Characterization of electrical property and band-structure in carbon nanotube/GaN hetero-interface

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ABSTRACT

Schottky diode property using the interface between multi-wall carbon nanotubes (MWCNTs) and GaN were investigated. The Schottky barrier height ϕ_B was determined to be 0.737 eV from current-voltage characteristics. The thermionic emission model was used. From the Schottky barrier height and the electron affinity of GaN, the workfunction of MWCNTs was determined to be 4.84 eV. This result is in good agreement with the value measured by photoelectron emission of MWCNTs.

Keywords: carbon nanotube, gallium nitride, hetero-interface, band-structure, electrical property

1 INTRODUCTION

Recently optoelectronic devices and electronic power devices using GaN-based materials have attracted much attention because they exhibit high optical and electrical power with high efficiency due to the wide band-gap [1-5]. These power devices are generally used in high temperature operation by the heat dissipation of devices. Therefore, for high device reliability, it is important to design the mounting structure for heat sink to obtain efficient heat spreading. Carbon nanotube is expected to be excellent heat conductor for heat spreading of the power device because of extremely high thermal conductivity [6-9]. Therefore, it is thought that carbon nanotube is very useful for electrode material with high thermal conductivity in the GaN power device. However, to our knowledge, there are no reports on detail electrical properties and band-structure for the hetero-interface between the carbon nanotube and the GaN. The Schottky barrier height is expected to depend on the workfunction of the electrode material [10-12]. Then, studies of the Schottky barrier of MWCNTs/GaN interface become of interest. In this paper, we present results of electrical characterization and Schottky barrier height for band-structure in carbon nanotube/GaN hetero-interface.

2 EXPRIMENT

Multi-wall carbon nanotubes (MWCNTs) were prepared electrophoretically on the n-type GaN using an established procedure [13, 14]. Commercial MWCNT particles were acidified with a mixture of nitric and sulfuric acid. Acid-treated MWCNTs were washed thoroughly with water and then centrifuged until the supernatant became neutral. After drying in an oven, the MWCNTs were dispersed in isopropyl alcohol to be charged with a positive charge. A constant DC voltage of 80 V was applied typically. The positively charged MWCNTs colloids were deposited on the negative GaN surface. Figure 1 shows a photograph of MWCNTs prepared electrophoretically on the n-type GaN.

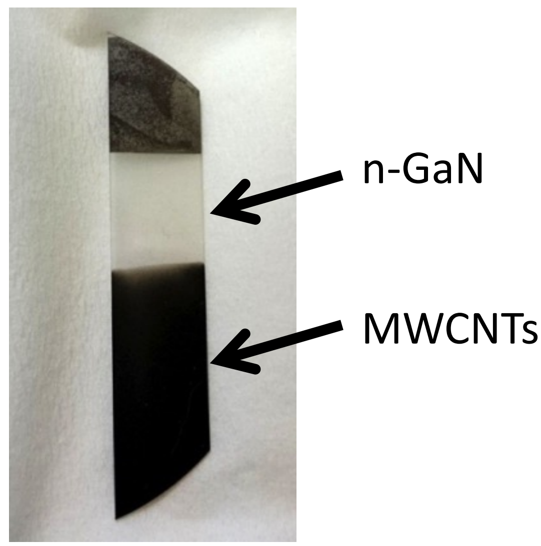

Fig. 1 Typical photograph of MWCNTs prepared electrophoretically on the n-type GaN.

The GaN films used in this experiment were grown on sapphire substrates by MOCVD. The carrier concentration was 9.79×10^{18} cm^{-3} by Si doping and the thickness was 5.4 μm. The Hall mobility and resistivity of the GaN films were 115 cm^2/Vs and 0.0055 Ωcm. Measurements of I-V and C-V were performed to estimate the barrier height of the interface between MWCNTs and GaN films. Usual Ti(30 nm)/Al(100 nm)/Ti(30 nm)/Au(50 nm) electrode was used for ohmic contact of n-GaN with annealing treatment (850 ℃, 20 s).

3 RESULS AND DISCUSSION

We obtained I-V characteristics between the Ti/Al/Ti/Au ohmic contact electrode and the MWCNTs electrode on the n-GaN film. Figure 2 shows a typical I-V characteristics of MWCNT/n-GaN contact. Schottky diode behavior was observed. From the Schottky diode property, the barrier height ϕ_B and n value were determined by the thermionic emission model [15] using

$$I = SA^* T^2 \exp\left(-\frac{q\phi_B}{k_B T}\right)\left\{\exp\left(\frac{qV}{nk_B T}\right)-1\right\} \qquad (1)$$

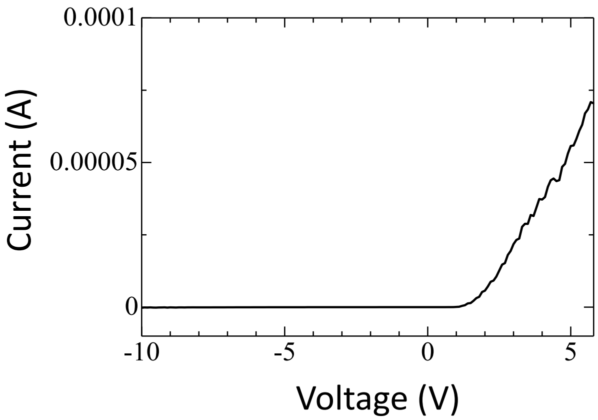

Fig.2 I-V characteristics of MWCNTs/n-GaN hetero -interface.

where A^* is the effective Richardson constant (24A/cm^{2}K^2 for n-GaN with m^*=0.2m_0), T is the temperature, q is the electron charge, k_B is the Boltzman constant and V is the applied voltage. S is the effective area of contact determined by C-V measurements at a frequency of 1 MHz. The 1/C^2 plot was not linear because of a transient response of capacitance due to deep levels. The average carrier concentration was estimated to be 9.79×10^{18} cm^{-3} as shown in Fig. 3 when the effective area of contact S was 1.23×10^{-6} cm^2. Combining the SIMS profiles and Ni/n-GaN, a reasonable value should be estimated.

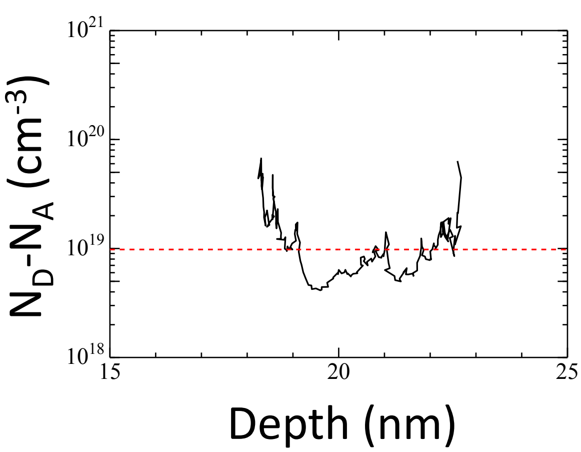

Fig.3 Carrier profile by C-V measurements.

Figure 4 shows a typical semilog I-V characteristics of the MWCNTs/n-GaN contact. From the analysis of linear regions in the forward I-V curves in terms of the thermionic emission model, the determined Schottky barrier ϕ_B was 0.737 eV and the n value was 3.6.

The electron affinity of GaN was reported to be a value of 4.10 eV [16]. It was also reported that the work function of Ni metal was 5.04 eV. And the barrier height ϕ_B was reported to be a value of 0.95 eV for the Ni/GaN Schottky barrier [17]. From this barrier height of Ni/GaN, the electron affinity of GaN is 4.09 eV.

By using a value of the GaN electron affinity of 4.10 eV the work function of the MWCNTs was determined to be as high as 4.84 eV. Previously, the work function of the MWCNTs was reported to be the value of 4.3 eV [18]. Different groups also reported the value of 4.8 eV [19] and 4.95 eV [20] measured by photoelectron emission. Therefore our result is in good agreement with the value from the photoelectron emission [19, 20]. The estimated band-structure is shown in Fig. 5. From these results, the MWCNTs electrode with relatively large workfunction could be useful for an ohmic contact of p-GaN because the metal electrode with the large workfunction such as Au, Pd and Ni is generally used for the p-GaN contact.

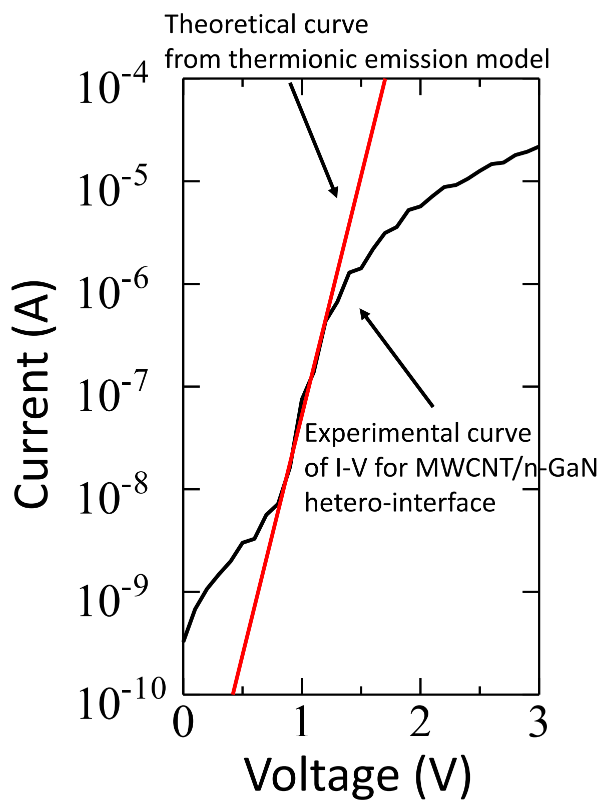

Fig.4 A semilog I-V characteristics of MWCNTs/n-GaN hetero-interface

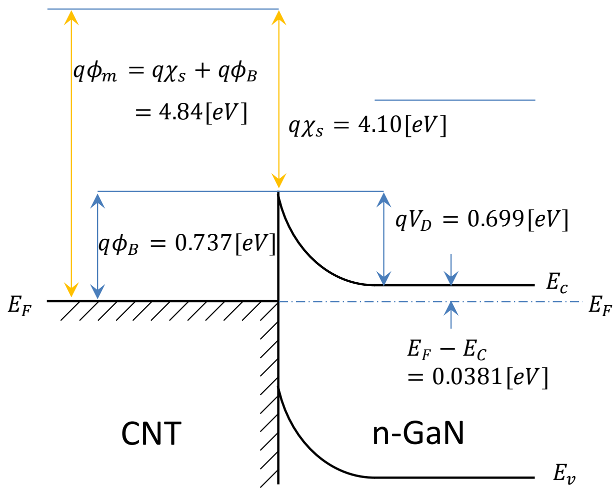

Fig.5 Band structure of MWCNTs/n-GaN hetero-interface.

4 SUMMARY

In summary, Schottky diode property using the interface between MWCNTs and GaN were obtained. Barrier height ϕ_B was determined to be 0.737 eV. The thermionic emission model was used. From the Schottky barrier height and the electron affinity of GaN, the workfunction of MWCNTs was estimated to be as high as 4.84 eV.

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