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High Power Performance of Metamorphic HEMTs using Pd Schottky contacts

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1. Introduction

GaAs-based InAlAs/InGaAs on metamorphic high electron mobility transistors (MHEMTs) are promising for opto-electronic application and wireless communication systems operating at millimeter-wave frequencies [1,2]. The problem of a poor gate-drain breakdown voltage as compared with the GaN-based HEMT still exists [3], which limits the device performance for high-power applications which is also a problem from a viewpoint of reliability. For further electrical improvement in InAlAs/InGaAs HEMTs, reducing the relatively high gate leakage current is one of the key issues. The excess leakage has been reported to contribute to low frequency noise [4,5] as well as the breakdown voltage of the device [6] that determine their practicability to the power operations. In this paper, in order to reduce the reverse-biased leakage current in Schottky contact, employing a Schottky metal possessing high work function. we demonstrate a Pd(0.7eV) [7] metal of maximizing the effective Schottky barrier height (ϕ_b) against InAlAs/InGaAs MHEMTs epitaxial layers. A drastic improvement in reverse-biased leakage current was attained in the Pd/Ti/Pt/Au system whereas degradation occurred in Pd by PECVD passivation at 280^{0}C for 15 min. These phenomena was confirmed to be dependent on the work function increase [7] and provides a flat and a uniform Schottky band diagram of Pd buried-gate metal. It was overcomes the parallel conduction effect, which limits the development of HEMT for microwave power device owing to the high gate leakage current, and will be generated during high input power swing [8]. The role of Pd in the Pd/Ti/Pt/Au system was also investigated, and it was found to be essential in obtaining better electrical performance in comparison with the diodes without Pd, such as Ti/Pt/Au Schottky electrodes. The InAlAs/InGaAs MHEMTs were fabricated using Pd/Ti/Pt/Au gate contacts. Reduction of the gate leakage current was successfully recorded by thermal treatment without degrading the transconductance of the transistor, and it was concluded that this technique was promising for high power InAlAs/InGaAs MHEMTs electronics.

2. Material Growth and Device Fabrication

The $In_{0.5}Al_{0.5}As/In_{0.5}Ga_{0.5}As$ MHEMTs structures were grown by the MBE on semi-insulting GaAs substrates. The grown wafers consist of an 1-μm thick composition graded $In_xAl_{1-x}As$ buffer layer with an indium content changing from x = 0% to 50%, followed by a 300 nm thick $In_{0.5}Al_{0.5}As$ buffer layer, a 15 nm $In_{0.5}Ga_{0.5}As$ channel layer, a 5 nm $In_{0.5}Al_{0.5}As$ spacer layer, a 5×10^{12} cm^{-2} Si delta doped layer, a 15 nm $In_{0.5}Al_{0.5}As$ Schottky layer, and a 15 nm $In_{0.5}Ga_{0.5}As$ doped-cap layer. TEM cross-section photograph demonstrates that the dislocations were all confined in the graded InAlAs buffer layer, and the device active layers are basically defect-free. The Hall mobility and sheet charge density at room temperature were 9500 cm^2/V-sec and 3.35 x 10^{12} cm^{-2}, respectively.

The device fabrication was realized by the use of conventional lithography and lift-off techniques. A $H_3PO_4/H_2O_2/H_2O$ (1:1:40) solution was used for the mesa etching. Ohmic contacts were formed by electron beam evaporating Ni/Ge/Au metallization, followed by a 290^{0}C, 50 sec RTA annealing in N_2 ambient. TLM measurements show a typical ohmic contact resistivity of 0.2 ohm-mm. T-shaped gates with gate-lengths of 0.25 um, locating in the center of the drain-to-source spacing (4-μm), were defined by using a bi-layer P(MMA-MAA)/PMMA resist process and an electron beam lithography system. As to the gate -recessed process, the selective gate recess etching was performed using a mixing solution of succinic acid and hydrogen peroxide, The gate metals, Pd/Ti/Pt/Au (3nm/20 nm/ 20 nm/ 400 nm) and Ti/Pt/Au (20 nm/ 20 nm/ 400 nm) control sample, were deposited by electron beam evaporating, respectively. Finally, we passivated the devices with 280^{0}C for 15 min remote plasma-enhanced chemical vapor deposition (PECVD) Si_3N_4 film of 250 nm.

3. Result and Discussions

The 0.25- μ m T-gate MHEMTs were characterized on-wafer for dc and RF performance. The output I–V characteristics are shown in Fig. 1 and the associated peak transconductance ($g_{m,max}$) are shown in Fig. 2. The MHEMTs have an $I_{ds,max}$ of 423 mA/mm, $g_{m,max}$ of 414 mS/mm with a low output conductance of 7.5 mS/mm for Pd gate MHEMTs and $I_{ds,max}$ of 416 mA/mm, $g_{m,max}$ of 405 mS/mm with a higher output conductance of 9.5 mS/mm for control gate MHEMTS, respectively. The device also exhibits a significant improvement in the gate diode characteristic (Fig. 3) with a forward Schottky turn on voltage of 0.88 V and a high gate breakdown voltage of 22V measured at 1 mA/mm for Pd gate MHEMTs and turn on voltage of 0.4 V and a lower gate breakdown voltage of 12V for control gate MHEMTs, respectively. Higher breakdown voltage and reducing gate leakage current gives a 2.4GHz RF power density of about 476 mW/mm for Pd inserted gate MHEMTs compared to 272.8 mW/mm of control gate MHEMTs. The S-parameters of 50 μm wide MHEMTs were measured using on-wafer probing and a

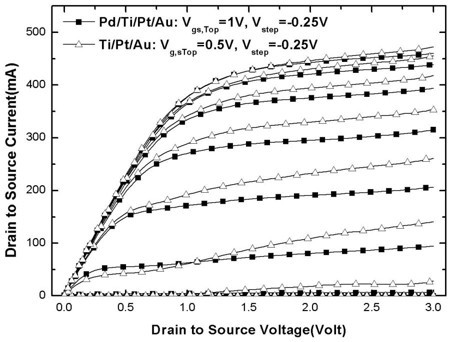

Fig.1. The DC I–V characteristics of a 0.25 × 50 μ m MHEMTs.

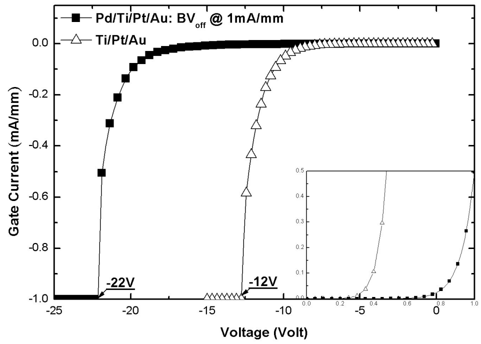

Fig.3. The Schottky diode characteristic of 0.25 × 50 μ m MHEMTs.

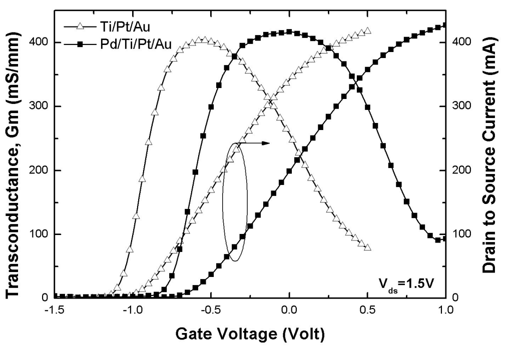

Fig.2. The associated peak transconductance of 0.25 × 50 μ m T-gate MHEMTs.

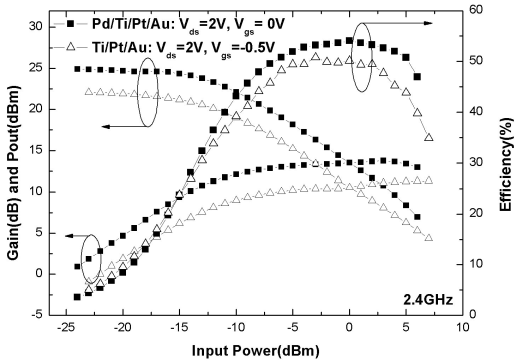

Fig.4. The output power and PAE versus input power at 2.4 GHz of a 0.25 × 50 μ m MHEMTs.

network analyzer (0.5–50 GHz). A current gain cut-off frequency (f_t) is 125 GHz for Pd gate MHEMTs and 105 GHz for control MHEMTs. Due to an improvement of device output characteristics, the power gain cut-off frequency (f_{max}) enhances from 140 GHz to 198 GHz by this Pd inserted gate MHEMTs, which corresponds to a 41% enhancement. The f_{max} were extrapolated from the and the maximum available gain (MAG) for a 0.25 μ m device biased at peak transconductance. Table.1 summarized of the other device DC and microwave characteristics.

3. Conclusions

In summary, the InAlAs/InGaAs MHEMTs were fabricated using Pd/Ti/Pt/Au Schottky contacts. Because of the Pd/InAlAs increased the Schottky barrier height that reduction of gate leakage current was successfully recorded by a thermal treatment without degrading the transconductance of the transistor. This device exhibits also a high breakdown voltage of 22 V and it has demonstrated a maximum output power of 476 mW/mm, a power added efficiency (PAE) of 54%. It is concluded that this technique is promising for high power InAlAs/InGaAs MHEMTs electronics.

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