Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 536-537

P5-4

Study of InGaP/InGaAs Double Doped Channel Heterostructure Field-effect Transistor (DDCHFET)

Hung-Ming Chuang, Chun-Yuan Chen, Po-Hsien Lai, Sue-I Fu, Yan-Ying Tsai, Chung-I Kao, and Wen-Chau Liu*

Institute of Microelectronics, Department of Electrical Engineering, National Cheng-Kung University,
1 University Road, Tainan, TAIWAN 70101, Republic of China.
Phone: +886-6-209-4786 or 886-6-234-5482
*Corresponding author. E-mail: wcliu@mail.ncku.edu.tw

1. Introduction

InGaAs/GaAs Field-effect transistors (FETs) have been studied extensively for high-speed microwave applications [1-2]. However, the device characteristics are limited by the critical thickness and indium mole fraction of InGaAs layer. In addition, doped-channel FETs (DCFETs) achieve excellent device linearity, current density, and breakdown voltage, as compared with PHEMTs [3]. However, the highly impact scattering effect leads to a degradation of transport properties. In this work, a new InGaP/InGaAs HFET with double δ-doped channel is introduced. The employed double channel structure can increase the effective thickness of InGaAs channel layer. In addition, the δ-doped sheets, acted as carrier supply layer, can reduce the impurity scattering effect [4-5]. Furthermore, the wide-gap $In_{0.49}Ga_{0.51}P$ material exhibits lower DX centers and lower reactivity with oxygen as compared to the AlGaAs material. Therefore, good device properties of high turn-on voltage, low leakage current, high and linear transconductance and microwave performances, and high temperature operation capability are simultaneously obtained.

2. Experimental

The epitaxial structure of the studied device was grown on a (100) oriented semi-insulating (S.I.) GaAs substrate by a metal-organic chemical vapor deposition (MOCVD) system. It consisted of a 0.5-μm GaAs buffer, a 500-Å $In_{0.49}Ga_{0.51}P$ buffer, a 50-Å $In_{0.2}Ga_{0.8}As$ channel, a delta-doped sheet of $\delta(n^+)=2\times10^{12}$ cm^{-2}, a 50-Å $In_{0.2}Ga_{0.8}As$ channel, a 80-Å GaAs spacer, a 50-Å $In_{0.2}Ga_{0.8}As$ channel, a delta-doped sheet of $\delta(n^+)=2\times10^{12}$ cm^{-2}, a 50-Å $In_{0.2}Ga_{0.8}As$ channel, a 300-Å $In_{0.49}Ga_{0.51}P$ gate "insulator", and a 500-Å n^+-GaAs ($n^+\geqq3\times10^{18}$ cm^{-3}) cap layers. For device fabrication, drain-source Ohmic contacts were formed on the n^+-GaAs cap layer by alloying evaporated AuGe/Ni/Au metals at 350 ℃ for 30s. The wet chemical etching process was used for device isolation. Finally, n^+-GaAs layer is removed and gate Schottky contacts with the gate length of 1 μm were achieved by evaporating Au metal on the $In_{0.49}Ga_{0.51}P$ "insulator".

3. Results and Discussion

The key feature of the studied device is using the double channel structure to increase the effective thickness of InGaAs channel layer and then keep with high In mole fraction. The large ΔE_C (~0.38 eV) at $In_{0.49}Ga_{0.51}P/In_{0.2}Ga_{0.8}As$ heterointerface offers the better carrier confinement in the InGaAs double channel structure even operated under higher forward gate bias regime and higher temperature. In addition, the delta-doped sheets locate at the center position of channels and act as supplier of transport carriers. This designed structure can reduce the impact scattering effect and enhance the carrier confinement due to the bending conduction band within channel region.

Figure 1 shows the gate-drain current-voltage (I-V) characteristics of the studied device at 300 to 450K. The turn-on voltage V_{on} and reverse gate leakage current I_G at V_{GD}=-20 V as a function of temperature are also demonstrated in the inset. Clearly, good Schottky- and breakdown-characteristics are observed among wide range of operation temperature. The high values of V_{on} at high temperature regime (even up to 450K) and low degradation rate ($\partial V/V\partial T$) of -1.35×10^{-3}/K in V_{on} with increasing the temperature are found. This indicates that the $In_{0.49}Ga_{0.51}P$ layer provides good Schottky characteristics and the presence of delta-doped sheet doesn't cause remarkable degradation of breakdown and turn-on voltage.

Figure 2 illustrates the transconductance g_m versus the drain saturation current I_{DS} at different temperature. The drain-source voltage is kept at V_{DS}=5 V. The maximum transconductance $g_{m,max}$ and maximum output current $I_{DS,max}$ are 162 (148) mS/mm and 499 (428) mA/mm at T=300 (450) K, respectively. The deviations of $g_{m,max}$, $I_{DS,max}$, and V_{th} from 300K to 450 K are insignificant. This is certainly suitable for high-temperature applications. In addition, the wide g_m flat region (defined as the drop of 10 % from the $g_{m,max}$) of 303 (248) mA/mm are obtained at T=300 (450) K. The common-source I-V characteristics of the studied device at various temperature are shown in the inset of Fig. 2. Clearly, due to the high Schottky behaviors and good carrier confinement associated with high V_{on}, the device can be operated at high gate-source voltage V_{GS} of 1.5 V with high transconductance g_m and without significant gate leakage current even at high temperature of 450K.

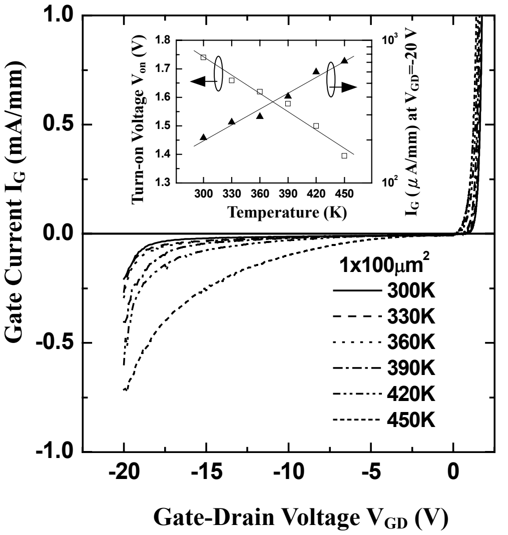

Fig. 1 The gate-drain I-V characteristics of the studied device at T= 300 to 450K. The inset shows the V_{on} and I_G at V_{GD}=-20 V as a function of temperature.

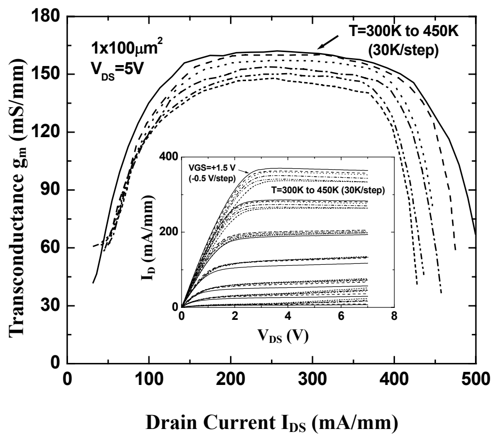

Fig. 2 The transconductance g_m versus drain saturation current I_{DS} at T= 300 to 450 K. The inset shows the common source I-V characteristics of the studied device at T=300 to 450 K.

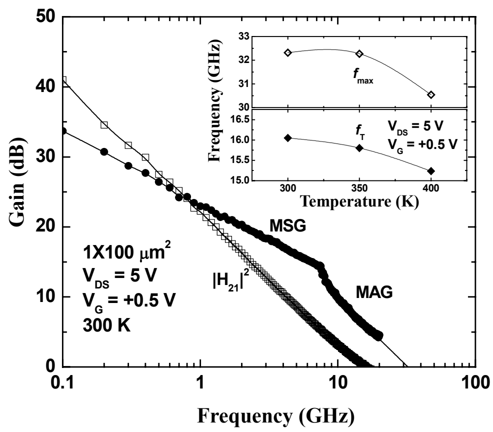

Fig. 3 The microwave performances of the studied device. The inset shows the f_T and f_{max} values at 300, 350, and 400K.

The microwave performances of the studied device are shown in Fig. 3. The unity current gain cut-off frequency (f_T) and maximum oscillation frequency (f_{max}) at 300, 350, and 400K are shown in the inset. For a 1×100μm^2 device, the f_T of 16 GHz and f_{max} of 32.3 GHz are obtained under the bias conditions of V_{GS}=+0.5 V and V_{DS}=5 V at 300K. In addition, the f_T and f_{max} still maintain at 15.2 and 30.5 GHz at 400 K. Thus, the studied device shows low degradation of microwave performances as the temperature is increased to 400 K.

4. Conclusions

A new and interesting InGaP/InGaAs HFET with double δ-doped channels is fabricated and demonstrated. The turn-on voltage of 1.74 V, gate leakage current of 207 μA/mm at V_{GD}=-20 V, maximum output current of 499 mA/mm, and maximum transconductance of 162 mS/mm with 303 mA/mm broad operation regime are obtained for a 1 μm gate length device. The microwave properties of f_T and f_{max} are 16 and 32.3 GHz, respectively. Furthermore, the degradations of device performances with the increase of temperature are insignificant. Consequentially, the studied device provides the promise for high-temperature and microwave circuit applications.

Acknowledgements

Part of this work was supported by the National Science Council of the Republic of China under Contract No. NSC-91-2215-E-006-016. The authors are also grateful to National Nano Device Laboratories (NDL) for RF measurements.

References

[1] S. S. Lu, C. C. Meng, Y. S. Lin, and H. Lan, IEEE Trans. Electron Devices 46 48 (1999)
[2] W. C. Hsu, H. M. Shieh, C. L. Wu, and T. S. Wu, IEEE Trans. Electron Devices 41 456 (1994)
[3] F. T. Chien and Y. J. Chan, IEE Electronics Lett. 35 427 (1999)
[4] E. F. Schubert, A. Fisher, and K. Ploog, IEEE Trans. Electron Devices 33 625 (1986)
[5] W. P. Hong, J. Harbison, L. T. Florez, and J. H. Abeles, IEEE Trans. Electron Devices 36 2615 (1989)