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Ohmic contact to p-GaN using a strained InGaN contact layer and its thermal stability

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1. Introduction

Low-resistance ohmic contacts are necessary and become more important for further improving device performance of GaN-based semiconductors. However, it is difficult to obtain Ohmic contacts to p-GaN with low specific contact resistance (ρ_c) of less than 10^{-4} Ω-cm^2, because the hole concentration of p-GaN is less than 10^{18} cm^{-3} due to its relatively deep acceptor level of Mg atoms in p-type GaN. To date, there have been various attempts to reduce the contact resistance: (1) Surface treatment by chemical solutions [1]; (2) metal deposition and annealing [2]. The other method was the contact using the polarization field at the surface by p-type AlGaN/GaN superlattices. It was proposed that polarization charges near the surfaces enhanced the tunneling transport [3]. These methods had a strong effect in reducing the ρ_c values to the 10^{-4} Ω-cm^2 range or less.

Recently, we have proposed the Ohmic contact for reduction of ρ_c using a strained p-InGaN contact layer on p-GaN. In this method, special chemical and thermal treatment is not needed. The ρ_c value considerably reduced to 1.1×10^{-6} Ω-cm^2 due to the enhancement of tunneling transport [4]. In this work, we evaluate the thermal stability up to 400°C of the Ohmic contact to p-GaN using a strained p-InGaN contact layer.

2. Experimental

Samples were grown by low-pressure metalorganic vapor phase epitaxy. Source materials were trimetylgallium and ammonia (NH_3) with hydrogen as a carrier gas for GaN growth, and triethylgallium, trimethylindium and NH_3 with nitrogen (N_2) as a carrier gas for InGaN growth. The p-type dopant source was bis-cyclopentadienylmagnesium. First, a GaN buffer layer was deposited at 500°C on c-face sapphire substrate. Next, an undoped GaN layer and a 1-µm-thick Mg-doped GaN layer were grown at 1000°C. Then, Mg-doped InGaN was grown from 760 to 780°C. The thicknesses and In mole fractions of the InGaN layers were varied from 1 to 15 nm and from 0.14 to 0.19, respectively. The Mg doping concentration in the Mg-doped GaN and Mg-doped InGaN was fixed at 4×10^{19} cm^{-3}, which was estimated by secondary ion mass spectroscopy. After the growth, all samples were annealed at 700°C in N_2 ambience. The ρ_c values were determined using circular transmission line model (CTLM) patterns with a contact inner radius (r_{in}) of 100 µm and spacings (d) from 5 to 30 µm. Pd (20 nm) /Au (130 nm) contact metals were deposited by electron beam evaporation after cleaning the surfaces by dipping in a HCl:H_2O (1:1) solution. To prevent parallel conduction in p-GaN and p-InGaN, exposed p-InGaN was removed by electron cyclotron resonance plasma etching. We carried out CTLM current - voltage (I-V) measurements to determine the ρ_c values at the temperature ranging from room temperature (RT) to 400°C.

3. Results and discussion

Figure 1 shows the ρ_c values as a function of the p-InGaN contact layer thickness. For all p-$In_xGa_{1-x}N$ contact layers except the 15-nm-thick one, ρ_c values were lower than that of p-type GaN and were 10^{-4} Ω-cm^2 range or less. The lowest ρ_c is 1.1×10^{-6} Ω-cm^2, for a 2-nm-thick p-type $In_{0.19}Ga_{0.81}N$ contact layer.

It is well known that the piezoelectric polarization field is mainly dominant in strained InGaN/GaN system. For example, the piezoelectric polarization field for $In_{0.19}Ga_{0.81}N$/GaN is calculated to be about 3 MV/cm; that is, the potential drop is 0.6V for 2 nm. The electric field due to the ionized acceptors in the surface

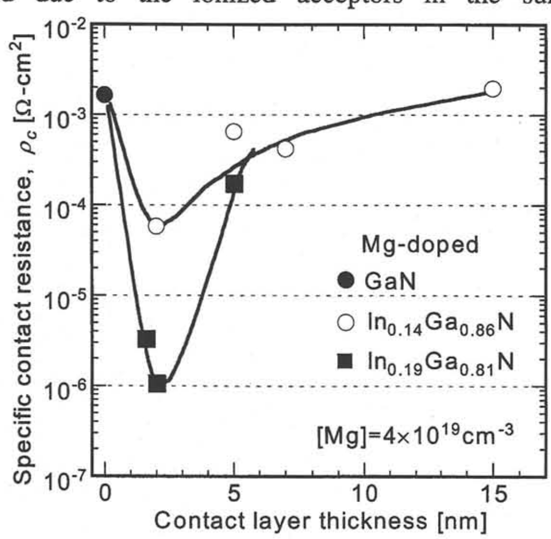

Fig. 1. The ρ_c values as a function of the p-type InGaN contact layer thickness.

depletion layer also exists at the surface. Therefore, the electric field in p-type InGaN contact layer consists of these two fields, resulting in the reduction of tunneling barrier width and hence contact resistance.

However, if the thickness of InGaN exceeds the critical layer thickness, the strain-induced piezoelectric field disappears due to the lattice relaxation, resulting in the increase of the tunneling barrier width and hence contact resistance. In fact, the critical layer thickness was estimated to be from 3 to 5 nm [5]. At the contact layer thickness of 2 nm, the minimum ρ_c was obtained for the p-type $In_{0.19}Ga_{0.81}N$ contact layer due to the largest piezoelectric polarization effect among the samples in this study.

Next, we evaluate the thermal stability of Ohmic contact using 1.6-nm-thick p-$In_{0.19}Ga_{0.81}N$ contact layer. The ρ_c value was 3.3×10^{-6} Ω-cm^2 at RT. Figure 2 shows the temperature dependence of the ρ_c value at the temperature ranging from RT to 400°C. In all the temperature range, the ρ_c values with p-InGaN contact layer were smaller than those without the contact layer. Considering the upper limit for the device temperature of 100°C, the ρ_c value was three orders of magnitude lower than that for conventional Mg-doped GaN. This result indicates that the strained InGaN contact layer has the ability to apply to the practical devices.

The reasons for the decrease of ρ_c value below 100°C with increasing in temperature might be the decrease of tunneling barrier height with the band gap energy and/or improvement of adhesion between a Pd metal and a p-type layer. On the other hand, the reasons for the increase of ρ_c values above 100°C might be the chemical reaction at the interface between Pd and a p-type layer, or desorption of the nitrogen from the p-type layer, because diffusion of Au atoms to the Pd layer was not observed by auger electron spectroscopy and transmission electron microscopy.

Figure 3 shows CTLM I-V characteristics at RT with and without a strained p-InGaN contact layer. Solid and broken lines indicate the measurements before and after thermal process for high temperature measurements, respectively. The degradation after thermal process was observed for Mg-doped GaN compared with a strained p-InGaN contact layer. This also indicates that the strained p-InGaN contact layer has another advantage for the practical devices.

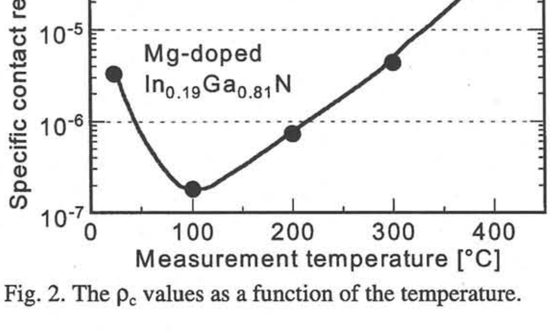

Fig. 2. The ρ_c values as a function of the temperature.

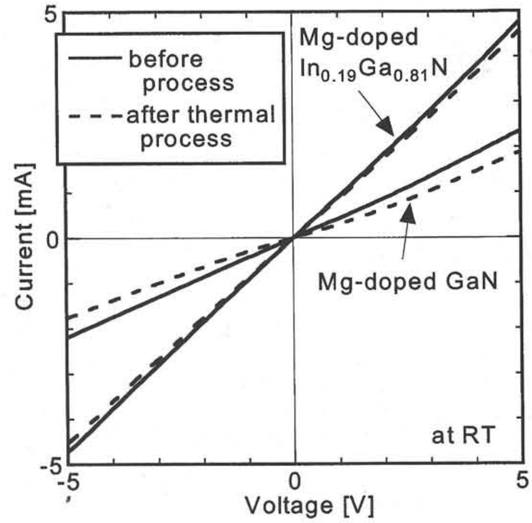

Fig. 3. CTLM I-V characteristics at RT with and without a strained p-InGaN contact layer. Solid and broken lines indicate the measurements before and after thermal process, respectively.

4. Conclusion

In conclusion, we have evaluated thermal stability of Ohmic contact using a strained p-InGaN contact layer. In the temperature range up to 400°C, the ρ_c values with p-InGaN contact layer were smaller than those without the contact layer. Furthermore, I-V characteristics of the Ohmic contact using a strained p-InGaN layer were less degraded even after thermal process. These two results for Ohmic contact using a strained p-InGaN layer are favorable to practical devices.

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