Influence of Inhomogeneous Barrier on I-V Characteristics of Metal/GaN Schottky Diodes

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Rapid progress of the epitaxial growth technique for GaN-based compounds makes these materials attractive for applications in high-temperature/high-power electronic devices operating at high frequencies as well as in blue-UV optoelectronic devices. Promising operations of metal-semiconductor field effect transistors (MESFETs) and high-electron mobility transistors (HEMTs) have so far been demonstrated. For advancement of these devices, a better understanding of electrical properties of metal/GaN Schottky contacts is inevitably required, because reported Schottky barrier heights (SBHs) for a metal on n-GaN samples are rather scattering. The purpose of this paper is to investigate the transport properties of metal/GaN (M-S) Schottky diodes with a special focus on I-V-T characteristics of n and p-GaN Schottky diodes, which can provide more detailed information about M-S interface properties.

GaN epilayers used in this study were undoped n-GaN (2.0 μm, $N_D = 1.8\times10^{17}cm^{-3}$) and Mg-doped p-GaN (2.0 μm, $Mg=5.0\times10^{18}cm^{-3}$) grown on Al_2O_3(0001) substrates by MOCVD. After pretreatment of GaN surface with 1HCl:$2H_2O$ solution, Au, Ni and Ag metals were deposited by thermal evaporation and circularly patterned (300 μmφ) using lift-off technique to form metal/GaN Schottky diodes. Some samples were annealed in a flowing N_2 at a temperature between 300-500℃ for 15 min. I-V-T measurements ranging from 150K to 500K were conducted using a Joule-Thomson refrigerator system with temperature stability of ± 0.1℃.

All metal/GaN Schottky structures fabricated on n and p-GaN epilayers exhibited rectifying characteristics, as shown in Fig.1. However, SBHs determined from C-V curves were 0.1-0.3 eV larger than those from I-V curves. Moreover, inflected I-V curves were sometimes observed in a low current region, giving somewhat larger n-values. These phenomena have also been reported by many researchers. Previously, we have shown that the I-V characteristics of Schottky diodes, if they are inferior under the as-deposited condition, are greatly improved after a brief annealing in N_2[1)]. The inflections of I-V curves were considerably reduced or completely disappeared with fairly good n-values, as shown in Fig.2.

The observed peculiar phenomena as well as the effect of thermal annealing on I-V characteristics for n-GaN Schottky diodes can be interpreted in terms of the leakage current arising from “surface patches” with low SBHs, as schematically illustrated in Fig.3. Based on the present “patch” model, the improvement of I-V characteristics is due to a considerable reduction of the leakage current resulting from the improved uniformity of the SBH after annealing. It has been reported that adsorbed OH^- species can desorb at relatively low temperatures (～400℃).

However, it is found that the Richardson plot, $\ln(J_S/T^2)$-1/T, does not fall on a theoretical straight line even for the annealed sample, as shown in Fig.4. Furthermore, the lower the temperature, the smaller the effective SBH is and the larger the n-value is. The result indicates that small patches still remain after annealing. Surface crystal defects with different chemical composition are likely the origin of the small patches. When the size of a patch is comparable or less than the depletion width, potential maximum will appear owing to two-dimensional field distribution, as shown in Fig.3. A dipole-layer approach developed by Tung[2)] was used to calculate the potential profile in a patch area. Calculated Richardson plots together with the temperature dependence of the effective SBH and n-value are also indicated in Fig.4. In the calculation, constant circular patch with radius of 1×10^{-6} cm and SBH of 0.4 eV, and the fraction of the total patchy area of 10^{-5} are assumed. Nevertheless, the gross behavior of I-V-T characteristics can be well reproduced.

The I-V-T characteristics of metal/p-GaN Schottky diodes were measured for the first time, and the result is shown in Fig.5, for an annealed Ni/p-GaN sample. The effective SBH and the n-value are calculated to be 1.15 eV and 2.8 at RT, and 1.64 eV and 1.6 at 650 K, respectively, using the theoretical A^{**} of 72.1 $A/cm^2/K^2$ for p-GaN. Relatively large n-values for the p-GaN sample seem due to combined effects of the inhomogeneous SBH and the series resistance. Tunneling current may be also concerned because of a high Mg-doping. However, it is found that the SBH deduced from asymptote of the Richardson plot agrees well with the effective SBH at 650 K, indicating the true SBH is around 1.64 eV. The observation indicates that the sum of the true SBHs of Ni/n and p-GaN samples is close to the GaN band gap, as usual, although the sum of the effective SBHs is rather small as compared with the GaN band gap at RT, as shown in Fig.6. Thus, all observed peculiar behavior of GaN Schottky diodes are consistently explained by the present “patch” model.

1) T.Sawada et al., Abstracts of 3rd Int. Symp. on Control of Semiconductor Interface, B4-3 (Karuizawa, 1999).
2) R.T.Tung, Phys. Rev. B, **45** (1992) 13510.

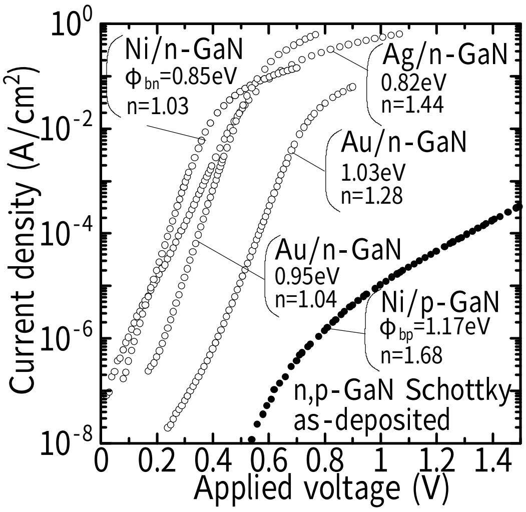

Fig.1 I-V characteristics of various metal/n and p-GaN Schottky diodes at RT. Some samples showed inflected I-V curves with relatively large n-values.

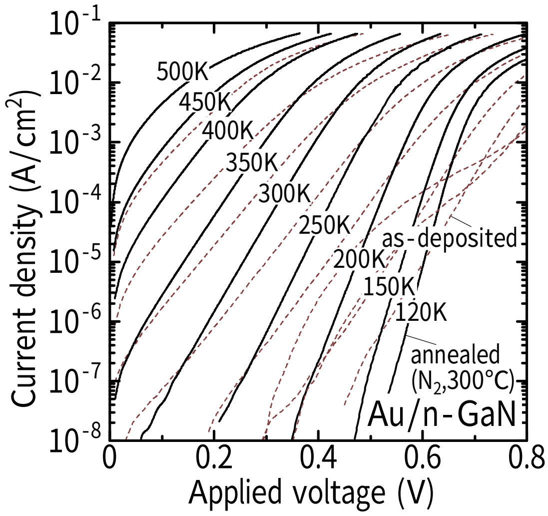

Fig.2 Comparison between I-V-T characteristics of an as-deposited and annealed Au/n-GaN sample, showing considerable improvement of the characteristics after the annealing.

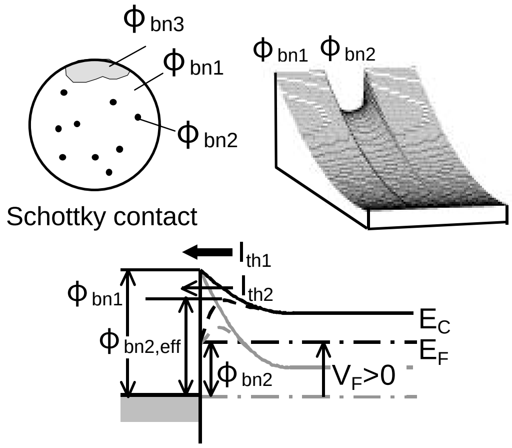

Fig.3 Schematic illustration of the leakage current arising from “surface patches” with low SBHs. Potential maximum may appear between the surface and the semiconductor for a small patch.

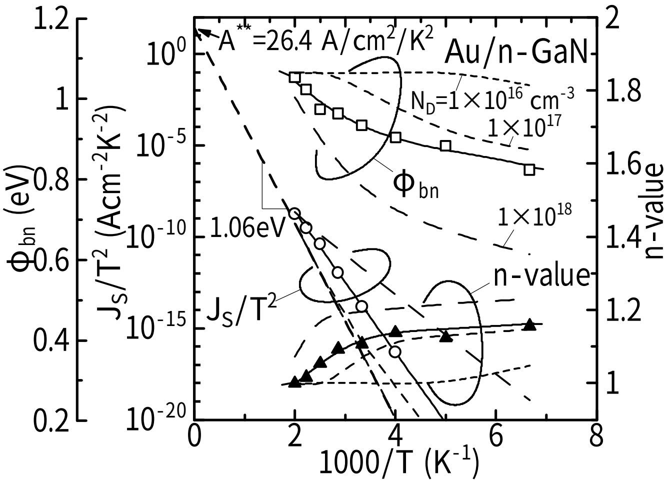

Fig.4 Richardson plot together with temperature dependence of the effective SBH and the n-value for annealed Au/n-GaN sample. Theoretical plots based on the “patch” model are also indicated using the donor density as a parameter.

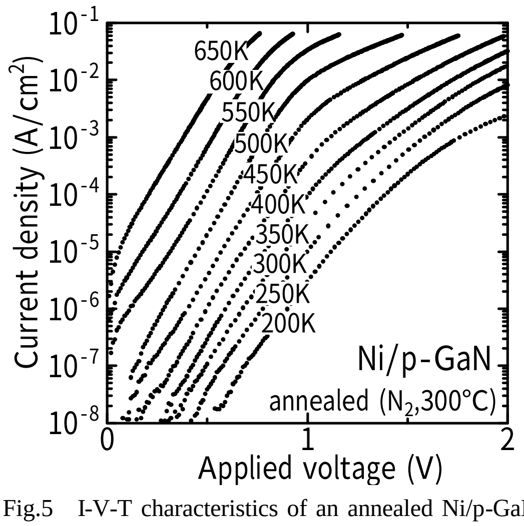

Fig.5 I-V-T characteristics of an annealed Ni/p-GaN Schottky diode, showing a relatively small temperature dependence.

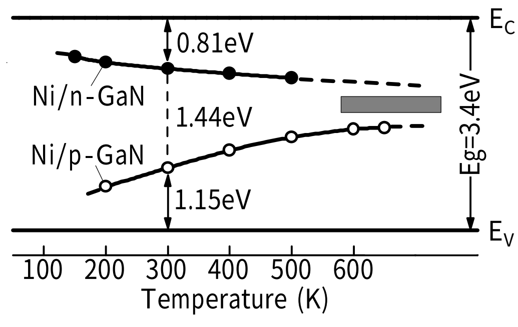

Fig.6 Temperature dependence of the apparent interface Fermi positions for annealed Ni/n and p-GaN samples. The sum of SBHs for n and p-GaN samples becomes close to the GaN band gap at high temperatures, as usual.