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High performance 70 nm $In_{0.8}GaP/In_{0.4}AlAs/In_{0.35}GaAs$ Metamorphic HEMT With Pd Schottky Contacts

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1. Introduction

For low noise and power applications in the millimeter wave range, InAlAs/InGaAs metamorphic HEMT (MHEMT) on GaAs substrate is a good alternative to GaAs PHEMT or InP HEMT. For 77 GHz MMICs, the epitaxial layer with the indium contents of channel and barrier in the range of 30~40 % could lead to optimum millimeter wave performances and breakdown characteristics [1]-[6]. Recently, thermally-treated Pt-buried gate process is commonly utilized as the Schottky gate contact in metamorphic HEMT owing to its high Schottky barrier height (SBH) [7]. However, as the distance of the gate to the channel in the device with Pt-buried gate process reduces, the breakdown voltage may decrease and the gate-source capacitance (C_{gs}) increases and, thereby degrading cutoff frequency (f_T) [8].

In this paper, we have investigated device performances on gate metals such as Pt and Pd Schottky contacts. In the MHEMT with Pd Schottky contacts, due to low diffusivity with InGaP of Pd as well as its high SBH [9], the distance between the gate and the channel is preserved and breakdown voltage improves compared to MHEMT with Pt Schottky contacts. Moreover, in aspect of reliability, MHEMT with Pd Schottky contacts might be better than that Pt Schottky contact due to its low diffusion of Pd to InGaP. The fabricated 70 nm MHEMT's with Pd Schottky contacts exhibited the excellent characteristics such as the maximum extrinsic transconductance (g_m) of 760 mS/mm, off-state breakdown voltage (BV_{off}) of 8 V, and f_T of 230 GHz, which is 27 % larger than that with Pt Schottky contacts in f_T.

2. Fabrication of 70 nm MHEMT

$In_{0.8}GaP/In_{0.4}AlAs/In_{0.35}GaAs$ MHEMT's layers were grown by MBE on GaAs substrate. The metamorphic buffer consisted of a 1 μm thick linearly graded InAlAs layer with a final indium content of 45 %. The active layers consisted of a 300 nm undoped $In_{0.4}AlAs$ buffer layer, a Si planar doping layer, a 4 nm $In_{0.4}AlAs$ undoped spacer layer, a 15 nm $In_{0.35}GaAs$ undoped channel layer, a 4 nm $In_{0.4}AlAs$ undoped spacer layer, a Si planar doping layer, a 9 nm $In_{0.4}AlAs$ undoped barrier layer, a 3 nm $In_{0.8}GaP$ layer and a Si-doped $In_{0.4}GaAs$ cap layer. In order to reduce the surface trap effects by high aluminum content in barrier layer, we inserted $In_{0.8}GaP$ layer on top of $In_{0.4}AlAs$ barrier with low surface defect density, which also functioned as an etch stop layer [10]. This structure achieved the sheet carrier density of 3.38×10^{12} cm^{-2} and the electron mobility of 7,830cm^2/V-s at 300 K. The devices were isolated by MESA formation by using wet chemical etching ($H_3PO_4/H_2O_2/H_2O$). Ge/Au/Ni/Au ohmic contacts were deposited and alloyed by rapid thermal annealing at 300 °C for 30 s. The devices were fabricated with a double recess scheme for the higher breakdown performance. 70nm T-gates were defined by e-beam lithography by using bilayer resist. Selective gate recess etching was employed in a same solution as MESA process. The gate metal of Pd/Ti/Pt/Au (4/30/20/350 nm) and Pt/Ti/Pt/Au (4/30/20/350nm) were evaporated. Finally, devices were passivated with Si_3N_4 of 1200 Å, which was grown by remote PECVD at 190 °C during 90 min [11]. This thermal treatment might have the stabilization bake. Figure 1 shows SEM image of 70 nm T-gate with the passivation.

3. Results

The MHEMT's depending on the gate metals were characterized on wafer for DC and RF performances. The DC I-V characteristics are shown in Fig. 3. A threshold voltage (V_T) with Pt Schottky contacts was moved to the positive and a maximum extrinsic g_m increased [Fig. 2]. The off-state breakdown voltages which were defined at gate current of 0.1 mA/mm were 8 V for Pd Schottky contacts, 6 V for Pt Schottky contacts, respectively. These are presumably due to the fact that the distance between the gate and the channel is reduced by the diffusion of the gate to InGaP layer with thermally treatment during the passivation. A forward turn-on voltage (0.85V) with Pd Schottky contacts was slightly smaller that (0.9) with Pt Schottky contacts due to its high SBH.

Small signal S-parameters were measured from 0.5 GHz to 40 GHz. The device with Pd Schottky contacts showed the f_T of 230 GHz at a drain voltage V_{DS} of 1.2 V and a gate voltage V_{GS} of -0.1 V extrapolated from the current gain (H_{21}), which was attributed to the reduction of C_{gs} by about 30 % compared to that of device with Pt Schottky contacts [Fig.3]. On the other hand, the maximum oscillation frequency (f_{max}), which was extrapolated from Mason's unilateral power gain (U), (348 GHz) with Pd Schottky contacts was comparable to that of (350 GHz) with Pt Schottky contacts. It should be noted that the ratios C_{gs} /C_{gd} and g_m/g_d are the figure of merit in the f_{max} and both the ratio C_{gs} /C_{gd} and g_m/g_d with Pt Schottky are higher than those with Pd Schottky contact due to the increases in both g_m and C_{gs} and the slightly decreases in g_d for Pt Schottky contacts [Table.1].

4. Conclusions

In conclusions, we have investigated device performances on gate metals such as Pt and Pd Schottky contacts. In the MHEMT with Pd Schottky contacts, since the distance between the gate and the channel is preserved due to its low diffusivity, C_{gs} decreases and, thereby improving f_T compared to MHEMT with Pt Schottky contacts. The 70 nm MHEMT's with Pd Schottky contacts exhibited the excellent characteristics such as the maximum extrinsic g_m of 760 mS/mm, BV_{off} of 8 V, f_T of 230 GHz, and f_{max} of 348 GHz in spite of low indium content of 35 % in the channel. These performances of MHEMT's might be potentially useful for high performance single-chip MMIC for 77 GHz automotive radars.

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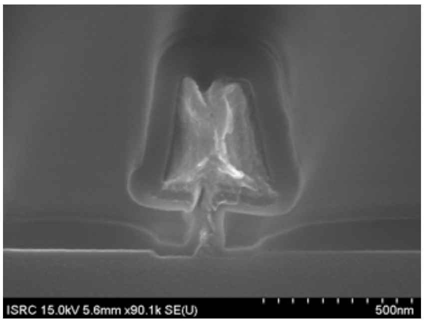

Fig. 1. SEM image of 70nm T-gate with Si_3N_4 layer passivation

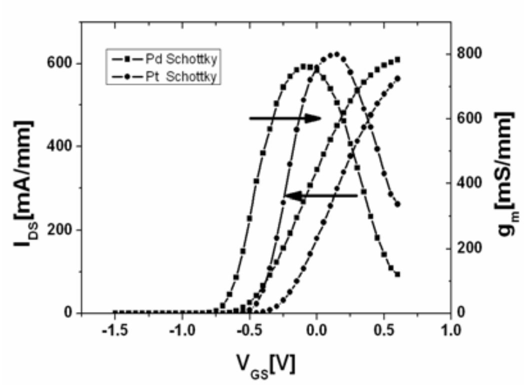

Fig. 2. DC transconductance curves of 0.07 × 50 μm^2 MHEMT with Pd/Pt Schottky contact, V_{DS} = 1.0 V

Gate Metal	BV_{off} (V)	g_m/g_d (mS)	C_{gs}/C_{gd} (fF)	f_T (GHz)	f_{max} (GHz)
Pd	8	24.7 (104/4.2)	8.3 (59/7.1)	230	348
Pt	6	28.6 (109/3.8)	11.5 (83/7.2)	181	350

Table. 1. Summary of device performances with Pt and Pd Schottky contacts. With small signal modeling, the parameters were extracted at V_{DS} of 1.2 V, V_{GS} of -0.1 V for Pd Schottky contacts and V_{DS} of 1.2 V, V_{GS} of 0 V for Pt Schottky contacts.

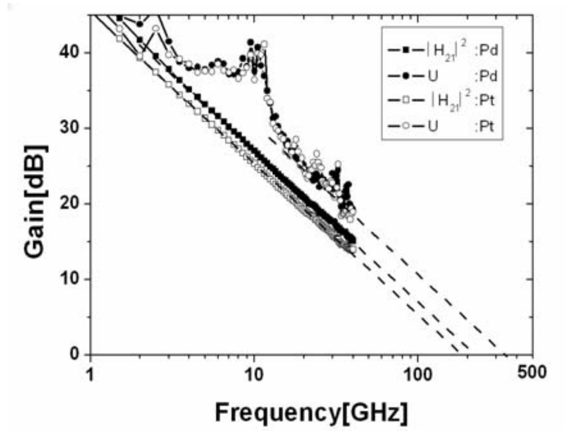

Fig. 3. RF characteristics of 0.07 × 2 × 50 μm^2 MHEMT with Pt and Pd Schottky.

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