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High temperature induced failure in Ti/Al/Ni/Au Ohmic contacts on AlGaN/GaN heterostructure

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ABSTRACT

Ti/Al/Ni/Au (200/1200/500/2000 Å) Ohmic contact on AlGaN/GaN was prepared and it was subjected to thermal aging experiments. Thermal processing at 400 and 500 °C did not change the contact resistance significantly, while high temperature storage at 600 °C resulted in a surge in the contact resistance. The Al–Au alloy in the contact metal is believed to re-melt because its lowest melting temperature is 525 °C. The liquid of Al–Au alloy is observed to diffuse to the AlGaN surface and consume some AlGaN layer. In addition, voids are found to be produced during thermal process, which can reduce the effective contact area and thus lead to higher contact resistance. The TEM and EDX results of Ohmic contact's cross sectional images provide evidence for this proposed mechanism.

1. Introduction

AlGaN/GaN HEMT offers significant advantages for high power, microwave signal amplification at elevated temperature environment [1–5]. The wide energy band-gap of GaN (3.39 eV) ensures GaN based power devices to work at very high temperature even beyond 368 °C [6]. High temperature endurance is very important for power devices because it helps to simplify the cooling system, thus reduce the equipment cost. Moreover, higher thermal stability is one of the basic criteria for devices' reliability.

The source and drain electrodes of HEMTs are all fabricated with Ohmic contacts, therefore the device's reliability would be influenced directly by performance stability of the metal/semiconductor contacts. Researchers have found that thermally induced interdiffusion between Ohmic metals and semiconductors, and metal migration along the electron channel in GaAs HEMTs [7] can cause device failure.

In AlGaN/GaN transistors, Ohmic contacts were typically formed by means of rapid thermal annealing (RTA) of Ti/Al/Ni/Au metal stacks [8–11]. The fabrication process is totally different from the Ohmic contact formation on Si and GaAs, where the Ohmic contacts are often prepared by ion implantation induced n^+ doping. Thus the failure mechanism of the Ohmic contacts on AlGaN/GaN HEMT should be different from those on Si and GaAs based devices.

In this article we fabricated typical Ti/Al/Ni/Au Ohmic contacts on AlGaN/GaN and observed their performance under different thermal conditions. We also analyzed the Ohmic contact's failure mechanisms. 525 °C is believed to be a critical temperature for the high temperature aging of Ti/Al/Ni/Au Ohmic contacts. When the temperature exceeds it, a rapid degradation will happen in Ti/Al/Ni/Au Ohmic contacts.

2. Experimental

$Al_{0.28}Ga_{0.72}N$/GaN heterostructure on sapphire (0001) were grown with metal organic chemical vapor deposition (MOCVD). The GaN buffer layer was firstly grown at 530 °C. Then a ~2 μm *i*-GaN layer was grown at 1070 °C. Finally an unintentionally doped $Al_{0.28}Ga_{0.72}N$ with thickness of 25 nm was deposited at 1090 °C. The 2DEG sheet density and *Hall* mobility of the wafers were $\sim 6 \times 10^{12}\ cm^{-2}$ and $\sim 900\ cm^2/V\ s$. We first cleaned the wafers ultrasonically with acetone, ethanol and de-ionized water for 5 min respectively. Then we patterned the wafers with Marlow's circular transmission line model (CTLM), which would be used to calculate the specific contact resistance (ρ_c) and contact resistance (R_c). In the CTLM patterns, the distance between the metal pads is 10, 15, 20, 25, 30, 35 μm respectively. The outer circles of all the six rings are all fixed at 125 μm. After photolithography, we cleaned the samples with HCl to remove the native oxide. Immediately after the cleaning, we deposited Ti/Al/Ni/Au (200/1200/500/2000 Å) onto the substrates with electron beam evaporator (EBE). After we carried out lift-off on the wafers, we processed the samples with rapid thermal annealing (RTA) in a N_2 atmosphere. The temperature and time of RTA was 900 °C and 30 s respectively. ρ_c and contact R_c of the Ohmic contact was $1.32 \times 10^{-5}\ \Omega\ cm^2$ and 0.752 Ω mm respectively.

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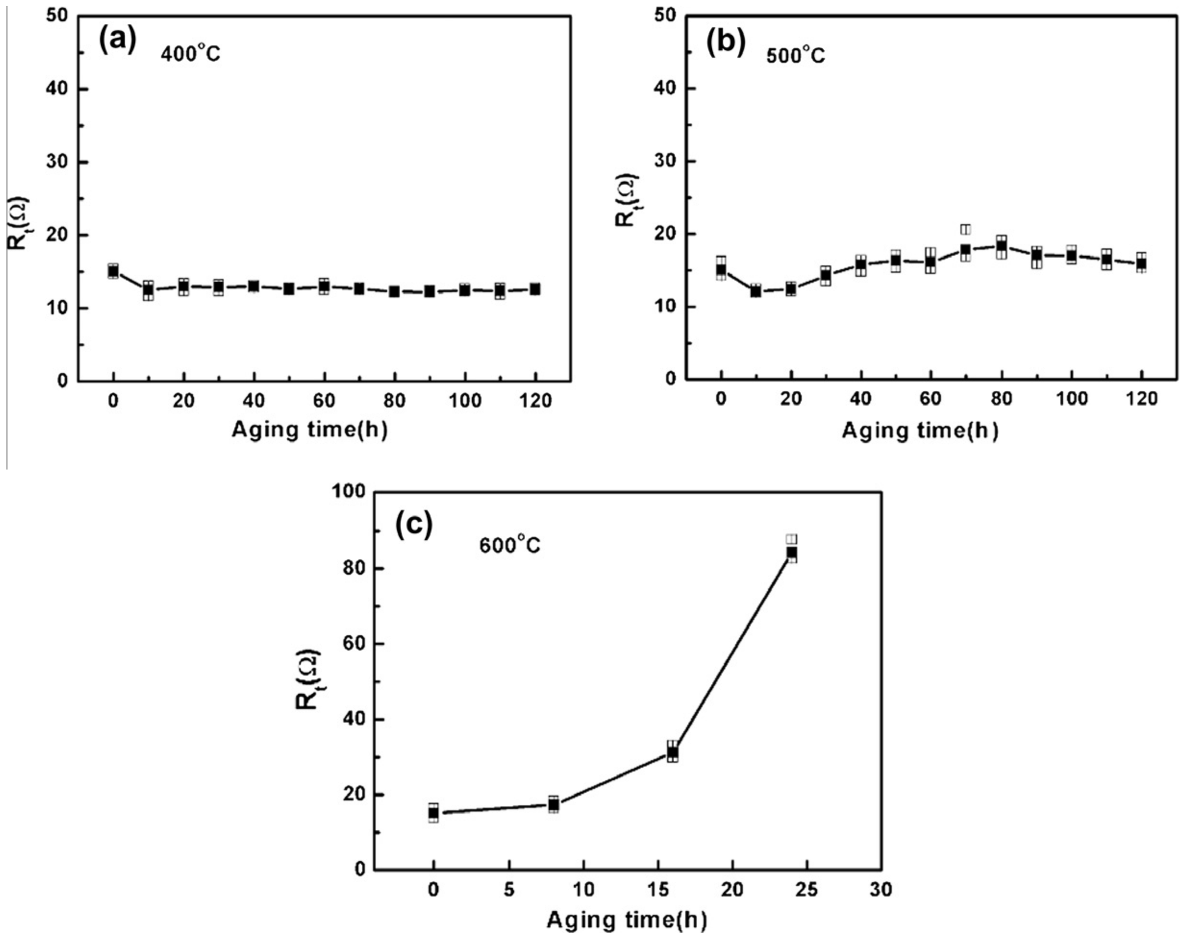

Fig. 1. Thermally induced changes in total resistance for the third gap of CTLM. (a) 400 °C, (b) 500 °C, (c) 600 °C.

We performed thermal aging experiments to analyze the thermally induced behaviors of the Ohmic contacts. The experiments were carried out at 400, 500 and 600 °C, in a pure N_2 atmosphere. We measured the *I*–*V* characteristics of the Ohmic contacts during the aging experiments. The measuring equipment we used in this article was HP 4156C Parameter Analyzer. We also observed the structural and composition changes of the Ohmic metal before and after the aging experiments. FEI TECNAI G^2 transmission electron microscopy (TEM) and electron dispersive X-ray spectroscopy (EDX) attached to the TEM were used to observe the cross sectional image and analyze the components.

3. Results and discussion

Fig. 1 shows the thermally induced changes on the resistance. We measured the total resistance (R_t) of the third ring (width = 20 μm) in CTLM patterns in the process of the thermal aging experiments. The average value for each R_t were given in

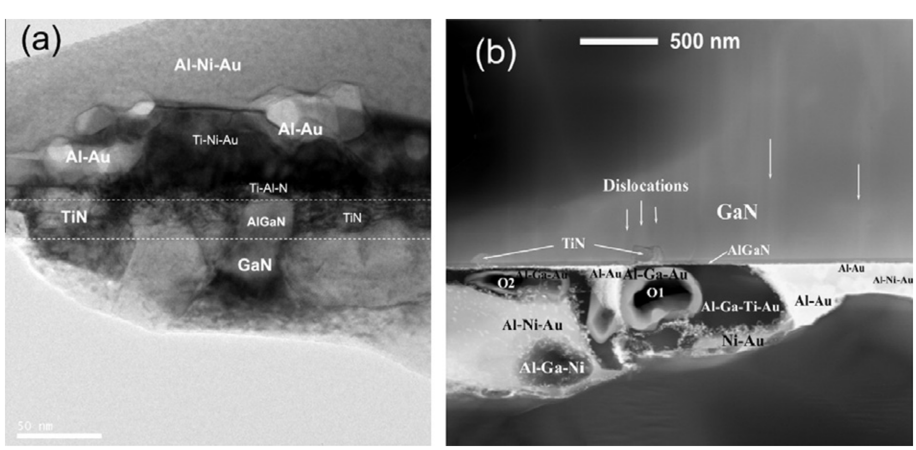

Fig. 2. The cross sectional image of Ti/Al/Ni/Au Ohmic contacts on AlGaN/GaN. (a) The contacts without any extra thermal processing; (b) the contacts after 24-h thermal processing of 600 °C. In figure (a), Al–Au near TiN islands was observed. In figure (b), Al–Au turned into Al–Ga–Au and voids (O_1 and O_2) formed in its center. Al–Au also diffused along the surface of AlGaN. The vertical arrows show some of the dislocations.