A Survey of Technology Issues in High performance GaN/AlGaN HEMT Devices

Jayachandran M
Assistant Professor

Abstract - $TiSi_2$ and TiC electrode can be Ohmic contact without depending on dislocation in AlGaN/GaN high-electron-mobility transistors (HEMTs) and decrease in thickness of AlGaN was confirmed with higher annealing temperature. Therefore, reduction of AlGaN thickness is an important role of decreasing contact resistance. $TiSi_2$ and TiC can be Ohmic electrode materials, which should realize dislocation independent conduction and also forming nitrogen vacancy at the surface of AlGaN. Moreover, thickness of AlGaN has decreased without degrading 2DEG density and lower contact resistance r_c can be obtained due to thinner AlGaN barrier. As Compared with conventional contact electrodes, annealing temperature is high, but these electrodes are useful Ohmic-contact-material for future dislocation-free wafers. Surface morphology has improved in some extent by using non-gold electrode and Surface defect causes the leakage current and the current collapse, which are estimated by I-V measurement and XPS.

Keywords - TiSi2, TiC, HEMT, 2DEG, Contact resistance (ρ_c).

1. INTRODUCTION

Power device is used to power conversion which is shown to convert voltage, current, frequency, coherent, number of phase and wave shape. Currently Silicon has been a dominant material to make power semiconductor devices (i.e IGBT, MOSFET…) [1] [2]. The conversion efficiency is about 94%. The performance of Silicon power devices will come to the limit of the material property in the reducing electric power loss, the break down voltage and things before long. However, a better power efficiency and higher breakdown voltage are required in commercial fields [6]. Therefore, new materials (GaN, SiC…) that have better material properties attract increasing attention. Table 1 is a table that compares the material properties (Silicon) with two new competing materials (GaN, 4H-SiC) [5].

So, high electron mobility and saturated velocity cause high frequency switching, and high breakdown field and thermal conductivity cause high power and high temperature operation [6]. Compared to silicon carbide, a great advantage of gallium nitride is, that GaN has relatively large discontinuity in bandgap with materials such as AlGaN, so it can be used to form good heterojunction structure. Compared to MOSFET, heterojunction field effect transistors (HFETs) develop a channel by a junction between two materials with different band gaps [11].

Table 1: Physical Properties of Semiconductor Materials

	Si	GaAs	4H-SiC	GaN
Band Gap [eV]	1.1	1.4	3.3	3.4
Breakdown Voltage [MV/cm]	0.3	0.4	3.0	3.3
Saturated Electron Velocity [10^7cm/s]	1.0	2.0	2.0	2.5
Electron Mobility [cm^2/Vs]	1500	8500	1000	1200
Hole Mobility [cm^2/Vs]	600	400	115	~10
Coefficient of Thermal Conductivity [W/cmK]	1.5	0.5	4.9	2.1

Electrical resistivity can be written as $\rho = 1/qn\mu$, where q is the charge on the particle; is the majority carrier density; μ is the mobility of the carrier. From equation, we know that the resistivity can be reduced by increasing the carrier density. But for increasing the carrier density will lead to decrease in mobility, to have low resistivity only by increasing the carrier density is difficult. To obtain both high carrier density and high mobility is important, but it is hard to realize in traditional MOSFET structure. In HEFT structure, as the material use in spacer is undoped, so the influence by impurity scattering is less. As a result, both high carrier density and high mobility can be realized in this structure [8] [9].

2. SYSTEM MODEL

AlGaN/GaN HEMT is the ability to achieve two-dimensional electron gases (2DEG) with sheet carrier concentration of $10^{13}cm^{-2}$ or higher close to the interface without intentionally doping [12]. It has been shown previously that piezoelectric effects can exert a substantial influence on charge density and Semiconductors grown in the (111) orientation [10]. There is the problem that AlGaN is stressed substrate direction which involve different thickness both center and edge. Although, buffer layer can be glowed gradient technique, 8-inch epitaxial wafer is made on Si (111) substrate. Being lager diameter substrate can be mass production once [10]. In conclusion it leads to reduction in cost. The electrical characters of HFETs with two dimensional electron gas (2DEG) have been reported in several articles. It is reported that high density 2DEG can be obtained by using positive polarization charges at the AlGaN/GaN interface [11] [12] [13]. Therefore, the 2DEG mobility is as high as 1000cm^2/Vs, so it is treated as important candidate for next generation power device [12]. Similar with 2DEG, two dimensional hole gas (2DHG) has been predicted in several articles, but reports in which 2DHG is observed are few. According to the prediction, 2DHG should have properties as high mobility and high density. Fig-1 illustrates a p-channel HFETs using GaN/AlGaN/GaN heterostructure [11]. As shown in this figure, 2DHG exists at the upper GaN/AlGaN interface, and 2DEG exists at the lower AlGaN/GaN interface. As only 2DEG is used in traditional HFET due to the high resistivity of 2DHG, CMOS circuit cannot be realized in HFET. In order to produce circuits CMOS contained, it is necessary to develop low resistance 2DHG. For illustration, Electric power conversion machine is considered can be modified to a one-chip circuit using the GaN-Based CMOS. High breakdown voltage is fatal to this kind of power device and GaN can satisfy it [6]. Using positive

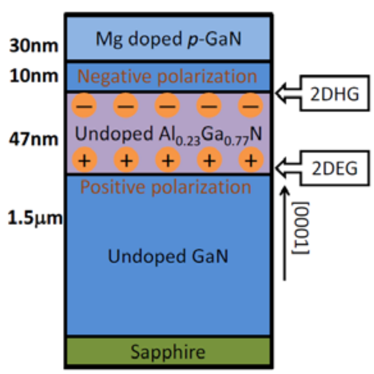

Fig. 1 Structure of sample

polarization charges at the AlGaN/GaN interface leads to high density 2DEG with the densities over10^{13}cm^{-2}can be obtained and a sheet carrier density of AlGaN/GaN interface of about 1.8 $\times 10^{13}$cm^{-2} at room temperature has been confirmed [11] [12] [13].

3. PROBLEMS TO REALIZE HIGH PERFORMANCE AlGaN/GaN HEMTS

AlGaN/GaN HEMTs are attractive as a new power device, but there are some problems to solve in order to realize an outstanding performance. First is a normally-on characterization of the AlGaN/GaN channel layer that cause the power consumption to increase. Second is a lot of crystal defects in AlGaN/GaN substrates that cause breakdown voltage to decrease. The Power consumption, high ohmic contact resistance (R_{con}) cause high electrical power losses and self-heating to increase in regardless of low channel resistance (R_{ch}).

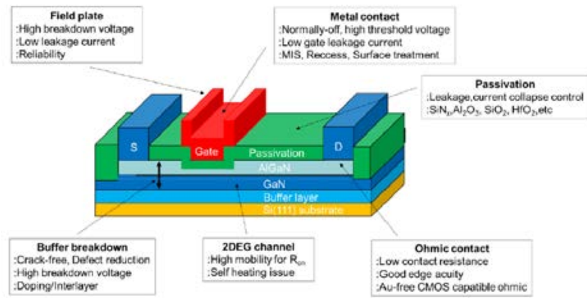

Fig. 2 Technology issues in GaN HFETs [14]

If the specific contact resistance (□cm^2) decrease from 10^{-5}□cm^2 to 10^{-6}□cm2, 40% of the electrical power loss in breakdown voltages under 1000V could be reduced [5]. Next, Leakage current expressed by thermionic emission, thermionic field emission and thin surface barrier model increase at Schottky contact [7] [25]. Finally, a current collapse and low reliability occur with passivation layer. These problem is thought to be occurred by electric trap in AlGaN surface.

4. PREVIOUS WORK

Now generally used as a contact material, Aluminum and Titanium are used as a metal material. Ti has a roll of forming nitrogen vacancies which is essential for ohmic contact and Al has a roll of controlling forming nitrogen vacancies by Ti. However narrow process parameter can only realize low contact resistance. Ti reacts locally with AlGaN layer and changes to TiN, which is called TiN island by high temperature annealing [1]. The formation of interfacial TiN was found to be critical in achieving Schottky-to-Ohmic transition. As annealing, TiN Island which have non- uniformly formed along threading dislocations and had penetrated through the AlGaN into the underlying GaN layer [1]. These conductive TiN islands established intimate contact between metal and 2DEG and allowed direct transport of carriers across the AlGaN. Furthermore keeping on annealing led to degrade contact resistance, which results from abnormal growth of TiN islands. This causes narrow process parameter for Ohmic contacts [12].

Common Ohmic contact process of two examples is described. One the common Ohmic contact process is Au/metal (Mo or Ni)/Al/Ti structure. Annealing condition is a rapid thermal annealing system at optimum conditions of

$850^{o}C$ in N_2 ambient for 30s. Excellent specific contact resistivity is 4.7×10^{-7}□cm^2. High temperature annealing result both intermixing of the metals and metal agglomeration. The minimization of interfacial energy is believed to be the driving force for the Mo baling up. And one type is the discrete TiN islands formed preferentially along threading dislocations. The contact mechanism has two competing pathways for electrons to be transported from the 2DEG to metal contacts, tunneling through AlGaN layer and the direct conduction through TiN protrusions. This contact method has problem that metal agglomeration and increasing threading dislocation which concern large leak current causing. Another the common Ohmic contact process is inserted Si_3N_4 passivation layer in metal/AlGaN [2] [12]. Annealing condition is a rapid thermal annealing at $800^{o}C$ in N_2 ambient for 90s. It seems that AlN as appointing allows. The formation of pseudo-morphic AlN at the interface is key factor for the Ohmic contact behavior. As the contact is Ohmic, even with an intact AlGaN has been created. The mechanism is arising $800^{o}C$ and more, Al react with AlGaN to extract N and form N vacancy rich AlN layer. The deactivation of Ti-AlGaN/GaN reaction has its origin in the introduction of Si_3N_4 passivation layer, which acts as N source to Ti. Excellent specific contact resistivity is about 10^{-5} order □cm^2. AlN layer is sensitive annealing temperature, which need to be stable extraction process of N from AlGaN layer [1] [2].

To form ohmic contact, there are some necessary conditions. First, it is critical for choosing low metal function used as a material of metal electrode on AlGaN/GaN. Electrons in metal can easily flow into GaN layer for selecting low metal function. Second, tunneling current occurred by band bending, which is also necessary for ohmic contact. Wide depletion region cannot flow tunneling current however band bending causes to narrow depletion region and tunneling current applied. Band bending is occurred by heavy doping on interface of semiconductor and applying H_2-plasma cleaning. This report proves that AlGaN and SiO_2 reacts with each other and n+ layer was formed in AlGaN layer, which causes band bending and realize ohmic contact. Finally, narrow AlGaN layer can also realize tunneling current by etching AlGaN layer physically with H_2-plasma etching and CH_4, H_2, Ar plasma. So plasma etching enables to cause tunneling current [10].

At present, most low resistance ohmic contact has been realized by using gold-based stacked metallization (Ti/Al/Ni/Au) by annealed at $800^{o}C$~$950^{o}C$, or non-gold-based stacked metallization (Ti/Al/W, Ta/Al/Ta, Ta/Si/Ti/Al/Ni/Ta). Also, ohmic contact has been available at low temperature ($550^{o}C$~$600^{o}C$) with recess etching that means AlGaN barrier in contact areas down to the location of 2DEG in a GaN substrate [12]. Their stacked metallization have achieved typical contact resistance (R_c) values below 1Ωmm (the R_c value of Ti/Al/Ni/Au is 0.15Ωmm etc.), and their specific contact resistance (ρ_C) is 0.7 to 2×10^{-6}□cm^2. The interface between electrodes (Ti/Al/Mo/Au) and the AlGaN/GaN substrate is considered that TiN and N vacancies in AlGaN are formed depending on the reaction between AlGaN and Ti. Especially, TiN is formed on crystal defects described as white arrows (TiN islands). It is said that there are two conduction paths in the case of ohmic contact. More and more N vacancies are formed, tunneling conduction between metal and semiconductor increases with it. But there is still the issue that if film-forming technology for AlGaN/GaN upgrades in the future, the crystal defects in AlGaN/GaN will be decreased and there is the possibility of increasing contact resistance because of the dependency to crystal defects [18].

In current researches, gold-based Ohmic (Ti/Al/Mo/Au) contact has rough and non-uniform surface morphology (the rms = 60nm~63.2nm). It is said that there is a risk for rough surface morphology and thereby reduced edge acuity because of the low melting point of Al ($660^{o}C$). There is a lot of agglomeration on the electrodes surface. Rough surface morphology causes reliability decreasing in fabrication process. On the other hand, smooth surface morphology and edge definition are important for scaling laws because rough surface morphology can result in misalignment between the gate and the source and drain. Therefore, smooth surface morphology and sharp edge definition are required. In conventional researches, surface morphology has been improved in some extent (rms = 5.54nm) by using non-gold electrodes (Ta/Si/Ti/Al/Ni/Ta). Also Ti/Al/Pt/WSi/Au electrodes has realized good surface morphology by interpolating WSi layer in the conventional ohmic contact (Ti/Al/Pt/Au) [16] [20].

5. PROPOSED METHODOLOGY

In Nitrogen vacancy is essential for ohmic contact of AlGaN and GaN. Ti made TiN and TiGa into crystal dislocation at AlGaN layer and current flows through these alloy and connect 2DEG. On the other hand, $TiSi_2$ forms nitrogen vacancy at AlGaN layer and this reaction didn't make alloy, that is, $TiSi_2$ doesn't depend on crystal dislocation and reaction with area surface. With high annealing temperature and long annealing time, $TiSi_2$ can make much nitrogen vacancies and contact resistance can be reduced. Furthermore, result of XPS objected interface of AlGaN and SiO_2 with annealing at 1000°C for 1min. SiO_2. This result proves that SiO_2 can form nitrogen vacancy at AlGaN layer, so generates band bending which causes tunneling current. However, we cannot get ohmic contact by SiO_2 capped annealing.

$TiSi_2$ electrode is examined for AlGaN/GaN. By XPS Al and Ga atoms in AlGaN layer remain intact with TiSi2 electrodes, which can extract of N to remain uniform interface. In 950°C annealing temperature, Ohmic characteristic was obtained, which is stable resistance for annealing time. $TiSi_2$ is extracted N vacancy model which can decrease contact resistance. High temperature is needed, but stable contact can be obtained. In conclusion, $TiSi_2$ is suggested that stable Ohmic contact, which may be lower specific contact resistivity to be extracted more N vacancy. In conclusion, $TiSi_2$ can be expected to stable contact metal layer after high temperature annealing. Especially, it is feature that extract of N to remain uniform interface.

Ti/C/TiN was used as new material for electrodes on AlGaN/GaN, and some characterizations are found out, which are described as follows. In 950°C~1050°C annealing temperature, ohmic contact to AlGaN/GaN substrate is realized, and the contact resistance is 2.1□mm~3.0□mm. Compared with conventional ohmic contacts, the annealing temperature is high and the contact resistance is tenfold higher than conventional ohmic contacts (~0.2 □mm). It is realized that good surface morphology of electrodes by using Ti/C/TiN. The reason can be assumed that carbide alloy is compounded from nm-size crystals which improve surface morphology. But the reason must be confirmed by XRD analysis or some physical analysis.

Ti/C/TiN electrodes can be expected to improve surface morphology of electrodes, which relate to product reliability, compared with conventional ohmic contacts and the contact resistance was 2.1□mm~3.0□mm. If the ohmic contact resistance is lower than conventional ohmic contacts by some treatment to substrates or different methods, carbide electrodes could have good morphology and low contact resistance without gold and contamination to other substrates including Si substrate.

6. RESULTS AND DISCUSSION

In Compared from the Mg-doped GaN, the AlGaN/GaN structure shows a constant property of carrier density. As the typical properties of Mg-doped GaN at low temperature are not observed in AlGaN/GaN structure, it is likely that conduction mechanism of AlGaN/GaN hetero-interface structure is different from Mg-doped GaN. Concretely speaking, the increasing carrier density while the temperature decreasing at low temperature, and the increasing mobility while the temperature decreasing at low temperature, are the two characteristics not observed in AlGaN/GaN hetero-interface structure.

The difference of leakage current among some kinds of metals in spite of strong pinning is revealed. It indicates that metal/AlGaN surface is important to understand leakage current. Finally, distribution of donor like defect is revealed by HXPES analysis. The tendency of leakage current and donor distribution is related. Current band alignment is derived by HXPES. Comparing the two samples such as EB and TEOS, it is noted that EB sample has a better quality, for a stable characteristic in high frequency, and no hysteresis showed here. Hysteresis in CV characteristics is usually treated as an evidence of the existence of traps, which leads to another evidence of existence of dislocations. At least in our experiments, silicon dioxide made by TEOS, can be treated better for passivation in GaN-related materials.

The distribution of surface defect that cause the serious problems such as the leakage current and the current collapse is estimated by two approaches. One is the I-V measurement, the other is XPS. The common approach to reduce contact resistance to AlGaN/GaN HEMTs is achieved by direct conduction with Ti-Al based metal or tunneling through AlGaN barrier with insertion of Si or Si_3N_4. These approaches depends on local electron conduction from metal to 2DEG. Therefore the contact resistance would be increase for future substrate with less crystal defects and reliability would be lost because of electric field concentration.

The novel material Ti-Si mixed metal and Ti-C mixed metal as new material for Ohmic contact substituting Aluminum. The motivation for selecting these materials has two reasons. The one is that silicide and carbide have thermal stability in high annealing temperature. The other one is that these materials can extract N atoms from AlGaN, which cause band bending of AlGaN and increase tunneling probability. Electrical characteristic and physical analysis of these electrodes were examined with focus on interface reaction between AlGaN and these materials. To reduce the contact resistance to AlGaN/GaN HEMTs and improving surface morphology of electrodes by using carbide electrodes. The motivation for selecting carbide electrodes is that carbide alloy is compounded from nm-size crystals which have the

possibility that improve surface morphology and carbon has high melting point to endure being annealed at high temperature and high chemical resistance, so the alloy compounded with carbon could be treated at annealing in high temperature to produce donor like N vacancies at an interface between metal and AlGaN/GaN substrates.
supposed that Ti forms alloy such as TiGa, however $TiSi_2$ doesn't make alloy and reacts with AlGaN layer over the entire surface. $TiSi_2$ can get ohmic contact for all range from 1min to 60min at 950^oC, however Ti can get ohmic contact only for 5min to 20 min at750^oC. So, $TiSi_2$ is able to have wide process time of ohmic contact. The results indicates that the Ti/C ratio have little or no effect on the AlGaN/GaN sheet resistance, and the total resistance depends on the contact resistance only if the sheet resistance is constant.

Compared with the surface roughness (~60nm) of conventional gold-based ohmic contacts (Ti/Al/Mo/Au), the RMS surface roughness of Ti/C/TiN is one-fifteenth as low as the surface roughness of conventional ohmic contacts. Therefore, the Ti/C/TiN electrodes have a great potential that holds long-term stability in high temperature and increase a reliability of products. Compared with gold-based electrodes, there are very few collection and ball up phenomenon on the surface of Ti/C/TiN electrodes. Also the Ti/Al/TiN electrodes have a good edge acuity but rough surface morphology. The high refractory alloy might be produced by depositing carbon which has high-melting-point as electrodes. The edge acuity could improve the reliability of AlGaN/GaN HEMT and prevent the misalignment.

Current-voltage characteristic was measured. It is aim to confirm leakage current when gate electrodes are different. Four kind of metals such as Ni, W, TiN and Al 50nm thickness electrodes are selected. Annealing temperature different conditions are examined to Current-Voltage measurement. In order to confirm the current-voltage characteristic, Schottky diode is prepared on condition that some kind of gate metal is used. Then, in the case of Schottky gate, leakage currents depend on the kind of metal in spite of strong pinning between metal and AlGaN surface. Presence or absence of annealing has less impact to the leakage current than the kind of metal. It is assumed that the impact metal sputtering on AlGaN surface is important to understand the leakage current.

Binding energy of electron in AlGaN is measured by HXPES. It is aim to analyze and estimate quantity and distribution of donor caused from nitrogen vacancy in AlGaN. Four kind of metals such as Ni, W, TiN and Al 8nm thickness electrodes are selected. In order to confirm the binding energy of electron in AlGaN, metal/AlGaN/GaN sample is prepared on condition that some kind of metal is used. Then, only constant electric field cannot explain measured spectrum whatever the kind of metal is. When surface donor is assumed, actually measured curve and theoretical curve correspond well. Therefore the difference of quantity of surface donor is revealed and its order is same as the order of leakage current. Finally, current band alignment is derived.

Ohmic contact of $TiSi_2$ is propo

It has been suggested that Si and C can be electrode for inducing nitrogen vacancy with annealing at 1075^oC for 1 min. These material can be candidate for Ohmic contact material being substituted for Aluminum. Moreover, interface layer and interface roughness between AlGaN and Si (or C) has been uniform rather than Ti-Al based metal. These results indicates that Si and C are Ohmic material for forming nitrogen vacancy like donors in high thermal treatment without depending on dislocations.

Ohmic contact has been achieved by using $TiSi_2$ electrode. From XPS analysis, the reaction of $TiSi_2$ and AlGaN with high thermal treatment causes VN in AlGaN layer. Donor concentration is enough high for obtaining Ohmic characteristic. Cross-sectional TEM image of $TiSi_2$/AlGaN shows that interface layer is formed uniform rather than conventional Ti-Al based electrode. Therefore, $TiSi_2$ is a candidate for contact material for AlGaN/GaN structures independent of dislocation density of epi-wafers.

Tic electrode can be independent-of-dislocation Ohmic contact in AlGaN layer from the TEM image. Higher Ti ratio for TiC electrode has reduced contact resistance and annealing temperature for obtain Ohmic characteristic. The minimum contact resistance is 0.17 □mm, specific contact resistance is $2.1\times10^{-7}cm^2$ for TiC with 90% Ti ratio in 1025^oC annealing. Therefore especially focused on TiC with 87.5% Ti ratio, cross sectional TEM image of electrode was observed. Then, AlGaN thickness wasn't related with Ohmic characteristic, compared with AlGaN thickness with each annealing temperature. There is no visible changes between 825^oC and 850^oC, so nitrogen vacancy at 850$^oC$is higher than it at 825^oC. This assumption suggested that Ohmic contact can be achieved by using TiC electrode annealed at 850^oC because of enough for nitrogen vacancy with 850^oC annealing.

6. CONCLUSION

In In conclusions, $TiSi_2$/TiN and TiC/TiN electrodes can be Ohmic contact for AlGaN/GaN structures. However, the minimum contact resistance of both $TiSi_2$ and TiC electrode competed with common electrode's minimum contact resistance, annealing temperature is higher. As a TiC electrode, annealing temperature to be Ohmic characteristic is lower with higher Ti ratio, but minimum contact resistance is made at $1025^{o}C$. So there is a problem that annealing temperature is much higher than common electrode, which should be solved. But $TiSi_2$ and TiC electrode can be independent-of-dislocation contact, so $TiSi_2$and TiC electrode can be Ohmic contact electrode for the future substrate with less dislocation.

7. FUTURE SCOPES

AlGaN/GaN high-electron-mobility transistors (HEMTs) are expected for future power devices with high efficiency, owing to its high mobility and large breakdown field [6].

REFERENCES

[1] Lin-Qing Zhang, Jin-Shan Shi, Hong-Fan Huang, Xiao-Yong Liu, Sheng-Xun Zhao, Peng-Fei Wang, and David Wei Zhang, "Low-Temperature Ohmic Contact Formation in GaN High Electron Mobility Transistors Using Microwave Annealing", IEEE Electron Device Letters, Vol. 36, No. 9, pp. 896-898, September 2015.

[2] Xinhua Wang, Sen Huang, Yingkui Zheng, Ke Wei, Xiaojuan Chen, Guoguo Liu, Tingting Yuan, Weijun Luo, Lei Pang, Haojie Jiang, Junfeng Li, Chao Zhao, Haoxiang Zhang, and Xinyu Liu, "Robust SiNx/AlGaN Interface in GaN HEMTs Passivated by Thick LPCVD-Grown SiNx Layer", IEEE Electron Device Letters, Vol. 36, No. 7, pp. 666-668, July 2015.

[3] Wael Jatal, Uwe Baumann, Katja Tonisch, Frank Schwierz, Senior Member, IEEE, and Jorg Pezoldt, "High-Frequency Performance of GaN High-Electron Mobility Transistors on 3C-SiC/Si Substrates With Au-Free Ohmic Contacts", IEEE Electron Device Letters, Vol. 36, No. 2, pp. 123-125, February 2015.

[4] Diego Marti, Student Member, IEEE, Stefano Tirelli, Valeria Teppati, Senior Member, IEEE, Lorenzo Lugani, Jean-François Carlin, Marco Malinverni, Nicolas Grandjean, and C. R. Bolognesi, Fellow, IEEE, "94-GHz Large-Signal Operation of AlInN/GaN High-Electron-Mobility Transistors on Silicon With Regrown Ohmic Contacts", IEEE Electron Device Letters, Vol. 36, No. 1, pp. 17-19, January 2015.

[5] Deok Won Seo, Hong Goo Choi, John Twynam, Ki Min Kim, Jeong Soon Yim, Sung-Woon Moon, Sungdal Jung, Jongsub Lee, and Sungwon D. Roh, "600 V-18 A GaN Power MOS-HEMTs on 150 mm Si Substrates With Au-Free Electrodes", IEEE Trans. Electron Device Letters, Vol. 35, No. 4, pp. 446-448, April 2014.

[6] Takuma Nanjo, Akifumi Imai, Yosuke Suzuki, Yuji Abe, Toshiyuki Oishi, Muneyoshi Suita, Eiji Yagyu, and Yasunori Tokuda, "AlGaN Channel HEMT With Extremely High Breakdown Voltage", IEEE Transactions on Electron Devices, Vol. 60, No. 3, pp. 1046-1053, March 2013.

[7] Marleen Van Hove, SanaeBoulay, Sandeep R. Bahl, Steve Stoffels, Xuanwu Kang, Dirk Wellekens, Karen Greens, AnneliesDelabie, and StefaanDecoutere, "CMOS Process-Compatible High-Power Low-Leakage AlGaN/GaN MISHEMT on Silicon", IEEE Electron device letters, Vol 33, No 5, May 2012.

[8] "Substrates for GaN Gased Devices: Performance Comparisons and Market Assessment" (2006)

[9] Umesh K.Mishra, Primit Parikh and Yi-Weng Wu, "AlGaN/GaN HEMTs-An Overview of Device Operation and Applications", PROCEEDINGS OF THE IEEE, Vol. 90, No 6, June 2002

[10] F.Semond, P. Lorenzini, N. Grandjean, and J. Massies, "High-electron-mobility AlGaN/GaN heterostructures grown on Si(111) by molecular-beam epitaxy", Applied Physics Letters, Vol 78, No 3, January 2001

[11] M. Asif Khan, J.N.Kuznia, D.T Olson, W.J. Schaff, J.W. Burm, and M.S. Shur, "Microwave performance of a 0.25 m gate AlGaN/GaN heterostructure field effect transistor", Applied Physics Letters, Vol. 65, No 9,August 1994

[12] O.Ambacher, J. Smart, J.R. Shealy, N.G. Weimann, K. Chu, M. Murphy, R. Dimitrov, L. Wittmer, M. Stutzmann, W. Rieger and J. Hilsenbeck, "Two-dimensional electron gases induced by spontaneous and piezoelectric polarization charges in N-and Ga-face AlGaN/GaN heterostructures", Journal of Applied Physics, Vol.85, No 6, 15 March 1999

[13] J.P. Ibbetson, P.T. Fini, K.D. Ness, S.P. DenBaars, J.S. Speck, and U.K. Mishra, "Polarization effects, surface states, and the source of electrons in AlGaN/GaN heterostructure field effect transistors", Applied Physics Letters, Vol. 77, No 2, July 2000

[14] Ho-young Cha, "High Efficiency GaN Power Device Technologies", Hongik University, NanoKISS, 2013

[15] W.Saito, Ichiro Omuram Tsuneo Ogura, Hiromichi Ohashi, "Theoretical limit estimation of lateral wide band-gap semiconductor power-switching device", Solid-State Electronics 48 1555-1562, 2004

[16] A.N. Bright, P.J. Thomas, M. Weyland, D.M. Tricker, C.J. Humphreys, R. Davies, "Correlation of contact resistance with microstructure for Au/Ni/Al/Ti/AlGaN/GaN ohmic contacts using transmission electron microscopy", Journal of Applied Physics, Vol 89, No 6, March 2001

[17] Yang Li, Geok lng Ng, Subramaniam Arulkumaran, Chandra Mohan Manoj Kumar, Kian Siong Ang, Mulagumoottil Jesudas Anand, Hong Wang, Rene Hofstetter, and Gang Ye, "Low-Contact-Resistance Non-Gold Ta/Si/Ti/Al/Ni/Ta Ohmic Contacts on Undoped AlGaN/GaN High-Electron-Mobility Transistors Grown on Silicon", Applied Physics Express, Vol 6, 116501, October 2013

[18] A. Malmros, H. Blanck, and N. Rorsman, "Electrical properties, microstructure, and thermal stability of Ta-based ohmic contacts annealed at low temperature for GaN HEMTs", Semiconductor Science and Technology, Vol 26, 075006, March 2011

[19] A. Firrincieli, B. De Jaeger, S. You, D. Wellekens, M. Van Hove and S. Decoutere, "Au-Free Low Temperature Ohmic Contacts for AlGaN/GaN Power Devices on 200mm Si Substrates", Extended Abstracts of the 2013 International Conference on SSDM, p914-915, 2013

[20] Liang Wang, Fitih M. Mohammed, and Ilesanmi Adesida, "Differences in the reaction kinectics and contact formation mechanisms of annealed Ti/Al/Mo/Au Ohmic contacts on n-GaN and AlGaN/GaN epilayers", Journal of Applied Physics, Vol 101, 013702, 2006

[21] B.Van Daele and G.Van Tendeloo, "Mechanism for Ohmic contact formation on Si3N4 passivated AlGaN/GaN high-electro-mobility transistors", Applied Physics Letters 89, 201908, 2006.

[22] Zhu Yanxu, Cao Weiwei, Fan Yuyu, Deng and Xu Chen, "Effects of rapid thermal annealing on ohmic contact of AlGaN/GaN HEMTs", Journal of Semiconducors, Vol 35, No.2, 2014

[23] Dieter K. Schroder, "SEMICONDUCTOR MATERIAL AND DEVICE CHARACTERIZATION", IEEE PRESS,2006

[24] Yuan Taur and Tak H. Ning, "Fundamentals of Modern VLSI Devices", Cambridge University press, 1994

[25] Junji Kotani, Tamotsu Hashizume, and Hideki Hasegawa, "Analysis of Excess Leakage Currents in Nitride-Based Schottky Diodes Based on Thin Surface Barrier Model", Techical Report of IEICE, ED 2004-42

[26] Hideki Hasegawa and Susumu Oyama, "Mechanism of anomalous current transport in n-type GaN schottky contacts", J.Vac.Sci. Technol. B 20(4), 2002

AUTHOR'S PROFILE

Jayachandran M has received his Bachelor of Engineering degree in Electronics & Communication Engineering from Anna University, Chennai in the year 2006 and Master of Engineering degree in Power Electronics and Drives from Anna University, Chennai in the year 2009. At present he is working as an Assistant Professor in E.S Engineering College, Villupuram. His area of interest is Nano Electronic Devices and its Applications.