PS-6-16L
Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp150-151

# Ideal transport characteristics of Schottky contacts on AlGaN/GaN structure grown on free-standing SI-GaN substrate

Takuma Nanjo, Kenichiro Kurahashi, Masayuki Tanaka, Akira Kiyoi, Akifumi Imai, Muneyoshi Suita, Yosuke Suzuki, Toshiyuki Tanaka and Eiji Yagyu

Mitsubishi Electric Corporation, Advanced Technology Research & Development Center
8-1-1, Tsukaguchi-Honmachi, Amagasaki, Hyogo 661-8661, Japan
Phone: +81-6-6497-7086 E-mail: Nanjo.Takuma@ap.MitsubishiElectric.co.jp

## Abstract

**Ideal transport characteristics were firstly demonstrated in AlGaN/GaN Schottky barrier diodes (SBDs) on free-standing SI-GaN substrate. This result indicates that unintentional doping levels due to the dislocations and defects were drastically reduced in the fabricated SBDs on SI-GaN substrate.**

## 1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) are now applying to high-power RF devices [1] due to its high-density and high-speed two dimensional electron gas and a high electric breakdown field. However, relatively large gate leakage currents are preventing further improvements of RF performances in AlGaN/GaN HEMTs, and ideal transport characteristics of Schottky contacts, which are explained by simple model, have not been reported yet. Conventional (Al)GaN related devices were generally fabricated on heterogeneous substrates such as SiC, Si and Sapphire. A lattice mismatch between (Al)GaN and these heterogeneous substrates attributes to the dislocations and defects. These dislocations and defects would prevent to obtain the ideal Schottky characteristics. Utilizing a homogeneous GaN substrate is most effective to reduce the dislocations and defects. Actually ideal transport characteristics were recently reported in Schottky barrier diodes (SBDs) on a single n-GaN epi layer grown on a free-standing n-GaN substrate [2]. It is also expected that the leakage currents are reduced and the ideal transport characteristics are obtained by using a free-standing GaN substrate even in the Schottky contacts on AlGaN/GaN structure, which has a strong polarization effects. In addition, an investigation of these characteristics is more important to resolve a mechanism of transport characteristics of AlGaN/GaN Schottky contacts.

In this study, the transport characteristics of AlGaN/GaN SBDs on a free-standing SI-GaN substrate were fabricated and investigated. As a result, ideal characteristics, which were explained a simple transport model, were firstly obtained in AlGaN/GaN SBDs.

## 2. Experimental

Figure 1 shows cross-sectional structure of fabricated AlGaN/GaN SBDs on a free-standing SI-GaN substrate. In this study AlGaN/GaN SBDs on a SI-SiC substrate were also fabricated. AlGaN/GaN epitaxial layers on both the substrates were set to the same structure except for a buffer layer. The epitaxial layers were directly grown on the SI-GaN substrate, while AlN buffer layer was employed on the SI-SiC substrate. Epitaxial layers were grown by a metalorganic chemical vapor deposition technique.

Fabrication process of SBDs started with a formation of alloyed Ti/Al/Ti/Au cathode electrodes on Si ion implanted high concentrated $n^+$ regions. Then, device isolations were performed by Zn ion implantation and Ni/Au Schottky anode contacts were formed. The fabrication was completed by depositing $SiN_x$ dielectric film using a catalytic chemical vapor deposition. Transport characteristics measurements were performed using finger type SBDs with a anode length of 20 μm and a width of 100 μm. A distance between an anode and a cathode was 2 μm.

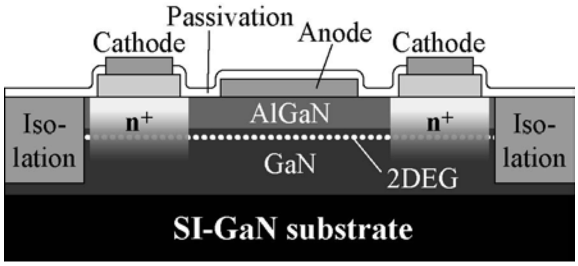


Fig.1 Schematic structure of fabricated AlGaN/GaN SBD on the free-standing SI-GaN substrate.

## 3. Results and discussion

Figures 2(a) and 2(b) show cross-sectional transmission electron microscopy (TEM) images of the AlGaN/GaN epitaxial layers on the free-standing SI-GaN and the SI-SiC substrates, respectively. A lot of dislocations were observed in a conventional epitaxial layer on the SI-SiC substrate, on the other hands, any dislocations were not observed in the epitaxial layer on the SI-GaN substrate. Densities of screw and edge dislocations, which were estimated from a number

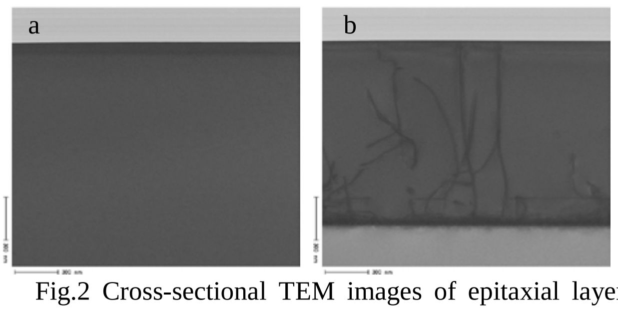


Fig.2 Cross-sectional TEM images of epitaxial layers on (a)SI-GaN substrate and (b)SI-SiC substrate.

Table I. Dislocation density in epitaxial layer

| Dislocation density ($cm^{-2}$) | on GaN | on SiC |
|---|---|---|
| Screw dislocation | $2.5\times10^4$ | $6.0\times10^6$ |
| Edge dislocation | $3.0\times10^6$ | $6.9\times10^8$ |

of etching pits by melting KOH, were summarized in table I. Both the screw and edge dislocations were decreased by two orders of magnitude in the epitaxial layers on the homogeneous SI-GaN substrate.

Figure 3(a) and 3(b) show forward current–voltage -temperature (I-V-T) curves in AlGaN/GaN SBDs on the free-standing SI-GaN substrate and the SI-SiC substrate, respectively. Figure 4(a) and 4(b) show reverse I-V-T curves in SBDs on the SI-GaN and the SI-SiC substrates, respectively. The reverse leakage currents were reduced by substituting the SI-SiC substrate for the SI-GaN substrate. Furthermore, temperature dependence of I-V curves became stronger in both the forward and reverse characteristics. In addition, the I-V-T curves in the SBDs on the SI-GaN substrate showed a very good agreement with calculated curves by Thermionic Field Emission (TFE) theory [3] in both the forward and reverse characteristics at the voltage regions of that current steeply increased. The obtained Schottky barrier height and donor concentration were 1.03~1.25 (eV) and 1.4~1.8 x $10^{18}$ ($cm^{-3}$), respectively. The Schottky barrier height was reasonable considering the difference of a work function of a Schottky metal and an electron affinity of AlGaN. The donor concentration was also not so strange value considering that deep levels in AlGaN were depleted by the strong polarization effects in AlGaN.

On the other hands, in the SBDs on the SI-SiC substrate, little temperature dependence was observed especially in the reverse characteristics. This weaker temperature dependence of I-V curves represents that the tunneling current through the Schottky barrier is the dominant component of the Schottky currents. Dislocations and defects in bulk and on surface would generate a lot of unintentional doping levels, which reduce the Schottky barrier thickness, and contribute an increase of tunneling currents through the Schottky barrier.

These results indicate that the component of tunneling currents was drastically reduced by using the free-standing SI-GaN substrate. It is also suggested that the unintentional doping levels at the interface of the Schottky contacts and in the bulk AlGaN, which were considered to be generated by the dislocations and defects, were sufficiently reduced to obtain the ideal transport characteristics.

## 4. Conclusions

We investigated the transport characteristics of AlGaN/GaN SBDs on the free-standing SI-GaN substrate and compared to the characteristics of conventional AlGaN/GaN SBDs on the SI-SiC substrate. The dislocation density was reduced by two orders of magnitude by substituting the SI-SiC substrate for the SI-GaN substrate. The reverse currents in the SBDs were reduced and the temperature dependence of I-V curves became stronger in the SBDs on the SI-GaN substrate. Furthermore the obtained transport characteristics in the SBDs on the SI-GaN substrate showed a very good agreement with calculated curves by simple TFE theory. These ideal characteristics indicate that unintentional doping levels due to the dislocations and defects were drastically reduced in the SBDs on the SI-GaN substrate.

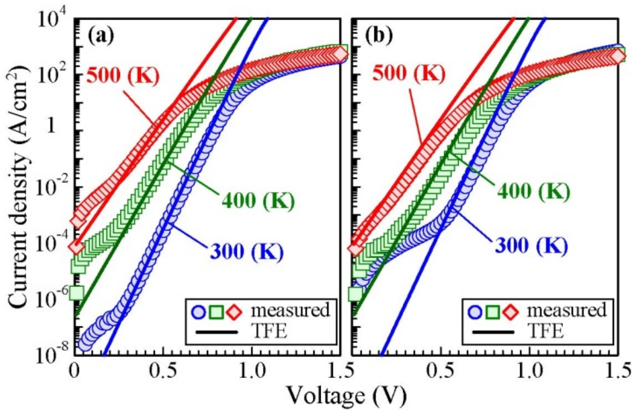


Fig.3 Forward I-V-T curves of the AlGaN/GaN SBDs on (a)SI-GaN substrate and (b)SI-SiC substrate.

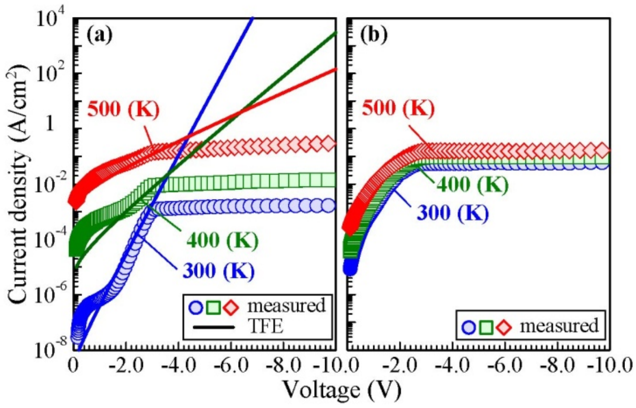


Fig.4 Reverse I-V-T curves of the AlGaN/GaN SBDs on (a)SI-GaN substrate and (b)SI-SiC substrate.

**Acknowledgment**

The authors would like to thank Prof. Hashizume at Hokkaido Univ. and Mr. H. Koyama, Mr. Y. Kamo, Mr. K. Onoe and Dr. Y. Hanamaki at Mitsubishi electric corporation for their collaboration in this study.

## References

[1] T. Yamasaki, Y. Kittaka, H. Minamide, K.Yamauchi, S. Miwa, S. Goto, M. Nakayama, M. Kohno, and N. Yshida: Int. Microwave Symp. Dig., 2010, p. 1384.
[2] J. Suda, K. Yamaji, Y. Hayashi, T. Kimoto, K. Shimoyama, H. Namita, and S. Nagao: Appl. Phy. Express 3 (2010) 101003.
[3] F. A. Padovani, and R. Stratton: Solid-State Electron. 9 (1966) 695.