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Thermal Stability of AlGaN/GaN HEMTs Using High Work Function Pd-gate, Ir-gate, Ni-gate Designs

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1. Introduction

Wide bandgap AlGaN/GaN high electron mobility trransistors (HEMTs) are emerging as excellent candidates for RF/microwave power amplifiers (PAs) because of their high frequency and power handling capabilities [1]. However, thermal effects can be an important issue in RF power devices, owing to the huge amount of heat generated during their operation [2]. A Schottky gate that is stable at high temperatures, and that has significantly less metal diffusivity and a large barrier height, must be developed. In this study, the temperature-dependent characteristics of AlGaN/GaN with a palladium(Pd)–GaN and a Iridium(Ir)-GaN Schottky contact are investigated and compared with conventional Ni-GaN Schottky contact devices cooperate to copper manufacture, in terms of their dc, flicker noise, microwave and RF power performance at temperatures ranging from room temperatures to 100 ℃ due to Pd and Ir exhibits low diffuse and corrodibility in chemical solution and high thermal stability [3][4]. Device with Pd-buried gate using Copper manufacture exhibit a lower degradation for dc and RF characteristics at high temperatures, which also results in better device reliability. Therefore, Pd-buried gate devices are very promising for microwave power device applications operating at high temperature.

2. Device Design and Fabrication

Fig.1 shows the structure cross section of the AlGan/GaN HEMT. A 1.8 µm undoped AlN buffer layer, a 0.8 µm undoped GaN layer, a 18 nm undoped $Al_{0.27}Ga_{0.73}N$ layer, and a 1 nm GaN cap layer were sequentially grown by metal-organic chemical vapor deposition on a 4-in. silicon substrate. For device fabrication, the active region was protected by photoresist and mesa isolation region was removed by BCl_3 + Cl_2 mixture gas plasma in reactive ion etcher (RIE) chamber. Device were processed by conventional optical lithography and lift-off technology. Ohmic contacts were formed by electron-beam deposition of Ti/Al/Ni/Au followed by a 850 ℃, 30 s RTA annealing in N_2 ambient. 1.0-µm gate-length Pd/Ni/Cu/Au or a Ir/Ni/Cu/Au (20nm/20nm/200nm/20nm) composite metal was deposited using an electron-beam evaporator to form gate electrodes. For comparison, the traditional Ni/Cu/Au gate AlGaN/GaN HEMT was also fabricated. Finally, the interconnection level was used by Ti//Cu/Au (30nm/1000nm/20nm) metal layer and an 200nm SiO_2 was deposited for device passivation.

3. Results and Discussion

A thermally stable Schottky barrier height is important in determining the channel control ability of the gate terminal as well as the devices reliability. The barrier heights and ideality factors for the Schottky diodes, determined by the characteristics of I_g-V_g, and the results are shown in Fig.2. The Pd-gate exhibited an excellent temperature-independent Schottky contact characteristic in terms of the Schottky barrier height and ideality factors that are comparable to Ir-gate and Ni-gate. The variation from room temperature to 100 ℃ is 3.56% for the barrier height (0.703~0.678 eV) and 3.91% for the ideality factor (1.28~1.33), respectively; these numbers are 7.99% (0.601~0.553 eV) and 10.87% (1.38~1.53); 5.32% (0.639~0.605) and 6.01% (1.33~1.41) for the Ni-gate and Ir-gate devices.

Further dc characteristic investigations of a 1.0-µm gate-length device are described in Fig.3, where two sets of drain-to-source current (I_{ds}) versus drain-to-source voltage (V_{ds}) curves of Ni-gate, Pd-gate and Ir-gate measured at room temperature and 100 ℃, respectively are shown. The Pd-gate demonstrate a small variation in the drain current at high bias, proving that the Pd-gate characteristics are less affected by temperature. Meanwhile, the pd-gate device transconductance (g_m) exhibits a slight decrease of 6.7% from room temperature to 100 ℃; 23.4% and 12.4% drop for Ni-gate and Ir-gate. In addition, three devices demonstrate a higher dc output resistance at 100 ℃ owing to higher self-heating in the channel. These results are corresponding to the degradation of Schottky gate performance directly.

Fig.4 and Fig.5 show the device dc transconductance and the maximum drain current, f_T and f_{max} for Ni-gate, Pd-gate and Ir-gate devices versus their operating temperatures from room temperature to 100 ℃, respectively. Both the dc and RF gains of Pd-gate demonstrate thermally stable characteristics (Peak g_m from 141.5 to 132 mS/mm, Id_{max} from 720 to 688 mA/mm, f_T from 9.5 to 8.5 GHz and f_{max} from 15.7 to 14.2 GHz) for this temperature range; however, the Ni-gate reveal almost average 20% decay in this temperature range.

Low frequency noise measurement, which was sensitive to the semiconductor interface, was made to elucidate further the relationship between the flicker noise and the interface property of the metal-semiconductor contact. As presented in Fig.6, the Pd-gate achieved a lower noise spectra density than the conventional Ni-gate because the inert property and lesser gate metal diffusivity.

Temperature-dependent microwave power measurements were performed by a load-pull system with automatic tuners to measure the optimum load impedance for the maximum output power. The microwave load-pull power performance was evaluated at 3.5 GHz, with a drain bias of 8 V for three devices, for 1x100 μm^2 gate–dimension devices. After raising the temperature up to 100 ℃, the Pd-gate reveal an P_{out} shift from 14.58 to 14.15 dBm shown in Fig.7 and a linear G_p from 11.97 to 9.59 dB. However, for the Ni-gate and Ir-gate results, these microwave power characteristics corresponded to a significant 43.7% and 32.5% drop, after raising the temperature to 100 ℃.

4. Conclusions

In conclusion, we investigated the device Schottky contacts, the dc, the RF and the microwave power characteristics, and all the experimental results lead to the same conclusion, that Pd-gate do exhibit better thermal performance and to improve the flicker noise in the device. These superior thermally stable properties, together with the high current driving capability and the better device linearity, prove Pd-gate HEMTs to be a very promising candidate for microwave power device applications.

References

[1] Yong Cai, et al., IEEE Electron Device Lett. **26** (2005) 435.

[2] H. C. Chiu, et al., IEEE Trans. Electron Devices, **48** (2001) 2210.

[3] B. F. Hung, et al., IEEE Trans. Electron Devices, **54** (2007) 257.

[4] L. Wang, et al., Appl. Phys. Lett. **89** (2006) 2119910.

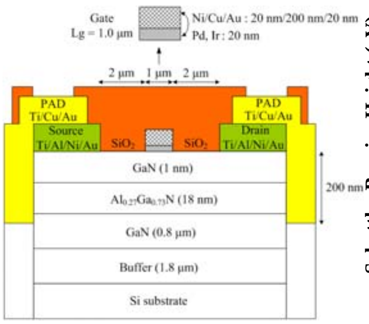

Fig. 1 The structure cross section of the AlGaN/GaN HEMT.

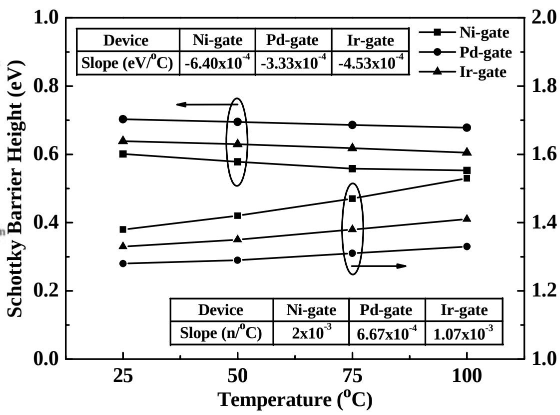

Fig. 2 Schottky barrier height and ideality factor versus temperatures for Ni-gate、Pd-gate and Ir- gate HEMTs.

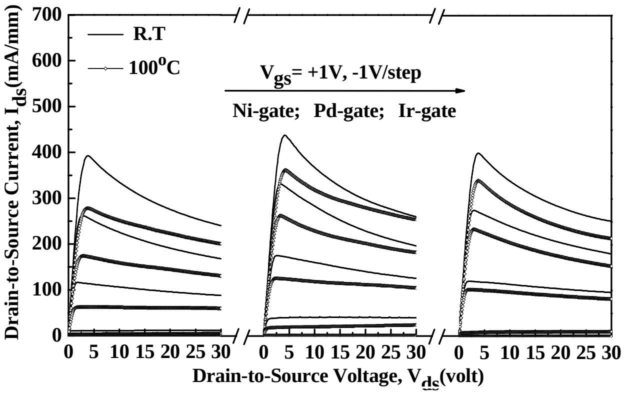

Fig. 3 Device I_{ds}-V_{ds} characteristics of three devices for a gate-length of 1.0 μm at 25 ℃ and 100 ℃.

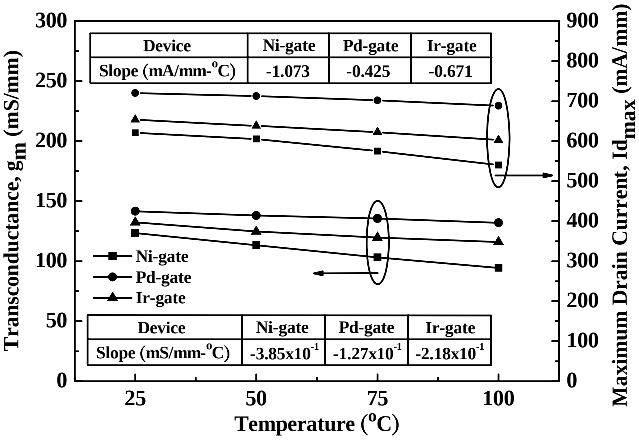

Fig. 4 g_m, I_{dmax} of three devices with a gate length of 1.0 μm at different temperatures.

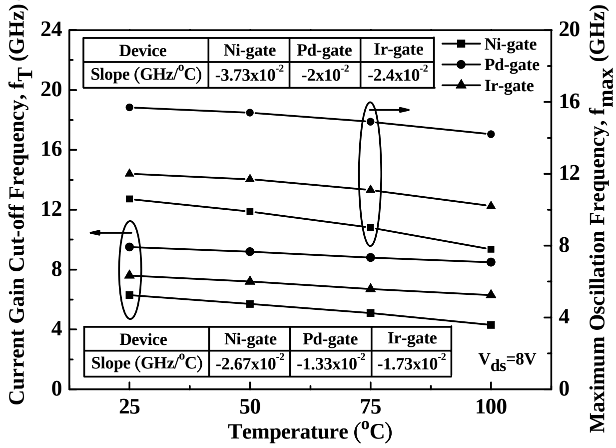

Fig. 5 f_T, f_{max} of Ni-gate、Pd-gate and Ir-gate HEMTs with a gate length of 1.0 μm at different temperatures.

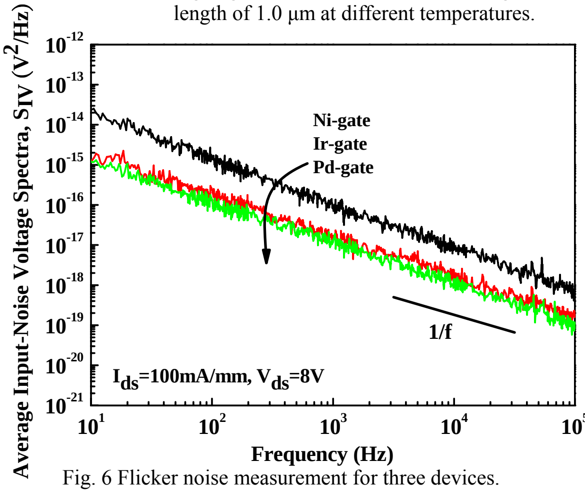

Fig. 6 Flicker noise measurement for three devices.

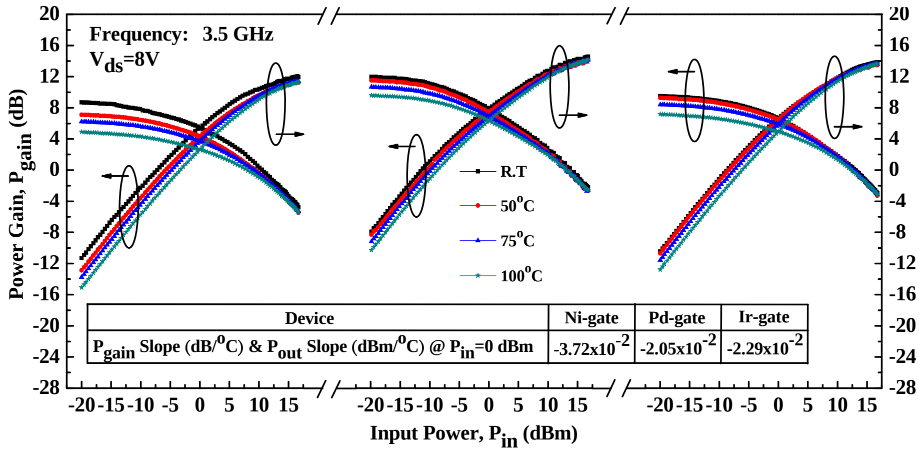

Fig. 7 Power performance of AlGaN/GaN three devices versus temperature at 3.5 GHz.