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# Al-doped ZnO Intermediate Layer for AlGaN/GaN HEMT Ohmic Contact

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## 1. Introduction

Recently, AlGaN/GaN High Electron Mobility Transistor (HEMT) has attracted many researchers to develop high frequency device, which needs high-power and high-voltage operation [1][2]. However, many problems still remain such as low resistance ohmic contact to AlGaN/GaN, where Ti/Al was commonly used [3].

We introduced Al-doped n-type ZnO for the intermediate layer in the ohmic electrode to reduce the effective barrier height. In this paper, we will report the concept and fabrication process of ZnO contact as well as the resistance values measured by TLM patterns and the effects of annealing on the resistance values.

## 2. Concept of ZnO ohmic contacts

The electron affinity of ZnO is reported as 4.1eV [4], which is slightly lower than 4.2eV of GaN [5]. So, if one uses n-type ZnO as an electrode, no barrier for electron conduction will be formed between n-ZnO and n-GaN. ZnO can be deposited at relatively low temperature by DC magnetron sputtering. These facts enable ZnO to act as low contact resistance material for GaN and AlGaN. Furthermore, having wurtzite structure as the same as GaN or AlGaN, single crystal ZnO shows piezoelectric effect and spontaneous polarization, which may reduce the barrier height at AlGaN and ZnO interface

Figure 1 shows the conduction band diagram of Al/ZnO/AlGaN/GaN contact structure, together with conventional Ti-Al/AlGaN/GaN structure. The barrier height between ZnO and AlGaN is given by the difference between the electron affinity for AlGaN and the Fermi level in ZnO. Since carrier concentration of n-type ZnO can be as high as $10^{21}$/cm$^3$ [6], Fermi level lies close to the conduction band and the barrier height become the difference of electron affinity between the two semiconductors. In addition, due to the high donor concentration in ZnO, depletion layer in ZnO layer should be always thin enough for electron tunneling.

## 3. Experimental procedure

The structure of AlGaN/GaN heterostructure epitaxial wafer used in this study is shown in Fig. 2. ZnO films were grown on the AlGaN/GaN epi-wafer by DC magnetron sputtering. Al content of the ZnO target was 3wt%$Al_2O_3$. The growth conditions for Al-doped ZnO films were as follows: sputtering current was 50mA, working pressure of the Ar sputtering gas was $3\times10^{-2}$ torr and substrate temperature was 300℃. The deposition rate was about 50Å/min and the thickness for the present experiment was about 1000Å. We prepared 4 samples with different surface treatments before ZnO deposition; (A)$O_2$ plasma treatment, (B) HCl treatment (25%,60℃×5min), (C) $NH_4OH$ treatment (28%,60℃×5min) and (D) no special treatment. Before surface treatment, the surface of all samples was cleaned with acetone, methanol and de-ionized water. The specific resistance of sputtered Al-doped ZnO films were 5～$10\times10^{-4}$ Ωcm which was measured by four-probe method at room temperature.

After the sputtering, ZnO islands were formed by wet chemical etching, and Al electrode was deposited on the ZnO islands by electron beam evaporation and lift-off process. Then, the samples were annealed at different temperatures for 10 minutes in $N_2$.

We prepared two sets of circular transmission line model (TLM) patterns. In type I, only the metal layer was patterned, while in type II, ZnO layer between the Al electrodes is removed, so both the metal and the ZnO layers are patterned. ( Fig. 3) With type I, we can measure the contact resistance at Al/ZnO interface($R_1$) and the sheet resistance of ZnO films. With type II, we can measure the total contact resistance ($R_{tot}$) from the Al electrode to AlGaN/GaN 2DEG ($R_{tot}=R_1+R_2+R_3$), where $R_2$ and $R_3$ denote the contact resistance of ZnO bulk, ZnO/AlGaN respectively and the sheet resistance of the 2DEG layer.

## 4. Results and discussion

Figure 4 shows the total contact resistance($R_{tot}$) values for different annealing temperatures. Even without post deposition annealing, $R_{tot}$ is 6.6 to 15Ωmm except for sample A with oxygen plasma treatment. As the annealing temperature increases, $R_{tot}$ values converged to 5Ωmm-7Ωmm range regardless of the surface treatment. The lowest contact resistance was 5.2Ωmm for sample C with $NH_4OH$ treatment.

Figure 5 shows the contact resistance between Al and ZnO($R_1$) and the sheet resistance of ZnO layer. Both of them slightly increase by the annealing. Combining the measured result of two TLM patterns, intrinsic ZnO/AlGaN contact resistance($R_1$) was estimated as 3.8Ωmm after annealing at 500℃ for sample C.

## 5. Conclusions

We applied Al-doped ZnO for ohmic electrode of AlGaN/GaN HEMT. Contact resistance of 6.6Ωmm was obtained without thermal treatment where the maximum process temperature was 300℃ for ZnO deposition. So, ZnO ohmic electrode will allow us lower processing temperature.

After annealing at 500℃, total contact resistance of 5.2 Ωmm was obtained, where the contact resistance at ZnO/AlGaN interface is estimated to be 3.8Ωmm. Though the values are slightly higher than that of conventional Ti/Al/Ni/Au contacts (∼1Ωmm), further investigation will be necessary to obtain lower contact resistances by using ZnO films.

## References


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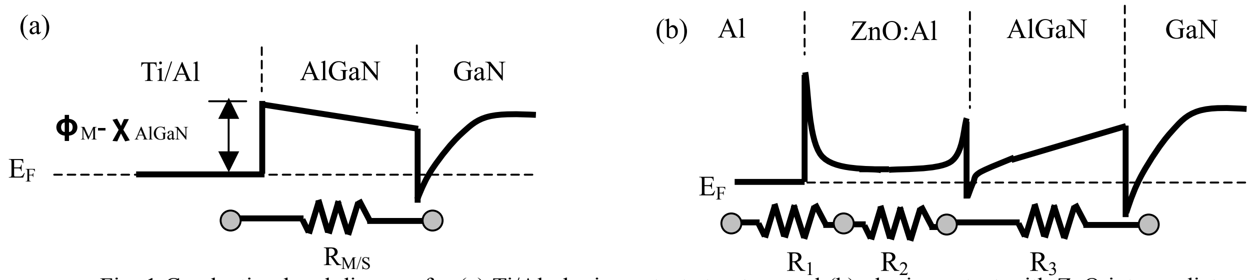


Fig. 1 Conduction band diagram for (a) Ti/Al ohmic contact structure and (b) ohmic contact with ZnO intermediate layer. $R_{M/S}$ denotes the contact resistance of Ti/Al/AlGaN, $R_1$,$R_2$ and $R_3$ denote the contact resistance of Al/ZnO, ZnO bulk, ZnO/AlGaN respectively.

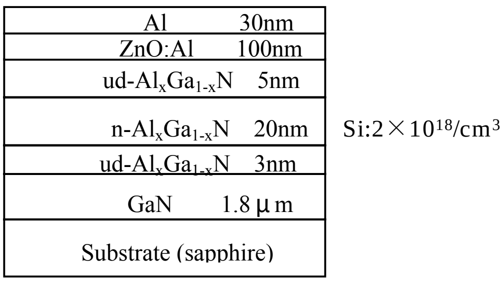


Fig. 2 Heterostructure of AlGaN/GaN epiwafer. Al composition of AlxGa1-xN layer is 0.25.

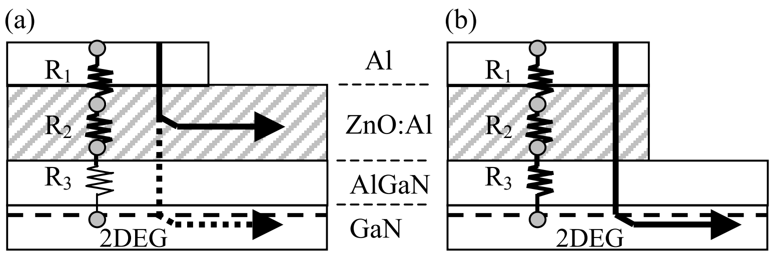


Fig. 3 Schematic cross section of the circular-TLM patterns. Arrows indicate the current paths. (a)Type Ⅰ pattern, (b) Type Ⅱ pattern.

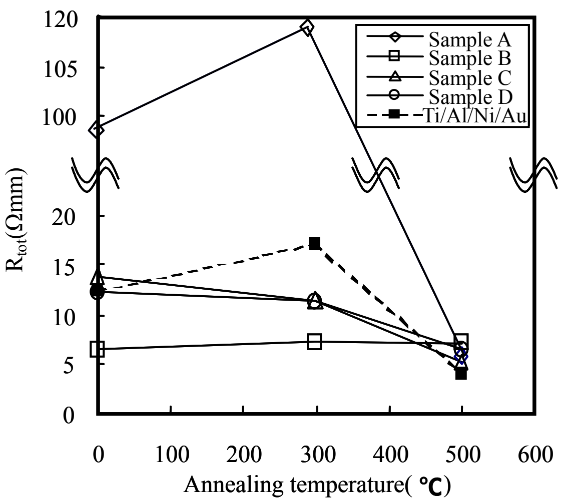


Fig.4 The relationship between the $R_{tot}(R_1+R_2+R_3)$ and annealing temperature.

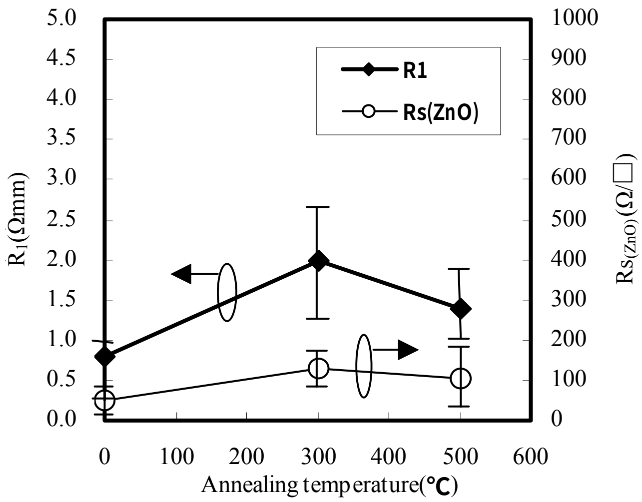


Fig.5 The annealing temperature dependence of contact resistance of $R_1$(Al/ZnO) and the sheet resistance of ZnO