Large Schottky barriers and memory capability for Ni contacts formed on low Mg-doped p-GaN

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For p-GaN, a Schottky barrier height (SBH) of above 2 eV can be expected because the sum of the SBHs of n and p types (SBH of n-type ~ 1 eV) adds up to the band gap of 3.4 eV. However, the contacts tend to exhibit very leaky Schottky characteristics. Consequently, the mechanism of current flow through the interface has not been established and the exact value of the SBH has not yet been found.

In this study, low Mg doping is examined as a way to improve the surface morphology and widen the depression layer width (W) of the Schottky contacts in order to suppress the tunneling current through the barrier.

The 2-μm-thick GaN films were grown on (0001) sapphire using metalorganic chemical vapor deposition (MOCVD). A mixture of Bis-cyclopentadienyl magnesium (CP_2Mg) in H_2 was the Mg precursor. The films were grown at 1075℃ with 25-nm-thick low-temperature (T_G=450℃) unintentionally doped GaN buffer layers. The Mg concentration was 1.3×10^{18} cm^{-3} according to secondary ion mass spectrometry measurements, and the carrier concentration was estimated from capacitance-voltage measurements to be 4×10^{16} cm^{-3}. A reasonable value of activation efficiency of 3% can be estimated. After buffered hydrofluoric acid treatment, Ni was deposited by electron-beam evaporation.

The many steps observed in atomic force microscopy (AFM) observations (Fig. 1) confirm that the surface of p-GaN is atomically flat. Dark spots indicating dislocations can be seen. The dislocation density (D_{dis}) is as low as 5.5×10^8 cm^{-2}, compared with n-GaN, for example, whose D_{dis} is 9×10^8 cm^{-2} with a mobility of 330 cm^2/Vs and a free electron concentration of 5×10^{17} cm^{-3}.

The contacts show Schottky behavior in current-voltage (I-V) characteristics, as shown in Fig. 2. Linear regions of more than two orders are seen in the forward semi-log I-V curves, and the reverse current is 1 pA at 10 V. The Schottky barrier is as high as 2.4±0.2 eV, and the n value is 1.84±0.06. Our results are in good agreement with the prediction that the sum of the SBH of n and p types adds up to the band gap, as the reported values of Schottky barriers of Ni/n-GaN are around 1 eV.

As a result of obtaining the large SBH, carrier capture and emission processes of deep levels in a depletion layer can be observed. Figure 3 shows typical memory capability in forward I-V characteristics. The sample was loaded in a measurement box, and probes were lowered onto the sample under white light. Then, the viewing window was closed to darken the inside of the box, and the first measurement was conducted with forward biasing from 0 to 10 V at a sweep speed of about 2 V/min. The current linearly increased as the voltage increased to 0.5 V. In the voltage region between 0.5 and 4 V, the current saturated around 1 nA. Above 4 V, the current gradually increased to 2×10^{-7} A at 10 V (not shown in Fig. 3). Just after the bias voltage was swept to 10 V, the second measurement was started from V= 0 V. The second I-V curve is completely different from the first curve. The current is very small when the bias voltage is 2.5 V or less. The diode turns on above 2.5 V. Taking account of the time delay of biasing from 0 V to turn-on, this second curve is for 2 min. after the first measurement. The current is limited at 10^{-10} A in all the I-V measurements except for the first measurement. Further I-V measurements were carried out up to 800 min after the first measurement. The turn-on voltage is decreased as the time from the first measurement becomes longer. At any time after illuminating the sample by white light and then putting it in the dark, the sample reproduces the first I-V curve.

Figure 4 shows the apparent $q\phi_B$, and n value from I-V measurements as a function of the time from the first measurement. From the result of the first measurement (t=0), SBH is 0.858 eV and n value is 1.93. In the second measurement (t=2 min.), the SBH is as high as 2.45 eV and the n value is as low as 1.73 (almost the same condition was used for the measurement shown in Fig. 2). The SBH gradually decreases and the n value increases as the time increases. Even after 800 min., SBH is over 1.76 eV.

Based on these results, the band diagrams of a metal/p-GaN contact for each stage were made as shown in Fig. 5. Suppose there are acceptor-like deep level defects in p-GaN and their concentration (N_{deep}) is much larger than that of shallow acceptor impurities (N_A). The W can be varied by light irradiation or forward current injection to the interface. After irradiation, because the deep levels are fully negatively ionized (a), W is small and the apparent SBH is low (~0.8 eV) due to the tunneling (b). After the injection (c), the deep levels become neutral, W is large and the original large SBH is seen (d). These processes are repeatable. Since the time constant is very long, this contact could be utilized as a memory device.

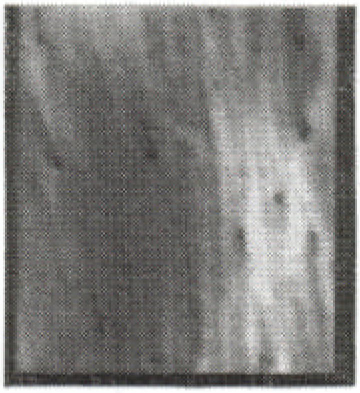

Fig. 1 An AFM image of a p-GaN surface (2x2 μm).

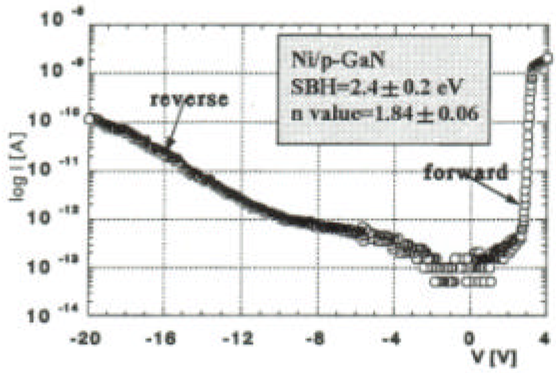

Fig. 2. A typical I-V curve of Ni/p-GaN in a semi-log plot.

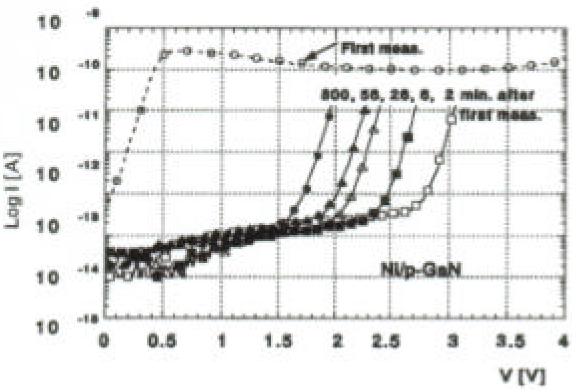

Fig. 3. Transient response of forward I-V curves of Ni/p-GaN.

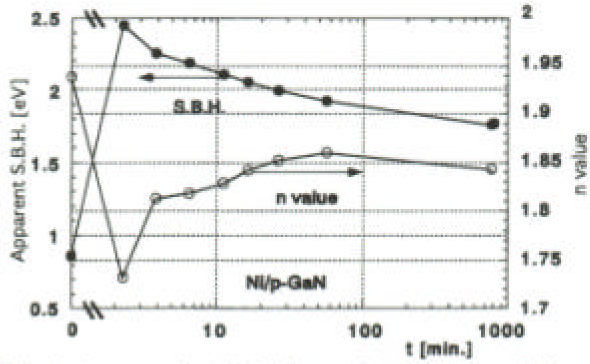

Fig. 4. Apparent barrier heights and n values from I-V measurements as a function of the time from the first I-V measurement.

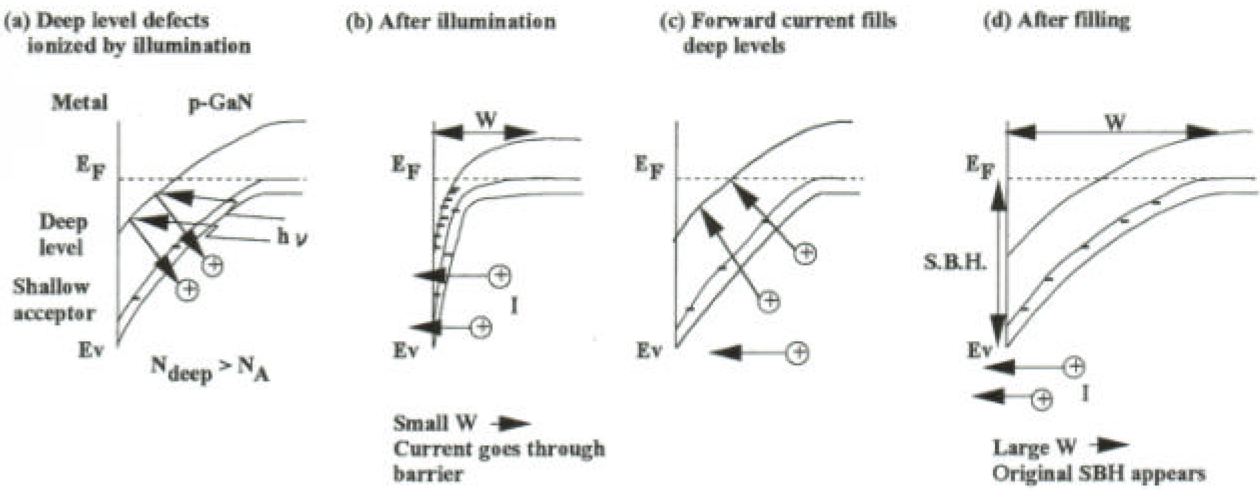

Fig. 5. Band diagrams of metal/p-GaN with carrier capture and emission by deep level defects.