problems include the existence of the defects and traps in the device's structure. It also includes self heating effect. All these problems effect and reduce the device reliability and reproducibility.

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