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Characteristics of GaN MESFET Grown on Sapphire Substrate by MOCVD

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1. Introduction

GaN materials are attractive for electronic devices operating under high-power and high-temperature conditions due to large band gap, large peak electron velocity, large saturation velocity, large breakdown field and chemical inertness. There have been many researches on GaN-based metal semiconductor field effect transistors (MESFETs), high electron mobility transistors (HEMTs), and metal insulator semiconductor FETs (MISFETs). The GaN layer grown on the sapphire substrate by MOCVD contains the high dislocation density in transmission electron microscopy observation and the deep level emission in photoluminescence (PL) measurement. However, the effects of these problems on the GaN MESFET have not been studied. In this study we report the electrical characteristics such as sidegating effect and microscopic uniformity, which are important for fabrication of GaN LSI.

2. Experimental

Figure 1 shows the cross-sectional structure of the GaN MESFET grown on a (0001) sapphire substrate by MOCVD. The epitaxial layers consist of a 30-nm-thick GaN nucleation layer, a 2.4-μm-thick undoped GaN layer and a 0.2-μm-thick n-GaN layer with Si doped to ~2×10^{17} cm^{-3}. Using standard photolithographic technique 22 x 215 μm mesas were defined on the n-GaN layer. These mesas were electrically isolated by reactive ion etching in a BCl_3 plasma and by using photoresist as the etch mask. The drain-source ohmic contacts were obtained with Ti/Al (25 nm/150 nm) annealed at 900 °C for 60 sec in N_2 ambient. The gate metalization was done by vacuum evaporation of Pt/Ti/Au (10 nm/40 nm/100 nm). The gate length and width of the GaN MESFET were 2 and 200 μm, respectively, and the channel opening (source to drain distance) was 10 μm. The test patterns which consist of the n-GaN layers separated from each other by 50-μm were used to study the uniformity of the electrical property. The 270-μm-wide sidegate electrodes were placed 5, 10, 20 and 60 μm away from the source electrode of the GaN MESFET. The undoped GaN layer on sapphire was studied by room-temperature PL excited with the 325 nm line of HeCd laser. Hall measurements were performed for the n-GaN layer in order to measure the electron mobility and the carrier concentration at 77, 130 and 300 K.

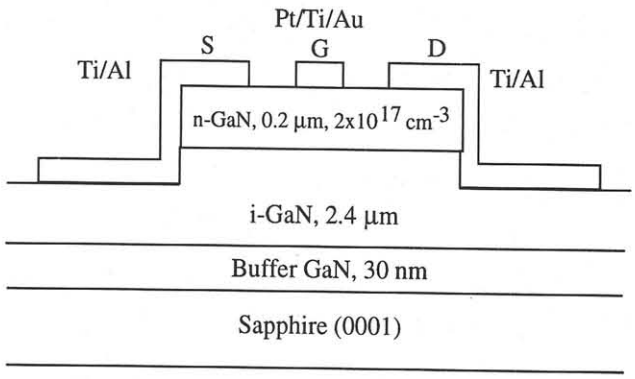

Fig. 1. Cross-sectional structure of GaN MESFET grown on sapphire by MOCVD.

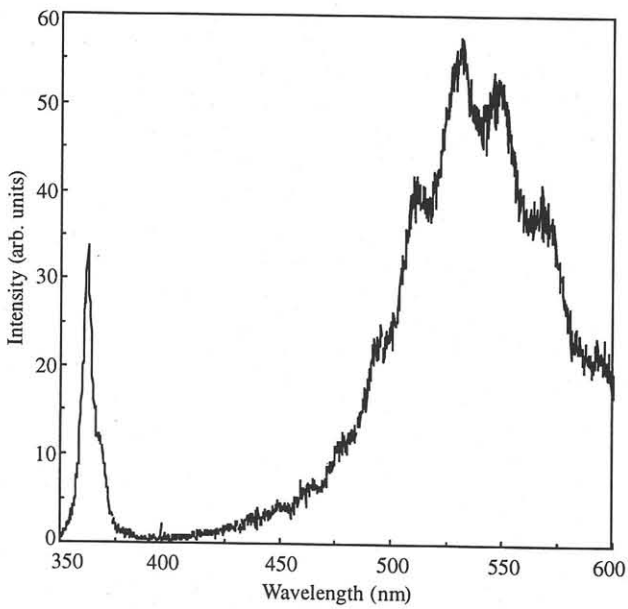

Fig. 2. PL spectrum at 300 K of the undoped GaN layer grown on sapphire by MOCVD.

3. Results and Discussion

Figure 2 shows the PL spectrum of the undoped GaN layer. PL spectrum showed the near-band emission at 361 nm and the deep-level emission centered at 532 nm. This deep-level emission has been associated with the clustering of native point defects or impurity atoms. The Hall mobilities of the Si-doped GaN layer were 585 $cm^2/V\cdot s$ with the electron carrier concentration of 1.1×10^{17} cm^{-3} at 300 K, and 1217 $cm^2/V\cdot s$ with 2.4×10^{16} cm^{-3} at 77 K. The maximum Hall mobility was 1476 $cm^2/V\cdot s$ with the electron carrier concentration of 5.4×10^{16} cm^{-3} at 130 K. The Hall mobility obtained in this sample is much higher than the previous results.

Figure 3 shows the drain-source current I_{DS} characteristic as a function of the drain-source voltage V_{DS} for the gate biases V_G ranging from +1 to -11 V at 300 K.

For V_{DS} = 20 V, the GaN MESFET showed the extrinsic gm of 31 mS/mm, which was higher than the previously reported MESFETs. The value of I_{DS} at V_G = 1 V was about 288 mA/mm at V_{DS} = 20 V. The GaN MESFET exhibited modulation characteristic with nearly complete pinch-off at a threshold voltage of approximately -11 V. An ionized donor concentration profile obtained from Schottky barrier C-V measurement is shown in Fig. 4. A sharp interface was obtained between the n-GaN and the undoped GaN layers. The good pinch-off characteristic in Fig. 3 results from the sharp interface. Figure 5 shows the normalized drain-source current I_{DS} as a function of the sidegate bias V_{SG}. The drain-source current decreases with increasing the negative sidegate bias and decreasing the distance between the source and sidegate pad. It was found that the reduction of transconductance and drain-source current related to the sidegate current. The sidegating effect in the GaN MESFET is thought to be caused by the deep-level observed in the PL emission.

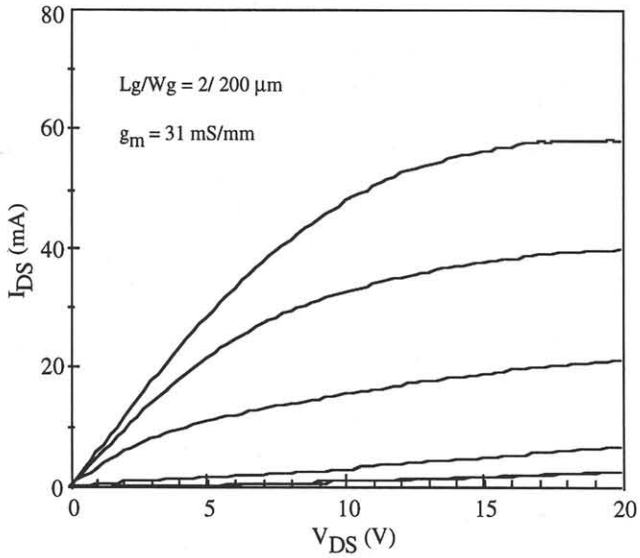

Fig. 3. Drain-source current I_{DS} characteristic as a function of the drain-source voltage V_{DS}. The gate length and width are 2 and 200 μm, respectively.

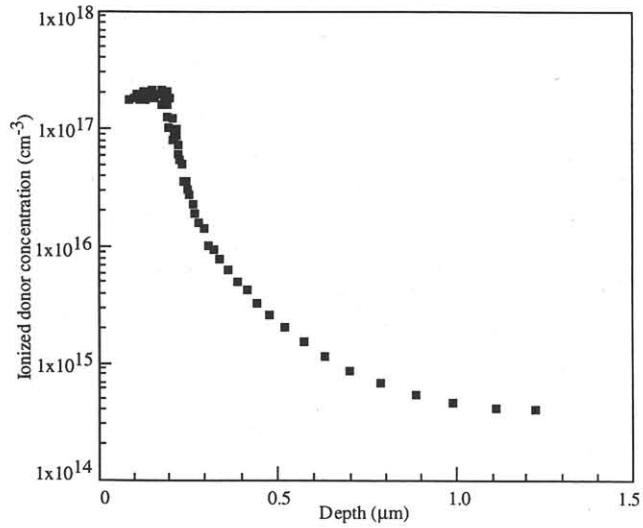

Fig. 4. Ionized donor concentration profile of GaN MESFET structure grown on sapphire by MOCVD.

Uniformity of the sheet resistance for the n-GaN layer is shown in Fig. 6. The values of average and standard deviation for the sheet resistance were 393.9 and 20.8 Ω/□, respectively. The uniformity of the electrical property seems to be insensitive to the high dislocation density in the GaN layer.

4. Conclusions

We have fabricated the GaN MESFETs on the sapphire substrate by MOCVD. The electron mobilities of the n-GaN layer were 585 and 1217 $cm^2/V\cdot s$ at 300 and 77 K, respectively. High current level of 288 mA/mm and large transconductance of 31 mS/mm have been achieved for the GaN MESFET with the gate length of 2 μm and width of 200 μm. The GaN MESFET showed the sidegating effect, which was thought to be due to the deep-level in the undoped GaN layer. The high dislocation density in the GaN layer does not affect the microscopic uniformity of the electrical property.

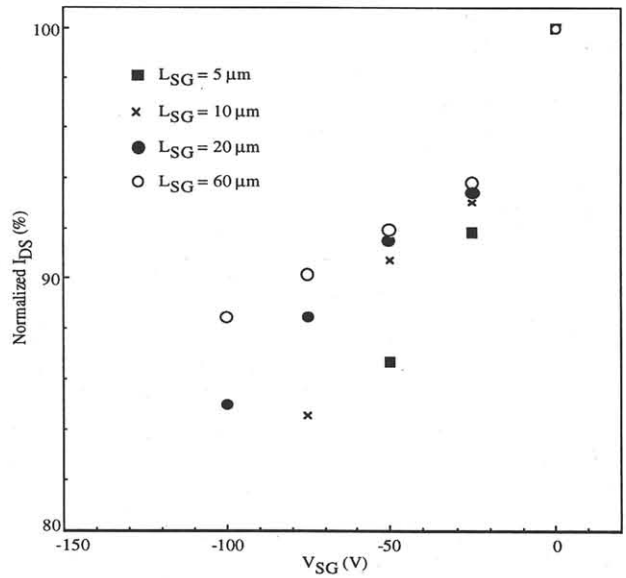

Fig. 5. Normalized drain-source current I_{DS} as a function of the sidegate bias V_{SG}. The sidegate pad is located 5, 10, 20 and 60 μm away from the source of the device.

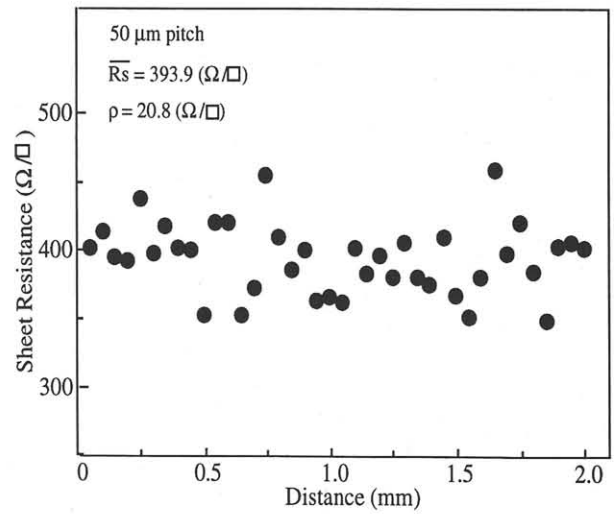

Fig. 6. Microscopic uniformity of sheet resistance for the n-GaN layer grown on sapphire.