Influence of SiC Substrate Misorientation on AlGaN/GaN HEMTs Performance

K. Matsushita, H. Sakurai, S. Teramoto, J. Shim, H. Kawasaki, K. Takagi, Y. Takada[1)] and K. Tsuda[1)]

Microwave Solid-state Department Toshiba Corp. 1) Advanced Electron Devices Laboratory,
Research and Development Center, Toshiba Corp. 1, Komukai Toshiba-cho, Saiwai-ku,
Kawasaki, 212-8581, Japan Phone +81-44-549-5282, Fax +81-44-548-5955, e-mail:
keiichi.matsushita@toshiba.co.jp

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Abstract

AlGaN/GaN HEMTs devices are fabricated on 3-inch SiC misoriented substrates. The misorientation angle, as measured from the wafer surface normal to the axis perpendicular to the (0001) c-plane, is varied from 0.06° to 0.47°. The surface morphology and wafer crystalline quality were investigated by using AFM and PL. Analysis of the data reveals the relationships between the SiC substrate misorientation and both the physical characteristics of the grown epi layer and the performance of the fabricated device.

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INTRODUCTION

AlGaN/GaN HEMTs devices are studied intensively for applications such as high power microwave devices [1, 2] for satellite communication systems and fixed wireless access systems. Because of its good thermal conductivity and its lattice constant close to that of GaN, SiC can be used as AlGaN /GaN epitaxial substrates. Additionally, these characteristics enables device to operate at higher power density. There are some reports about influences on epitaxial layer quality on off-angle SiC or Sapphire wafer caused by off-angle [3-6]. In this work, we investigated the characteristics of HEMTs devices on misoriented SiC substrates and it is found that the device performances strongly depend on amount of misoriented angle.

EXPERIMENT

The $Al_{0.25}Ga_{0.75}N$/GaN epitaxial layers were grown on vicinal 3-inch SiC substrates by MOCVD. The off-angles of substrates used are varied from 0.06° to 0.47° from the axis along with (0001) c-plane. HEMTs devices are fabricated on these wafers. Before the device fabrication, epitaxial wafers are determined by atomic force microscopy (AFM) and photoluminescence (PL). PL measurements were carried out with 325nm He-Cd laser.

Figure 1 shows a cross sectional view of fabricated HEMTs. The fabrication process began with mesa isolation by ICP-RIE etching. Next, Ti/Al were evaporated by E-beam thermal evaporator and annealed with RTA at N_2 ambient to form the source and drain electrodes. A Schottky gate electrode was formed with E-beam evaporated Pt/Au. SiN film was deposited by PE-CVD for surface passivation. The backside of the device was thinned to 150μm by mechanical polishing.

The DC tests run under constant drain bias, gate bias and channel temperature. The test condition was as follows. The drain voltage is 30V. The channel temperature was, 250°C. Channel temperature ware estimated by the thermal resistance which was measured by infrared images. The saturated drain current (Idss) was measured by interrupting the DC test.

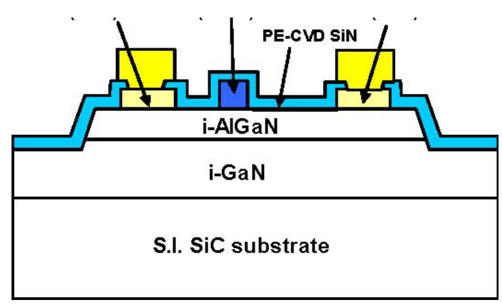
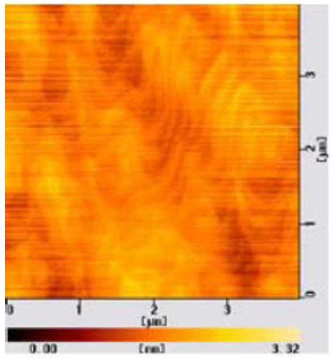


Figure 1 Cross-section of device structure.

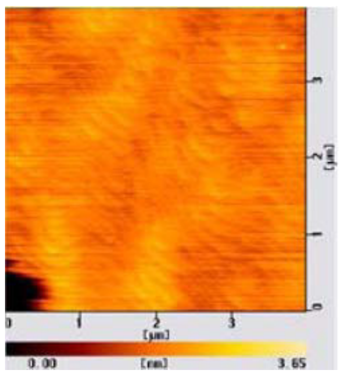
RESULTS AND DISCUSSION

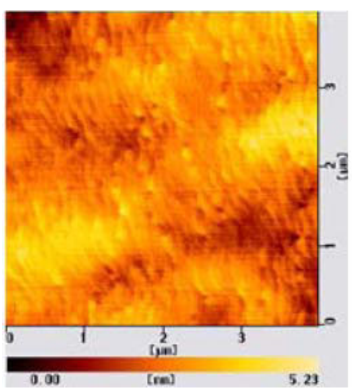
Figure 2 shows AFM results of as grown AlGaN/GaN surface morphology. It is evident from the figure that the dominant growth mechanism of AlGaN/GaN layers is step-flow growth. Additionally, the terrace width of steps decreases as the misorientation angle increases. From these measurements, it can be assumed that the threading dislocation density is decreased as the misorientation angle increase.

The drain current-voltage characteristics of the HEMTs with gate width of 100μm were shown in figure3. The gate voltages applied are varied from +1 to −4 volts. Each color shows the currents swept from each maximum drain voltage of 5V, 50V, 100V. The current collapse is decrease as misoriented angle increase. Accordingly, RF performance shall be also improved with decreased current collapse, because the current collapse exerts detrimental affect upon RF power.



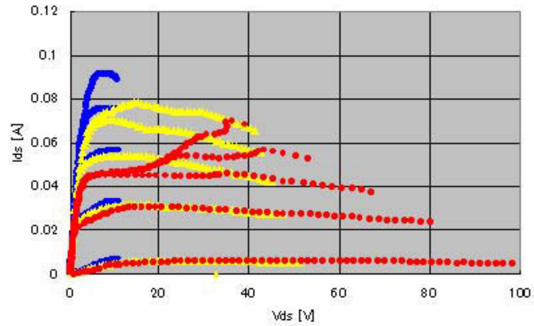
(A)



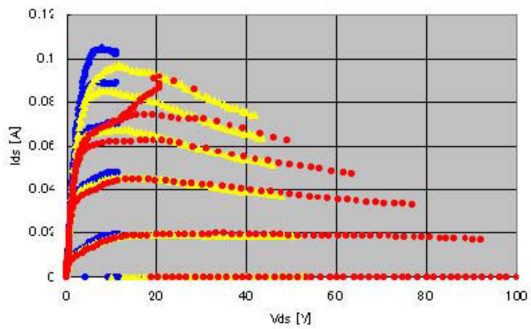


(C)

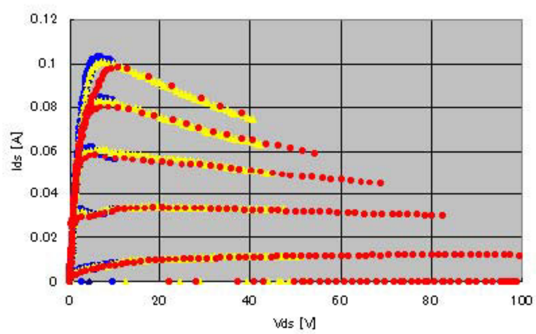
Figure 2 4µm × 4µm AFM image of the AlGaN/GaN surface morphology on orientation angle
(A) 0.06° (B) 0.11° (C) 0.47° SiC.



(A)



(B) (B)



(C)

Figure 3 The drain current-voltage characteristics of 100µm. Drain bias swept from 5V, .50V, 100V.
(Vgs= +1V to −4V, step −1V)

Figure 4 show the relation between BL/BE of PL (Photoluminescence) and misoriented angle of AlGaN/GaN epitaxial wafer. BL/BE is the ratio of Band Edge (360nm) and Blue (430nm) luminescence intensity. It is clear that the BL/BE depends on misoriented angle. This relation between the PL and the current collapse is in good agreement with previous study [6].

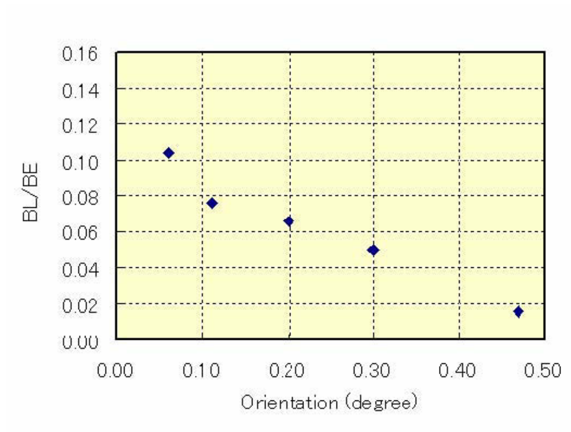
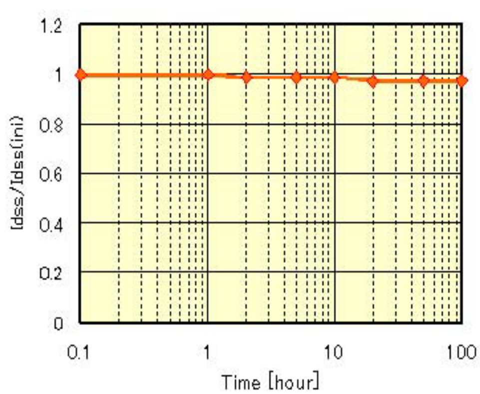
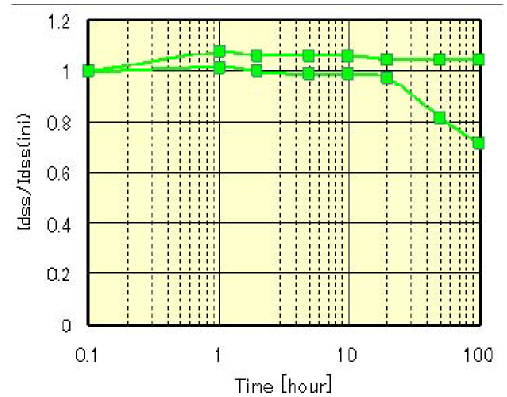
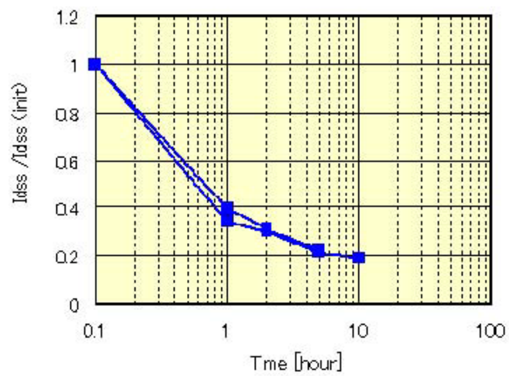


Figure 4 The BL and BE ratio of Photo luminescence dependency on SiC wafer orientation angle

Finally, accelerated tests were performed to these devices. The conditions of tests were the drain bias (Vds) of 30V and channel temperature (Tch) of 250°C. Rapid degradation of Ids are took place in the device on misorientation angle of 0.47° SiC (Figure 5). No degradation was observed low misoriented angle 0.06° sample.







(C)

Figure 5 Accelerated test of the device on various off-angle wafers, (A) 0.06° (B) 0.11° (C) 0.47°.

CONCLUSIONS

The results described above indicate that the orientation of SiC substrates affect the grown AlGaN/GaN crystal quality such as dislocation density, impurity concentration and surface conditions. Consequently, the current collapse characteristics and reliability performance of fabricated HEMTs are both affected by the magnitude of the off-angle. Data indicates that larger substrate off-angle results in better (less) current collapse, but worse (faster) current degradation.

REFERENCES

[1] K. Takagi et.al., "X-band AlGaN/GaN HEMT with over 80W Output Power", 2006 CSIC Symp, N-5

[2] E. Mitani et. al., "A kW-class AlGaN/GaN HEMT Pallet Amplifier for S-band High Power Application",2007 European Microwave Integrated Circuits Conference, Vol. 8-10 (2007) 176.

[3] D.Lu et. al., "Sapphire substrate misorientation effects on GaN nucleation layer properties" J. Cryst. Growth 272 (2004) 353.

[4] N. Nakamura et. al., “Electrical properties of MBE-grown AlGaN/GaN HEMT structures by using 4H-SiC (0 0 0 1) vicinal substrates” J. Cryst. Growth 301 (2007) 452.

[5] C. Lee et. al., “Uniformity Correlation of AlGaN/GaN HEMTs grown on 3-inch SiC Substrates” 2007 CS MANTECH Technical Digest p297

[6] H. Fujimoto, et al., "Wafer Quality Target for Current-Collapse-Free GaN-HEMTs in High Voltage Applications" 2008 CS MANTECH Technical Digest 5.2

ACRONYMS

HEMTs: high electron mobility transistors
AlGaN: Aluminum Gallium Nitride
SiC: Silicon Carbide
MOVPE: Metal Organic Vapor Phase Epitaxy
ICP-RIE: Inductive Coupled Plasma Reactive Ion Etching