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Temperature-Dependent Characteristics of an Sulfur-Passivated AlGaAs/InGaAs/GaAs Pseudomorphic High Electron Mobility Transistor (PHEMT)

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1. Introduction

Recently, pseudomorphic HFETs are well developed and exhibit superior microwave performance [1-2]. For achieving high power and good stability, the improvement of breakdown characteristics between gate and drain is a necessary condition. Unfortunately, the poor surface properties of compound semiconductors degrade the performances of electronic and optical devices based on the metal-semiconductor structure. To improve the device performances, the development of an appropriate surface passivation of semiconductor materials has attracted significant interest [3]. One effective method to prepare a flat and stable surface is known as the sulfur passivation of the surfaces [4]. Even for the highly defective surface of the III-V compound semiconductors, the method involving chemical treatment with $(NH_4)_2S_x$ solution was shown to be more useful to passivate the device surface [5-6]. In this work, for the first time, the characteristics of an AlGaAs /InGaAs/GaAs pseudomorphic high electron mobility field-effect transistor (PHEMT) with $(NH_4)_2S_x$ treatment are studied and demonstrated. The sulfur passivation is performed on the surface of AlGaAs barrier layer. This passivation can remove the native oxide and enhance the dependence of the Schottky barrier height on the work function of the contact metal [5, 7]. This implies that the gate depletion layer can be properly formed, which is of benefit to control the device parameters. Therefore, good DC and microwave properties, higher temperature operation capability, and relatively temperature -insensitive behaviors can be expected.

2. Results and Discussion

The schematic cross-section of the studied device is illustrated in Fig. 1. The studied device was grown on a (100)-oriented semi-insulating (S.I.) GaAs substrate by a metal-organic chemical vapor deposition (MOCVD) system. The epitaxial structure consisted of a 4000-Å GaAs buffer, a 200-Å AlAs buffer, a 50-Å $Al_{0.25}Ga_{0.75}As$ spacer, a delta-doped sheet $\delta_2(n^+)=1\times10^{12}$ cm^{-2}, a 50-Å $Al_{0.25}Ga_{0.75}As$ spacer, a 150-Å $In_{0.15}Ga_{0.85}As$ channel, a 50-Å $Al_{0.25}Ga_{0.75}As$ spacer, a delta-doped sheet $\delta_1(n^+)=4\times10^{12}$ cm^{-2}, a 400-Å $Al_{0.25}Ga_{0.75}As$ ($n=3\times10^{17}$ cm^{-3}) barrier, a 300-Å n-GaAs ($n=3\times10^{17}$ cm^{-3}) spacer, and a 500-Å n^+-GaAs ($n^+ \geqq 3\times10^{18}$ cm^{-3}) cap layers. The upper $Al_{0.25}Ga_{0.75}As$ layer provides good Schottky characteristics and lower AlAs layer suppresses the substrate leakage current through the substrate leakage path. After epitaxial growth, the wet chemical etching process was used for device isolation. Drain-source Ohmic contacts were formed on the n^+-GaAs cap layer by alloying evaporated AuGe/Ni/Au metals at 430°C for 3 minutes. Then, n^+-GaAs cap and n-GaAs space layers were removed. Prior to gate metal deposition, the sample (device A) was immediately passivated by soaking in the ammonia-sulfide ($(NH_4)_2S_x$, 5%) solution for 10 minutes at room temperature. For comparison, another device (denoted device B) prepared with the same process only without $(NH_4)_2S_x$ treatment was also included in this work. Finally, gate Schottky contacts with the gate length of 1 μm were achieved by evaporating Pt/Au metal on the $Al_{0.25}Ga_{0.75}As$ barrier layer.

Figure 2 shows the Schottky barrier height (Φ_B) and ideality factor (n), determined by the gate-drain I-V characteristics, as a function of temperature. The inset shows forward logarithmic I_G versus V_{GD} at T=300 and 510K. The deviations of Φ_B and n are 2.1 (3.1) % and 10.1 (11.5) % of device A (B) as the temperature is increased from 300 to 510K. Obviously, device A demonstrates lower degradation rates with temperature. In addition, the sulfur passivation enhances the dependence of Schottky barrier height on metal work functions [5-7]. Hence, the deposition of Pt/Au on the sulfur-passivated AlGaAs surface moves the Fermi level within the band gap toward the band bending direction [5-6]. This implies that the relatively higher turn-on voltage of device A can be obtained. As a result, the sulfur-passivated device allows a large induced current in the channel which can enhance the output power capability. The typical common-source I-V characteristics of the device A at different temperature are shown in Fig. 3. The applied gate-source voltage is V_{GS} =-0.5 V/step and maximum V_{GS} is +1.0 V. It is known that a thermal stable Schottky contact is important in channel control ability as well as device reliability [1-2,8]. Due to the excellent Schottky behaviors and carrier confinement effect associated with high turn-on voltage and insignificant gate leakage current, good pinch-off and saturation characteristics are obtained under various temperature as shown in Fig. 3. Apparently, upon the $(NH_4)_2S_x$ treatment, the Schottky and breakdown characteristics are improved.

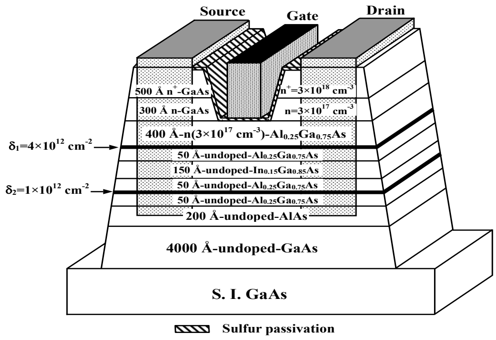

Fig. 1 Schematic cross-section of studied device.

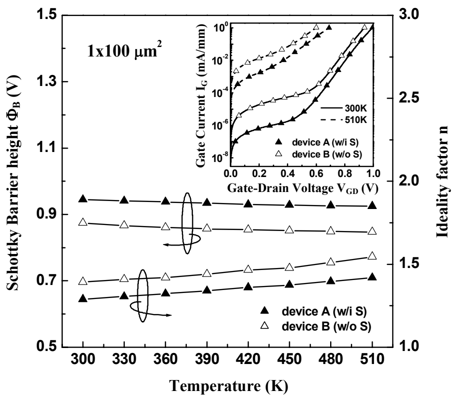

Fig. 2 The Φ_B and n as a function of temperature. The inset shows logarithmic I_G versus V_{GD} at 300 and 510K.

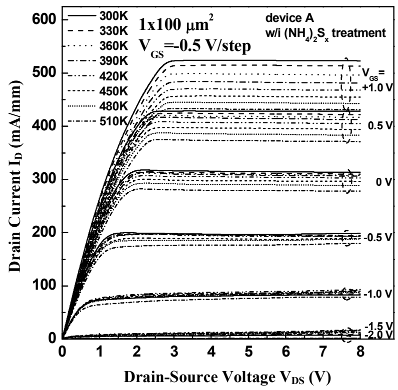

Fig. 3 Typical common-source I-V characteristics of the device A at different temperature.

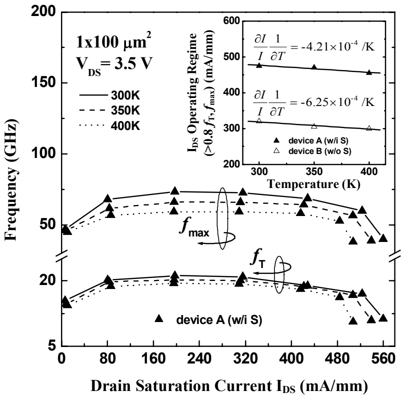

Fig. 4 The f_T, f_{max}, and I_{DS} operating regime (>0.8 f_T, f_{max}) as a function of temperature.

This can enhance the gate voltage swing and then cause the potentiality of enhancement-mode operation even at higher temperature environments [8].

The dependences of f_T and f_{max} on the I_{DS} at different temperature are illustrated in Fig. 4. The inset shows I_{DS} operating regime (>0.8 f_T, f_{max}) as a function of temperature. The bias condition is fixed at V_{DS}=3.5V. All profiles of device A display the plateau distributions broader than those of device B. Especially, the I_{DS} degradation rate with temperature ($\partial I/I \cdot 1/\partial T$), from 300 to 400 K, of device A is only of -4.21×10^{-4}/K. This value is lower than that of device B and is relatively insignificant. Therefore, based on the better linearity and thermal stability in wide I_{DS} operating regimes of device A, the sulfur treatment is also useful in microwave characteristics.

3. Conclusions

The influences of $(NH_4)_2S_x$ treatment on an AlGaAs /InGaAs/GaAs PHEMT are studied and demonstrated. The related temperature-dependent characteristics are also studied. Under the sulfur treatment, the remarkable improvements on the DC and RF characteristics of the studied device are obtained. Moreover, the sulfur -passivated device shows better high-temperature performances and thermal stability over the operating temperature range (300 ~ 510K). Consequentially, the studied device with $(NH_4)_2S_x$ treatment provides the promise for high-performance digital and microwave device applications.

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