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The leakage current mechanisms in the Schottky diode with a thin Al layer insertion between $Al_{0.245}Ga_{0.755}N$/GaN heterostructure and Ni/Au Schottky contact

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This paper investigates the behaviour of the reverse-bias leakage current of the Schottky diode with a thin Al inserting layer inserted between $Al_{0.245}Ga_{0.755}N$/GaN heterostructure and Ni/Au Schottky contact in the temperature range of 25–350 °C. It compares with the Schottky diode without Aluminium inserting layer. The experimental results show that in the Schottky diode with Al layer the minimum point of I–V curve drifts to the minus voltage, and with the increase of temperature increasing, the minimum point of I–V curve returns the 0 point. The temperature dependence of gate-leakage currents in the novelty diode and the traditional diode are studied. The results show that the Al inserting layer introduces interface states between metal and $Al_{0.245}Ga_{0.755}N$. Aluminium reacted with oxygen formed Al_2O_3 insulator layer which suppresses the trap tunnelling current and the trend of thermionic field emission current. The reliability of the diode at the high temperature is improved by inserting a thin Al layer.

Keywords: gate leakage current, interface states, tunnelling current, thermionic field emission current

PACC: 7340N, 7280E, 7360L

1. Introduction

GaN-based compounds have been successfully used in short-wavelength optoelectronic devices, such as blue light-emitting diodes (LEDs) and LDs. These materials are also attractive for applications in high-speed/high-power electronic devices because of their superb properties.[1,2] However, many factors limit the performance and reliability of GaN high electron mobility transistors for high-power radio-frequency applications. One of the major factors is their relatively high gate leakage current.[3,4] Recently researchers have demonstrated an Al layer as thin as 3 nm inserted between the AlGaN barrier layer and the gate contact can reduce the gate leakage current and improve an AlGaN/GaN high electron mobility transistor (HEMT) by decreasing oxygen-related trap density at the AlGaN surface.[5] The temperature dependence of gate-leakage current in AlGaN/GaN HEMTs has been prevalent in the literature for more than four decades. However, a more complete understanding of the relevant mechanisms of current transport is desirable on fundamental scientific grounds. In this paper, we reported the temperature dependence of gate-leakage current of the Schottky diode with a thin Al inserting layer and without Al layer and analysed gate leakage mechanisms.

2. Experiments

Figure 1 shows the cross sections of the fabricated AlGaN/GaN Schottky diode with Al layer and without Al layer. The AlGaN/GaN Schottky diode structures were grown on (0001)-oriented sapphire using metal-organic chemical vapour deposition (MOCVD). The device structure consists of a 30 nm undoped AlGaN barrier layer and 1.3 μm insulating GaN(i-GaN)

layer on a buffer layer [GaN(20 nm)]. The Al content of AlGaN layer was maintained as 24.5%. The carrier concentration of $1.26\times10^{13}\,\mathrm{cm}^{-2}$ and carrier mobility of $1200\,\mathrm{cm}^2/(\mathrm{V\cdot s})$ were obtained by Hall measurement at room temperature.

Then, for the fabrication of Schottky diodes, ring-shaped ohmic contacts were formed by standard photolithography on $Al_{0.245}Ga_{0.755}N$ surface, using a Ti/Al/Ni/Au (25/120/45/50 nm) alloy annealed at 850 °C in N_2 for 30 s in a rapid thermal annealing system. Before Schottky metallization, the wafers were cleaned by conventional organic cleaning process. A very thin Al layer of 3 nm was deposited by electron beam evaporation system in a high vacuum condition below 1×10^{-4} Pa. Then Schottky contacts of Ni/Au (25/200 nm) were formed by e-beam evaporation respectively. The diameter of circular Schottky contacts is 800 μm. The diodes were annealed in N_2 for 35 min at 400 °C before the measurement of I–V characteristics to improve their thermal stability. The temperature-dependent I–V characteristics of the diodes were performed in vacuum using an Agilent 4155C semiconductor parameter analyser and an Accent HL 5590 hot stage.

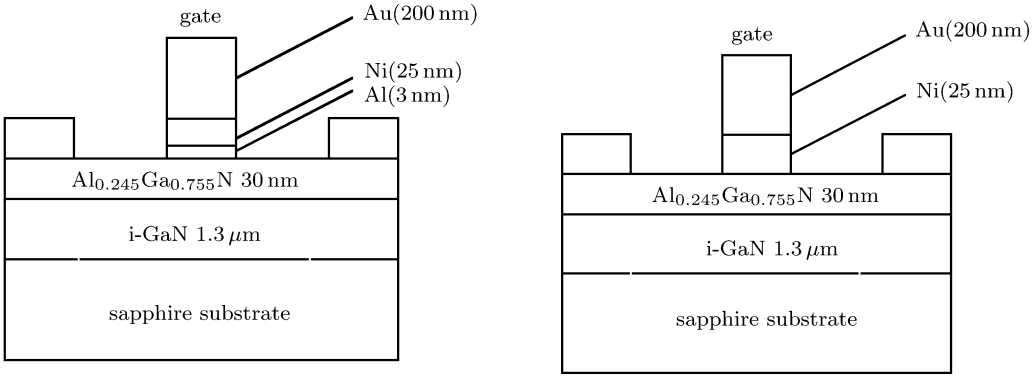


Fig.1. The cross sections of the fabricated AlGaN/GaN Schottky diode with Al layer and without Al layer. (a) the Schottky diode with Al layer; (b) the Schottky diode without Al layer.

3. Results and discussion

Figure 2 shows that the minimum point of I–V curves in the diode without Al layer and with Al layer. As we can see, the minimum point of I–V curve in the diode with Al layer drifts to the minus voltage. However, the minimum point in the diode without Al layer does not drift. The minimum point in the diode with Al layer returns to the 0 V voltage when the temperature reaches 75 °C. These asymmetries of I–V curves may be caused by the interface states located at the interface between Al_2O_3 and $Al_{0.245}Ga_{0.755}N$ barrier.[6] Because the Al inserting layer highly reacts with oxygen located at the boundary of $Al_{0.245}Ga_{0.755}N$ surface and the gate metal, aluminium and oxygen form the Al_2O_3 insulated layer. Many interface states exist at the interface. When we increase the bias voltage from –10–3 V, the electrons from the channel will

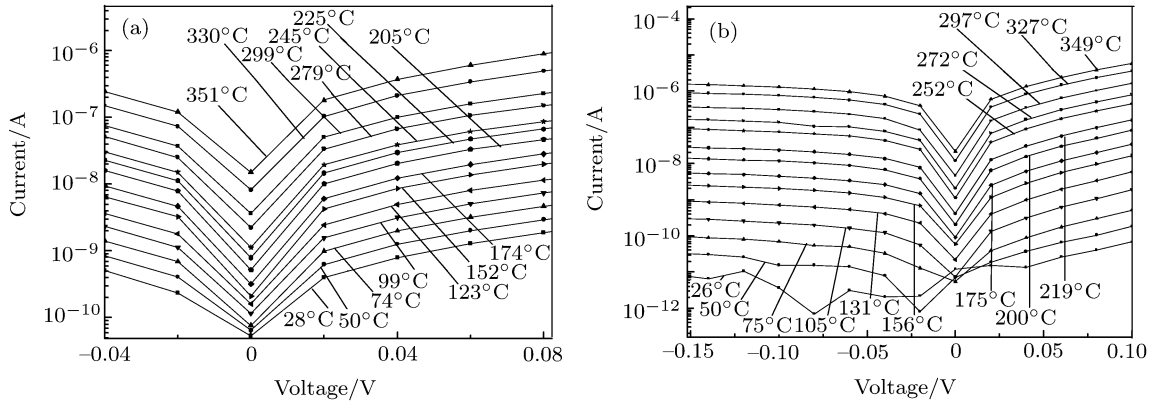


Fig.2. The minimum point of I–V curve. (a) the I–V curve without Al layer; (b) the I–V curve with Al layer.

fill the interface state and induce forward charging current. The forward charging current will counteract the reverse leakage current. This leads to the drifting of the minimum point of I–V curve in the diode with Al inserting layer. When the temperature increases, the interface states will be crammed. The minimum point of I–V curves will return the 0 V voltage.

In order to gain the conduction mechanism, we describe the gate-leakage current at –8 V voltage in the diode without Al layer and the diode with Al layer in Fig.3. On the one hand, from Fig.3 we can see that the rapid increase with the increase of temperature is less than that in the traditional diode, on the other hand, the gate leakage current in the diode with Al layer is less than that in the diode without Al layer as mentioned in Ref.[5]. It has been observed that the leakage current is nearly independent of the temperature between 28–225 °C in the diode without Al inserting layer. Above 225 °C, the leakage current rapidly increases with the temperature. However, in the diode with Al layer, the current smoothly increases with the increase of the temperature.

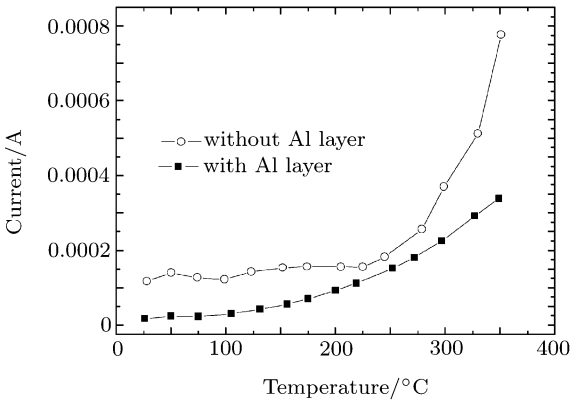


Fig.3. The gate-leakage current at –8 V voltage in the diode without Al layer and the diode with Al layer.

We are aware of some reports which discuss the change of the leakage current with the change of the temperature.[7–9] The literature reported that trap-assisted tunnelling dominates below $T \sim 223$ °C, and thermionic field emission dominates at higher temperatures in the Ni/Au/$Al_{0.245}Ga_{0.755}N$/GaN Schottky diode.[10] In our report, the model is used. And it is thought that traps are induced by dislocation in $Al_{0.245}Ga_{0.755}N$.[10] Oxygen located at the surface of $Al_{0.245}Ga_{0.755}N$ is distributed around concentrative dislocation.[11] The conduction mechanisms are shown in Fig.4.

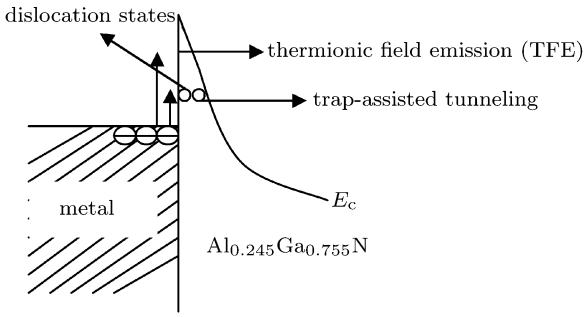


Fig.4. Schematic diagram showing possible conduction mechanisms responsible for Ni/Au/AlGaN/GaN Schottky diodes.

When the thin Al layer is inserted between Ni/Au gate and $Al_{0.245}Ga_{0.755}N$/GaN, the oxygen distributed around dislocation highly reacts with Aluminium. At the same time Al_2O_3 insulated layer is formed. So the electrons are not able to traverse the Al_2O_3 insulated layer into the dislocation line. And they are not able to permeate into 2DEG channel through the dislocation line. The trap-assisted tunnelling current is suppressed obviously. In the diode with Al layer, the trap-assistant tunnelling is suppressed, and thermionic field emission dominates at 25–225 °C. This is the reason that the gate leakage current in the diode with Al layer is less than in the diode without Al layer. At the same time because oxygen disappear, the barrier becomes thicker. And if the electrons want to arrive at $Al_{0.245}Ga_{0.755}N$, they must traverse the Al_2O_3 barrier and the $Al_{0.245}Ga_{0.755}N$ triangle barrier. Because the total barrier is thicker than the diode without aluminium, the trend of thermionic field emission current increasing with the increasing temperature is also suppressed. The conduction mechanisms are shown in Fig.5.

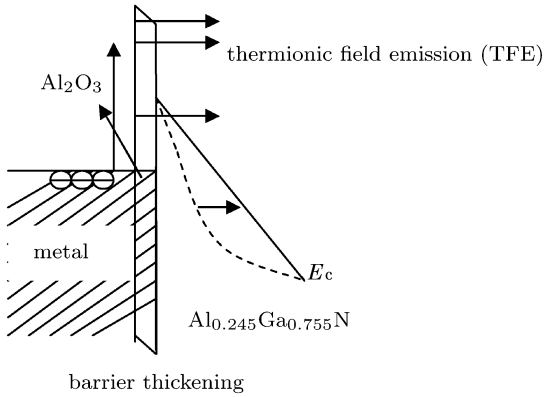


Fig.5. Schematic diagram showing possible conduction mechanisms responsible for the Schottky diodes with Al inserting layer.

In summary, the temperature dependence of gate-leakage current in the Schottky diode with a thin Al inserting layer in the temperature range of 25–350 °C is investigated. The results show that Al layer reacted with oxygen formed Al_2O_3 insulator layer, and the interface states exist at the interface between Al_2O_3 and $Al_{0.245}Ga_{0.755}N$ barrier. The interface states introduce that the minimum point of I–V curve drifts to the minus voltage. And for the Al_2O_3 insulator layer the trap-assisted tunnelling current is reduced obviously and the trend of TFE current is also suppressed. So the gate leakage in the diode with Al layer is not only less then that in the diode without Al layer, but also the rapid increase with the increasing temperature is less than that in the traditional diode.

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