Influence of annealed ohmic contact metals on polarisation of AlGaN barrier layer

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The influence of annealed ohmic contact metals on the polarisation of the AlGaN barrier layer has been investigated by the Schottky contacts on the AlGaN/GaN HFET structure. The analysed result shows that annealed ohmic contact metals weaken the polarisation of the AlGaN barrier layer. When ohmic contact metals are close to Schottky contact metals, the weakened polarisation decreases the 2DEG sheet carrier concentration in the channel.

AlGaN/GaN heterostructure field-effect transistors (HFETs) have been a subject of intense investigation and are excellent candidates for high voltage, high power operation at microwave frequencies because of the unique material properties [1, 2]. It has been shown that the piezoelectric and spontaneous polarisation can exert a substantial influence on the concentration and distribution of free carriers in strained AlGaN/GaN based HFETs [3, 4]. For high frequency AlGaN/GaN HFET devices, the gate length is submicron, and the distance between gate and source drain is very small. To date we have not seen any reports of whether annealed source and drain metals have an influence on the polarisation of the AlGaN barrier layer or not. If annealed source and drain metals affect the polarisation of the AlGaN barrier layer, which will directly affect the characteristics of the channel under the gate, such as the two-dimensional electron gas (2DEG) sheet carrier concentration and the barrier height of gate metals, it is important to investigate the influence of annealed ohmic contact metals on the polarisation of the AlGaN barrier layer. In the work reported in this Letter, Schottky contacts with different separation between ohmic contact metals and Schottky contact metals were made on the undoped AlGaN/GaN HFET structure. With the measured *C–V* characteristics, we investigated the influence of annealed ohmic contact metals on the polarisation of the AlGaN barrier layer.

The layer used in this study was epitaxially grown by metal organic chemical vapour deposition (MOCVD) on a (0001) sapphire substrate. It consisted of a 40 nm AlN nucleation layer, followed by a 3 µm undoped GaN, and a 20 nm thick undoped $Al_{0.25}Ga_{0.75}N$. Hall measurement indicated a sheet carrier density of around 9×10^{12} cm^{-2} and an electron mobility of 1100 cm^2/Vs at room temperature. For the device processing, ohmic contacts of Ti/Al/Mo/Au were performed by e-beam evaporation and lift off. These contacts were annealed at 900°C for 30 s in a rapid thermal annealing system (RTA). The circular Schottky contacts of 120 µm diameter of Ni/Au (600 A/3000 A) were then deposited by e-beam evaporation. The separations between ohmic contact metals and Schottky contact metals are 40, 20 and 10 µm, separately. *C–V* measurements were performed using an Agilent 4284A at 10 kHz frequency.

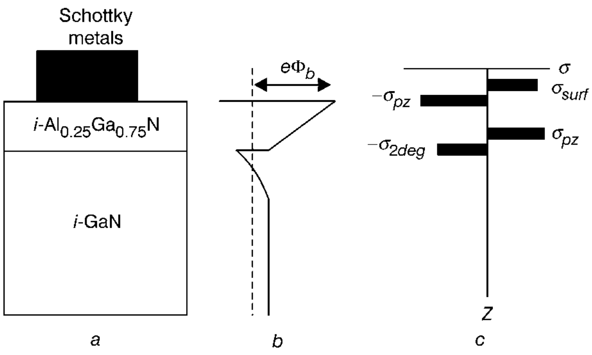

Fig. 1 *Schematic diagrams of structure*

a Schematic diagram of nominally undoped $Al_{0.25}Ga_{0.75}N$/GaN HFET structure
b Conduction-band energy diagram
-------- represents Fermi level $e\Phi_b$: Schottky barrier height
c Schematic diagram of surface states, piezoelectrically induced and free-carrier charge distribution

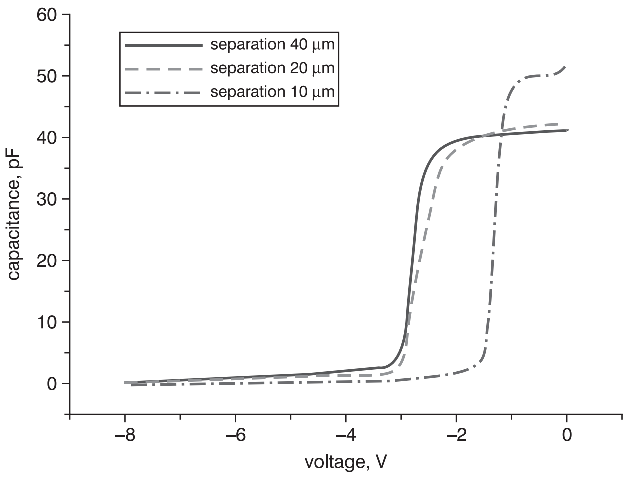

Fig. 2 *Capacitance–voltage curves for Schottky contacts with different separations between ohmic contact metals and Schottky contact metals*

The undoped $Al_{0.25}Ga_{0.75}N$/GaN HFET structure, the conduction-band energy diagram, and surface state, polarisation-induced and free carrier charge distribution are shown in Fig. 1. The polarised charges σ_{pz} and $-\sigma_{pz}$ are formed at the AlGaN/GaN interface and at the AlGaN surface, respectively, due to the strong polarised electric field in the strained $Al_{0.25}Ga_{0.75}N$ layer. The electrons of $Al_{0.25}Ga_{0.75}N$ surface states flow to the $Al_{0.25}Ga_{0.75}N$/GaN interface and a 2DEG is formed [5]. The negative charges of the 2DEG cancel partially induced polarised charges [6], which reduces the polarisation electric field in the AlGaN barrier layer and the barrier heights for Schottky contacts on the AlGaN barrier layer. Thus, the sheet charge density of the 2DEG is strongly related to the Schottky barrier height. Fig. 2 shows the *C–V* curves of Ni Schottky contacts with different distance between ohmic contact metals and Schottky contact metals at room temperature. There is a capacitance platform in the *C–V* curves, and with 40 and 20 µm separation between ohmic contact metals and Schottky contact metals the capacitance platform value is almost the same, while the capacitance platform value with 10 µm separation between ohmic contact metals and Schottky contact metals is higher than that of 40 and 20 µm separation. The capacitance platform corresponds to the change of 2DEG charge quantity in the channel under applied AC signal (ΔV), and the greater change of 2DEG charge quantity in the channel results in a higher capacitance value. Moreover, the 2DEG charge density is decreased when the bias is decreased. Therefore, the 2DEG charge quantity can be obtained by the *C–V* curve integration [7]. The integrated results show that the 2DEG sheet carrier concentrations of Ni Schottky contacts with 40, 20 and 10 µm separation between ohmic contact metals and Schottky contact metals are 6.4×10^{12} cm^{-2}, 6.1×10^{12} cm^{-2} and 3.7×10^{12} cm^{-2}, respectively. With 40 and 20 µm separation between ohmic contact metals and Schottky contact metals, the integrated 2DEG sheet carrier concentrations are almost the same. This shows that this integrated 2DEG sheet carrier concentration corresponds to the 2DEG electrons under Schottky contact metals, which does not include the 2DEG electrons between Schottky contact metals and ohmic contact metals. With 10 µm ohmic contact metals and Schottky contact metals separation, the integrated 2DEG sheet carrier concentration is lower than that of 40 and 20 µm separation. The reason for the different 2DEG sheet carrier concentrations is attributed to the influence of the annealed ohmic contact metals on the polarisation of the AlGaN barrier layer. As the distance between the ohmic contact metals and Schottky contact metals becomes less, the influence of the annealed metals on the polarisation of the AlGaN barrier layer which is located under the Schottky contact metals is increased. The surface donor states of the AlGaN barrier layer is the source of 2DEG electrons in the channel for undoped AlGaN/GaN HFET structure [5]. With different polarisation, the polarisation electric field in the AlGaN barrier layer is different. When the polarisation is weak, the polarisation electric field in the AlGaN barrier layer is also weak. Then less donor states have an energy above the Fermi level, as is shown in Fig. 3, and less surface donor electrons are ionised to go into the AlGaN/GaN interface and form the 2DEG. This is the reason why there is less 2DEG sheet carrier concentration for 10 µm ohmic contact metals and Schottky contact metals separation. Therefore, the conclusion can be made that annealed ohmic contact metals weaken the polarisation of the AlGaN barrier layer. When annealed ohmic contact metals are close to Schottky contact metals, the weakened polarisation decreases the 2DEG sheet carrier concentration in the channel.

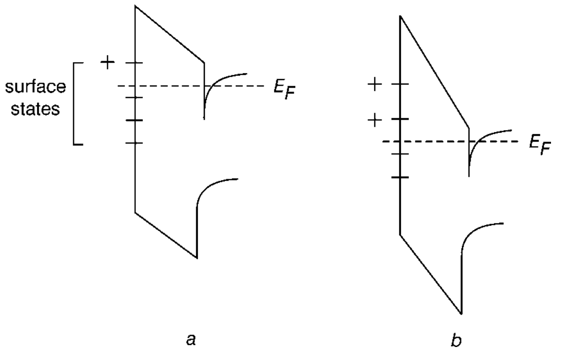

Fig. 3 *Schematic energy band diagram for different polarisation*
a Weak polarisation *b* Strong polarisation

Conclusion: We have investigated the influence of annealed ohmic contact metals on the polarisation of the AlGaN barrier layer by Schottky contacts on the undoped AlGaN/GaN HFET structure. With the measured Schottky contact *C–V* curves of different separation between ohmic contact metals and Schottky contact metals, the 2DEG sheet carrier concentrations are obtained. The analysed result shows that annealed ohmic contact metals weaken the polarisation of the AlGaN barrier layer. When ohmic contact metals are close to Schottky contact metals, the weakened polarisation decreases the 2DEG sheet carrier concentration in the channel.

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