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Electrical Characteristics of n-GaN Schottky Contacts on Cleaved Surfaces of Free-Standing Substrates -- Metal Work-Function Dependence of Schottky Barrier Height --

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Abstract

We report *I-V* characteristics of Schottky contacts with 8 different metals (Ag, Ti, Cr, W, Mo, Au, Pd, Ni) formed on clean *m*-plane surfaces by cleaving free-standing GaN substrates, comparing with Ga-polar *c*-plane n-GaN surfaces grown on GaN substrates. We found that the reverse *I-V* curves of the both samples can be explained with the thermionic field emission theory and the *m*-plane contacts have the metal work-function dependence of Schottky barrier heights as large as that of the Ga-polar *c*-plane n-GaN contacts.

1. Introduction

In commercially available GaN-based optical and electron devices, *c*-plane crystals are normally used. However, spatial separation of electrons and holes in the active layer due to the polarization along the *c*-axis makes the light-emitting efficiency low, and large induced sheet carrier density impedes an E-mode operation in high electron mobility transistors. One solution for eliminating the polarization effects is the use of non-polar or semi-polar orientations, but epitaxial growth of such crystals is still challenging.

In manufacturing semiconductor devices, a metal-to-semiconductor contact is one of the most important elements. An ideal metal-to-semiconductor interface would be provided by damage-free metal deposition on a clean and atomically flat semiconductor surface. In order to obtain such a clean surface, cleaving method was preferentially studied in Si and GaAs [1].

We have adopted crystal cleaving to form Au/Ni Schottky contacts on clean and flat *m*-plane HVPE-grown n-GaN surfaces, and reported that the Schottky barrier heights ($q\phi_B$) and the ideality factors (n-value) are 0.76±0.03 eV, and 1.025±0.020, respectively [2]. In this study, we conducted current-voltage (*I-V*) measurements for Schottky contacts with 8 different metals formed on cleaved *m*-plane n-GaN surfaces to characterize metal work-function ($q\phi_m$) dependence.

2. Device structure

Figure1 shows the device structure used in this study. A free-standing Si-doped (Si : 1.88×10^{17} cm^{-3}) n-GaN substrate was grown on a sapphire substrate by HVPE along the *c*-direction, and then peeled and polished in 474 μm thick in the *c*-plane. Just after we cleaved the wafer in the *m*-plane without any surface treatment, the sample was loaded into a vacuum chamber and 8 different Schottky metals (Ag, Ti, Cr, W, Mo, Au, Pd, Ni) layer (100 μmϕ) was deposited on the *m*-plane surface by electron beam evaporation. Finally, an InGa ohmic contact was formed on the same surface.

We also prepared Ga-polar *c*-plane n-GaN samples as a reference. The low-free-carrier-concentration n-GaN layers (n = 2×10^{16} cm^{-3}) doped with silicon and carbon were epitaxially grown by MOCVD on freestanding GaN substrates.

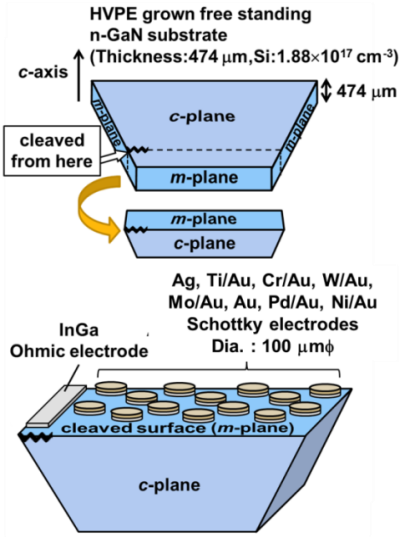

Fig. 1 Device structure of the metal/*m*-plane n-GaN Schottky contacts.

3. Experimental results and discussion

Fig. 2 shows forward *I-V* characteristics in a semi-log-plot of the metal/*m*-plane n-GaN Schottky contacts. In the low voltage region, linear relationships based on the thermionic emission model are seen for all the 8 kinds of contacts. We calculated $q\phi_B$ and *n*-value using the thermionic emission model. The $q\phi_B$ have the metal work-function dependence and the n-value is as good as 1.02 to 1.12.

In Fig. 3, we show reverse *I-V* characteristics of the metal/ (a) *m*- and (b) *c*-plane n-GaN Schottky contacts. In order to reveal current transport mechanism, we carried out

calculation by using the thermionic field emission (TFE) theory. We obtained good agreement with the measured *I-V* curves for the both samples even if the Schottky metal was varied.

The metal work-function dependences of the $q\phi_B$ are shown in Fig. 4, along with reported values of the *c*-plane n-GaN contacts grown on a sapphire substrate [3]. In general, the metal work-function dependence of the $q\phi_B$ is used to describe the quality of the contacts with an index of an *S*-value:

$$S = \frac{\Delta\phi_B}{\Delta\phi_m} \qquad (1)$$

It has been reported that the *S*-value was 0.385 for metal/ *c*-plane grown on a sapphire substrate contacts [3]. In our experimental results, the *S*-value of the samples on the cleaved *m*-plane and the *c*-plane grown on GaN substrates were obtained to be 0.451 and 0.760, respectively. These results tell us that the cleaving method can provide the clean *m*-plane surfaces where Fermi-level pinning is as small as those of the *c*-plane.

4. Conclusions

We conducted *I-V* measurements for the n-GaN Schottky contacts with 8 different metals formed on the cleaved *m*-plane and epitaxially grown *c*-plane surfaces. The measured reverse *I-V* characteristics agree with the calculated curves by using the TFE theory. The *S*-values of the samples on the *m*-plane and *c*-plane n-GaN were obtained to be 0.451 and 0.760, respectively. It was found that the *m*-plane contacts have metal work function dependence of $q\phi_B$ as large as that on the Ga-polar *c*-plane n-GaN contacts.

Acknowledgement

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References

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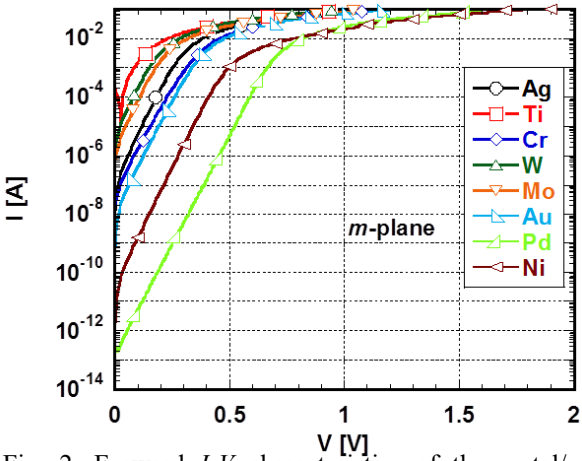

Fig. 2. Forward *I-V* characteristics of the metal/*m*-plane n-GaN Schottky contacts with 8 kinds of electrode metal.

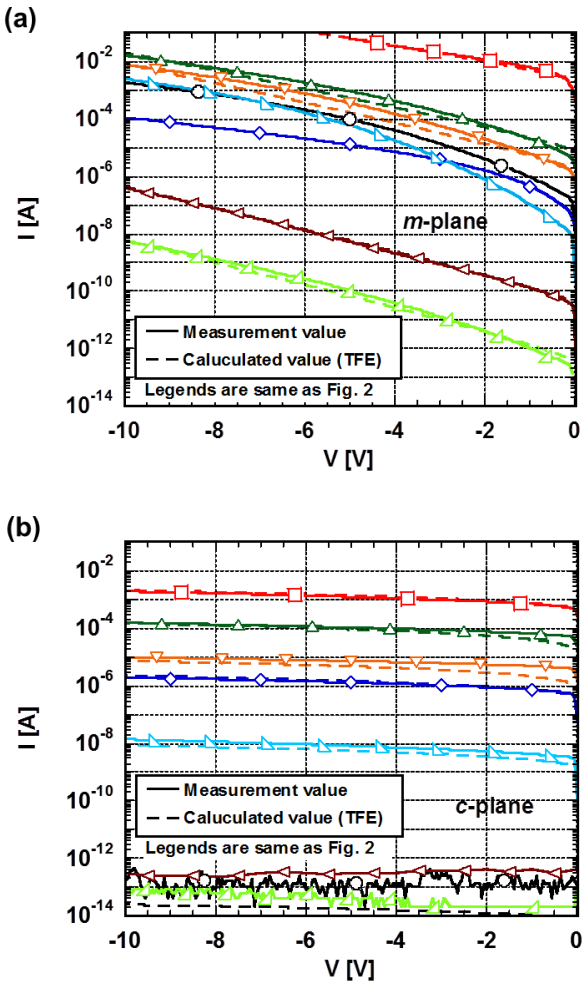

Fig. 3 Reverse *I-V* characteristics of the metal/ (a) *m*- and (b) *c*-plane n-GaN Schottky contacts. The measured curves agree with the calculated curves using the thermionic field emission theory.

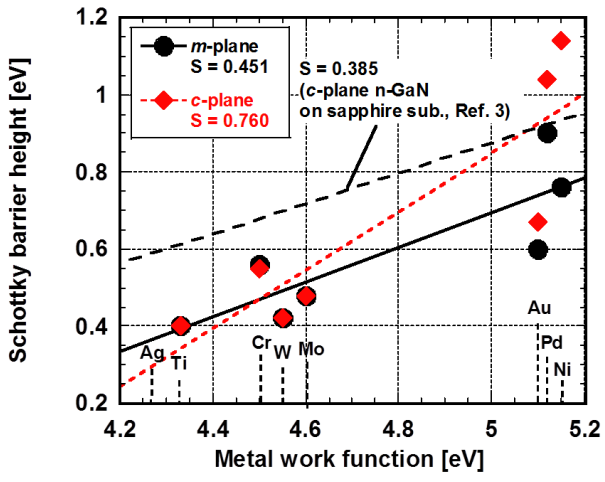

Fig. 4. The metal work function dependences of $q\phi_B$ obtained from the forward *I-V* results of the metal/n-GaN contacts.