Features of GAN Semiconductor & Performance Comparison of Various Gallium Nitride PN Junction Diodes

Mrs.C.Rekha[1] S.Thangamalar[2]
[1]Assistant Professor [2]PG Student
[1,2]Department of Electronics & Communication Engineering
[1,2]PET Engineering College, Vallioor

Abstract— Nowadays Gallium Nitride material mostly used in the wide band gap semiconductor devices for high frequency applications. The Gallium Nitride is a new material for the field of emerging electronics, whose performance is to be analyzed. In these papers, vertical GaN p-n diodes fabricated on bulk GaN substrates. Then the breakdown voltage increased in the GaN diode by decreasing the drift layer donor density as well as by increasing the drift layer thickness. The measured characteristics are temperature dependency of V-I characteristics, breakdown voltage and extracted modeling parameters such as electron mobility and minority carrier lifetimes.

Key words: GAN Semiconductor, Gallium Nitride PN Junction Diodes, GAN diode

I. INTRODUCTION

Due to the technology advancement semiconductor devices have shown vast improvement in the performance, efficiency and reduction size, weight. Since the fundamental semiconductor material likes silicon, germanium are approaching the material limits, it is the right time to switch over to a new semiconductor device which would satisfied all the basic requirements. The new material here we explained is GaN, this material properties as suitable for high power applications and high frequencies.

The high lighting features of GaN parameter is figure of merit which is better than silicon and germanium. The desirable properties are like high band gab energy, low intrinsic carrier concentration, high melting point made the GaN to be suitable for high temperature applications.

parameters	Ge	Si	GaN
Crystal structure	Diamond	Diamond	Wurtzite
Band gap energy(eV)	0.66	1.1	3.4
Lattice constant(Å)	5.646	5.431	5.185
Electron effective mass(m_e)	1.64	0.98	0.2
Heavy hole effective mass(m_e)	0.28	0.49	0.8
Bulk modules(dyncm^{-2})	7.5x 10^{11}	9.8x 10^{11}	20.4x 10^{11}
Melting point(°c)	937	1412	>2500
Specific heat ($Jg^{-2}°c^{-2}$)	0.31	0.7	0.49
Thermal conductivity(W $cm^{-2}°c^{-2}$)	0.58	1.5	1.3
Thermal diffusivity (cm^2s^{-2})	0.36	0.8	0.43
Electron mobility (cm^2/Vs)	3900	1500	2000
Hole mobility (cm^2/Vs)	1900	450	350
Electron diffusion constant (cm^2/s)	101	39	25
Hole diffusion constant (cm^2/s)	49	12	9
Intrinsic carrier concentration (cm^{-3})	6x10^{13}	1x10^{10}	1x10^{10}

Table 1: Comparison of Si, Ge and GaN

Since crystal structure wurtzite, GaN material is durable and can be used for wide band gap of 3.4eV. The electron and hole diffusion constant is lower than Si and Ge. The effective mass is a quantity that is used to simplify band structures by modeling the behavior of a free particle with that mass. The GaN has low electron effective mass and heavy hole effective mass. The inherent transporter fixation is bring down in higher band hole materials. On the other hand expanding the temperature makes it more probable that an electron will be energized in to the conduction band which will build the charge bearers. The warm conductivity of the GaN is not as much as the Si and more noteworthy than the Ge. The materials with low thermal conductivity prevent heat transmission in and out of the house, optimize the capacity of the materials and operating cost, and reduce energy consumption. The thermal conductivity increases with the cross section area. This is because with the increase of size, more phonons are excited, which results in the increase of thermal conductivity. The GaN materials are very strong. They have high melting points, high heat and electrical conductivity. It has melting point range more than 2500°c. Thecarrier mobility in a semiconductor is one of the most important parameters for the operation of electronic devices. Actually, the mobility measures the ability of free carriers (electrons or holes) to move in the material. The electron and hole mobility of GaN is low compared to silicon and germanium.

II. DEVICE DESIGN

The GaN semiconductor based PN junction diode is grown by low pressure metal organic chemical vapor deposition (MOCVD) on 2-inch bulk GaN substrates with low defect densities (< 3x$10^{16}$$cm^{-3}$). A schematic cross sectional diagram of a GaN based PN junction diode is shown in Fig. 1. In this diode have three regions, which is PN junction region, lightly doped drift region and edge termination / isolation region. An isolation structure is used to spread the potential applied to the anode over a distance which is greater than the drift region thickness. In the wafer process, the anode is formed by e-beam deposition and patterning of P_d/P_t based metallization scheme to contact the P-type GaN. P-type layers are doped with Mg, at a concentration 2x$10^{19}$$cm^{-3}$, and a higher doped layer at the surface for reduced contact resistance. P-type material has been characterized by Hall measurements that indicate a room temperature hole concentration of 4x10^{17}cm^{-3} and a hole mobility of 12cm^2/V.The desired breakdown voltage isdetermined by the n-type drift-layer doping and the thickness. Typical doping densities are 1–3x10^{16}cm^{-3}, whereas drift layer thicknesses of 6–40μm are targeted. The bulk GaN substrate was thinned to 180μm by backside grinding and polishing. Subsequently, a cathode electrode was formed.

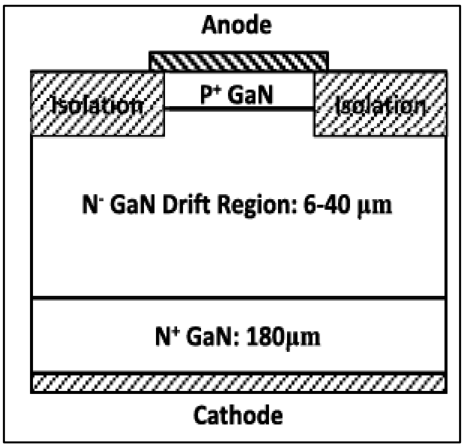


Fig. 1: Schematic cross-section of GaN based PN junction diode on bulk GaN substrate.

III. COMPARISION OF VARIOUS GAN DIODE

A. 0.7KV GaN diode

TheGaN diode fabricated with bulk GaNsubstrates and the substrate thickness is 180μm. The desired breakdown voltage is determined by the drift layer doping density and the region thickness. So the drift region thickness is 6μm and the doping density is 2x$10^{16}cm^{-3}$. As a result the breakdown voltage is 0.7KV. Then the magnesium doped p-type GaN layer on top of the n-type GaN region and the thickness of the region is 0.5μm. The doping density of the p-type region is 1x$10^{19}cm^{-3}$.

B. 2.6KV GaN diode

The n-type drift region grown on top of the bulk GaN substrates. This GaN diodehas the concentration of 20μm region thicknessand 3x$10^{16}cm^{-3}$drift layer doping density which makes the break down voltage occurs at 2.6KV. The magnesium doped p-typeGaN layer is placed over the n-typedrift region and the thickness of the area is 0.5μm.

C. 3.7KV GaN diode

The previous GaN diode design clearly said that the breakdown voltage is increased by decreasing the drift layer donor density as well as by increasing the drift layer thickness. Therefore the while designing diode the drift region thickness is increased 35μm and the doping density is reduced 5x$10^{15}cm^{-3}$. Then the Mg doped p-type GaN layer on top of the n-type drift region and the thickness of the region is 0.5μm. The doping density of the p-type region is 1x$10^{19}cm^{-3}$.

Characteristics	0.7KV GaN diode	2.6KV GaN diode	3.7KV GaN diode
Drift region doping densities(cm^{-3})	2x10^{16}	3x10^{16}	5x10^{15}
Drift layer thickness (μm)	6	20	35
Breakdown voltage (KV)	0.7	2.6	3.7
Current(A)	400	10	0.5
pulse width(ms)	0.1	0.3	3
Temperature (k)	300	300	300
Defect density (cm^{-2})	>10^6	10^6	10^4
Active areas (mm^2	16	0.72	0.055
Hole concentration (cm^{-3})	<2x10^{20}	5x10^{17}	4x10^{17}

Table 2: Characteristics of various GaN diodes

In these table three types of GaN diodes are compared. The 700V GaN diode has2x$10^{16}cm^{-3}$drift region doping density and 6μm drift layer thickness.As a result the breakdown voltage is 0.7KV and the current is 400A (0.1ms pulse width). Then the 2.6KV GaN diode has 3x$10^{16}cm^{-3}$drift region doping density and 20μm drift layer thickness. As a result the breakdown voltage is 2.6KV and the current is 10A (0.3ms pulse width). And the 3.7KV GaN diode has 5x$10^{15}cm^{-3}$ drift region doping density and 35μm drift layer thickness. As a result the breakdown voltage is 3.7KV and the current is 0.5A (3ms pulse width).These comparisons clearly say the breakdown voltage increased in the GaN diode by decreasing the drift layer donor density as well as by increasing the drift layer thickness.

IV. RESULT & DISCUSSION

The gallium nitrate has higher electron mobility, which leads to faster switching capabilities. It has higher temperature operating capabilities because the larger energy gap. The band gap energy of the GaN is 3.4eV.As doping is added the level of conduction band reduced and level of valance band increased such that electron can easily move from valance band to conduction band.As the doping is added the carrier mobility of the hole is increased and the mobility of the electron is reduced.

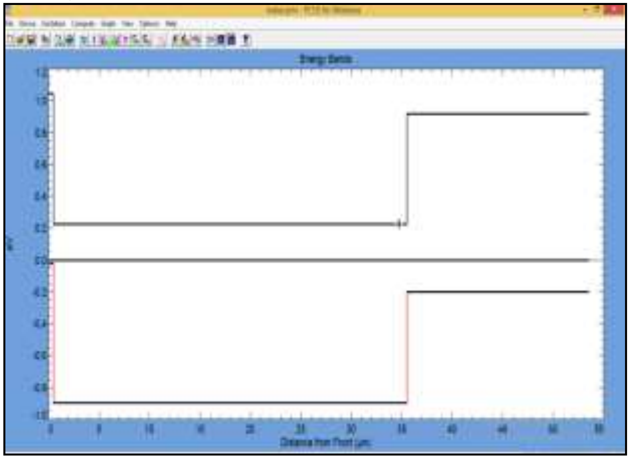


Fig. 2: Energy band of the GaN diode

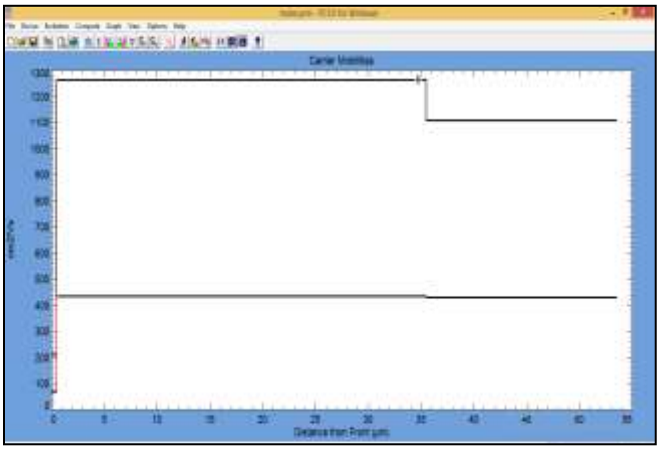


Fig. 3: Carrier mobility of the GaN diode

In this table the forward I-V characteristics of a 0.7KV GaN diode is shown in fig. (a), the active area of the diode is $16mm^2$ and its capable of handling pulsed current is 400A. The forward I-V characteristics of a 2.6KV GaN diode is shown in fig. (b),the active area of the diode is less than $1mm^2$and its capable of handling pulsed current is 10A.Then the forward I-V characteristics of a 3.7KV GaN diode is shown in fig. (c),the active area of the diode is $0.055mm^2$ and its capable of handling current is 0.5A.

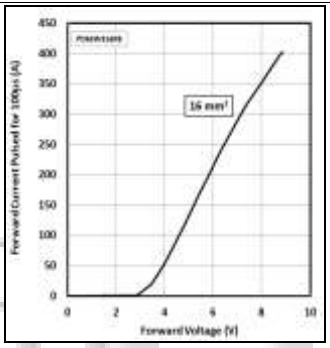
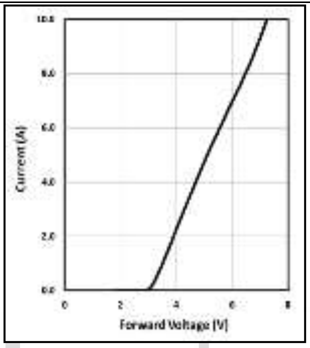
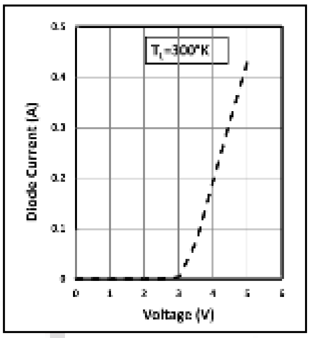
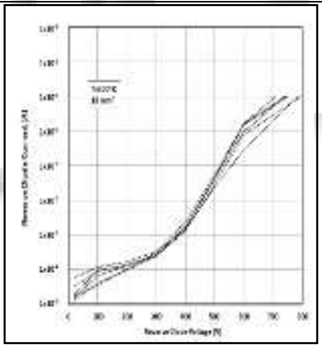
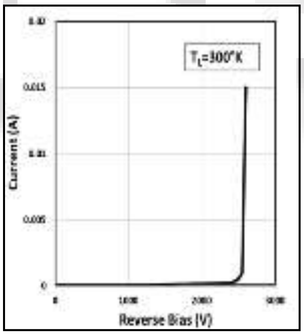
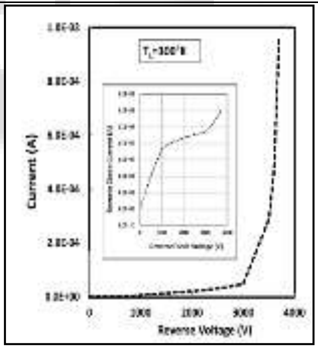
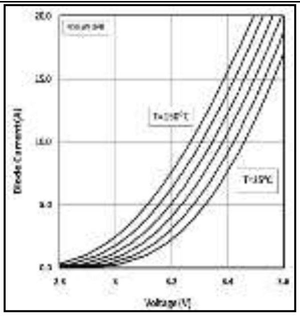
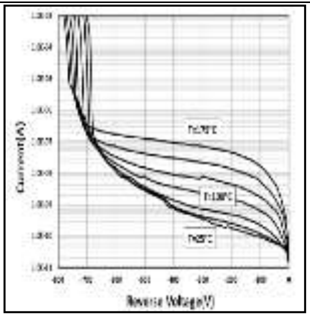
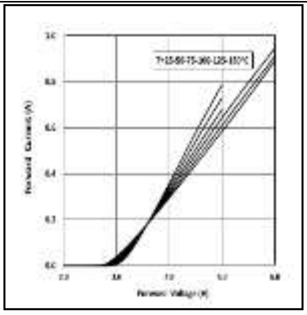
Characteristics	0.7KV GaN diode	2.6KV GaN diode	3.7KV GaN diode
Forward I-V characteristics	 (a)	 (b)	 (c)
Reverse I-V characteristics	 (d)	 (e)	 (f)
Temperature dependent I-V characteristics	 (g)	 (h)	 (i)

Table 3: Comparison of I-V characteristics of variousGaN diode

In this table the reverse I-V characteristics of a 0.7KV GaN diode is shown in fig. (d),the reverse leakage current at 500V is less than 10μA. This diode reach the reverse current is 1mA.The reverse I-V characteristics of a 2.6KV GaN diode is shown in fig. (e), the break down voltage of the p-n diode reaches 2600V at 300K. This diode reach the reverse current is 15mA.The reverse I-V characteristics of a 3.7KV GaN diode is shown in fig. (f), the reverse bias current depends on the area, temperature and type of semiconductor material. This diode reach the reverse current is 1mA.

In this tablethe temperature dependent of I-V characteristics of a 0.7KV GaN diode is shown in fig. (g), this diode the temperature varied from 25 °C to 150 °C and VF<4.5V. As a result decrease the electron mobility in the n-type drift region with temperature.The temperature dependent of I-V characteristics of a 2.6KV GaN diode is shown in fig. (h), the temperature is improved 25 °C to 150 °C. As a result the breakdown voltage should increase with the temperature (breakdown voltages between the 600V to 2500V).The temperature dependent of I-V characteristics of a 3.7KV GaN diode is shown in fig. (i), the temperature is improved 25 °C to 150 °C. As a result the current through the PN junction diode increases with temperature.

V. CONCLUSION

The GaN material is a new material which can be recently used in the electronics market. In this paper, comparison of various GaN diodes by decreasing the drift layer doping density and drift region thickness. As a result the performance of the GaN diode was analyzed and the breakdown voltage was increased. Future work will focus on applying advanced materials.

REFERENCES

[1] N. Mohan, Power Electronic: A First Course. New York, NY, USA: Wiley, 2012.
[2] J. Palmour, J. Zhang, M. K. Das, et al., “SiC power devices for smart grid systems,” in Proc. IEEE Int. Conf. Power Electron., Jun. 2010, pp. 1006–1013.
[3] J. W. Johnson, A. Zhang, W. Luo, et al., “Breakdown voltage and reverse recovery characteristics of free-standing GaNSchottky rectifiers,” IEEE Trans. Electron Devices, vol. 49, no. 1, pp. 32–36, Jan. 2002.
[4] Y. Uemoto, D. Shibata, M. Yanagihara, et al., “8300 V blocking voltage AlGaN/GaN power HFET with thick poly-AlN passivation,” in Proc.IEEE IEDM, Dec. 2007, pp. 861–864.
[5] Y. Dora, A. Chakraborty, L. McCarthy, et al., “High breakdown voltage achieved on AlGaN/GaN HEMTs with integrated slant field plates,” IEEE Electron Device Lett., vol. 27, no. 9, pp. 713–715, Sep. 2006.
[6] Y. Hatakeyama, K. Nomoto, N. Kaneda, et al., “Over 3.0 GW/cm2 figure-of-merit GaN p-n junction diodes on free-standing GaN substrates,” IEEE Electron Device Lett., vol. 32, no. 12, pp. 1674–1676, Dec. 2011.
[7] Y. Saitoh, K. Sumiyoshi, M. Okada, et al., “Extremely low on-resistance and high breakdown voltage observed in vertical GaNSchottky barrier diodes with high-mobility drift layers on low-dislocation-density gansubstrates,” Appl. Phys. Exp., vol. 3, pp. 081001-1–081001-3, Jul. 2010.
[8] B. Lu and T. Palacios, “High breakdown (>1500V) AlGaN/GaN HEMTs by substrate transfer technology,” IEEE Electron Device Lett., vol. 31, no. 9, pp. 951–953, Sep. 2010.
[9] C. Mion, J. Muth, E. Preble, et al., “Accurate dependence of gallium nitride thermal conductivity on dislocation density,” Appl. Phys. Lett., vol. 89, pp. 092123-1-092123-3, Sep. 2006.
[10] J. Laroche, F. Ren, K. Baik, et al., “Design of edge termination for GaN power Schottky diodes,” J. Electrochem. Mater, vol. 34, no. 4, pp. 370–374, 2005.
[11] A. Bolotnikov, P. Muzykov, Q. Zhang, et al., “Junction termination extension implementing drive-in diffusion of boron for high-voltage SiC devices,” IEEE Trans. Electron Devices, vol. 57, no. 8, pp. 1930–1935, Aug. 2010.
[12] A. M. Ozbek and B. J. Baliga, “Planar nearly ideal edge-termination technique for GaN devices,” IEEE Electron Device Lett., vol. 32, no. 3, pp. 300–302, Mar. 2011.
[13] H. Nie, A. Edwards, D. Bour, et al., “Vertical power devices in bulk GaN for 600–1700V applications,” in Proc. GOMAC Tech, 2013, pp. 265–268.
[14] I. C. Kizilyalli, A. Edwards, H. Nie, et al., “High voltage vertical GaN p-n diodes with avalanche capability,” IEEE Trans. Electron Devices, vol. 60, no. 10, pp. 3067–3070, Oct. 2013.
[15] D. Disney, H. Nie, A. Edwards, et al., “Vertical power diodes in bulk GaN,” in Proc. ISPSD, 2013, pp. 59–62.
[16] K. Shenai, R. Scott, and B. Baliga, “Optimum semiconductors for high-power electronics,” IEEE Trans. Electron Devices, vol. 36, no. 9, pp. 1811–1823, Sep. 1989.