

InGaP/InGaAs PHEMT with high IP3 for low noise applications

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A low noise InGaP/InGaAs pseudomorphic high-electron-mobility transistor (PHEMT) with high IP3 was developed. The device utilises InGaP as the Schottky layer to achieve a low noise figure and uses AlGaAs as the spacer to reform the electron mobility and contains dual delta doped layers to improve the device linearity.

Introduction: An InGaP/InGaAs based pseudomorphic high-electron-mobility transistor (PHEMT) with AlGaAs spacer for low noise and high linearity application is developed. The device structure is as shown in Fig. 1. It uses high doping concentration n^+ -GaAs as cap layer to form good ohmic contact for the drain and source electrodes. The InGaP layer is used as the Schottky layer. The use of InGaP instead of AlGaAs as the Schottky layer for the PHEMT has the following advantages. Foremost, InGaP has higher energy bandgap that can reduce the gate leakage current. Additionally, InGaP does not form a deep-complex (DX) centre at the desired doping level. Finally, high etch selectivity between InGaP and GaAs can be achieved, which improves the gate recess uniformity [1]. In this Letter, we use AlGaAs as the spacer layer above and below the InGaAs channel layer to increase the electron mobility, and high electron mobility of $6410 \text{ cm}^2/\text{Vs}$ in the 2DEG channel region was achieved. This is believed to be highest electron mobility formed in the InGaP/InGaAs PHEMT. Two delta-doped layers are used above and below the quantum well region to improve the transconductance flatness of the device [2, 3]. Finally, AlGaAs/GaAs superlattice was used to reduce the leakage current from the substrate.

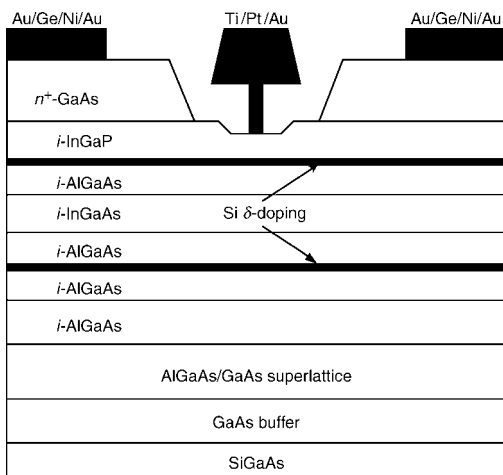


Fig. 1 Structure of InGaP/InGaAs PHEMT

Device manufacturing process: There are five major steps in the InGaP/InGaAs PHEMT process. These include definition of the device active region, ohmic metal deposition and annealing, wet chemical recess, gate formation by electron beam (EB) lithography and lift-off process and gold plating of airbridges for the interconnects. The mesa etch was achieved using HCl/H₂O solution etching for the InGaP layer [4] and HF/H₂O₂/H₂O solution for the other layers. The AuGe/Ni/Au was evaporated to form the ohmic contacts and was annealed at 340°C for 30 s by rapid thermal annealing. The gate recess was formed using a highly selective citric acid/H₂O₂/H₂O solution [5] for selectively removing the cap GaAs material and HCl/H₂O solution for etching the InGaP Schottky layer. The Ti/Pt/Au was then deposited for the Schottky gate by lift-off technique. The gate length for the device is 0.25 μm.

Results: Because of the use of InGaP layer and the AlGaAs spacer with dual delta doped structure, the device has very low leakage current, low-noise with very high IP3 that can be of great use for microwave applications.

The fabricated $0.25 \times 160 \mu\text{m}^2$ PHEMT device shows saturation current of 243 mA/mm and the high extrinsic transconductance is 414.2 mS/mm at $V_{ds} = 1.5 \text{ V}$. The device drain to gate breakdown voltage can reach up to 15.2 V. The 160 μm gate-width device has a noise figure of 0.59 dB with 11.7 dB associated gain at 12 GHz and the f_i and f_{max} are 80 and 190 GHz, respectively. The $0.25 \times 300 \mu\text{m}^2$ PHEMT device shows high output 3 order intercept point (IP3) of 28.1 dBm and the output power 1 dB compression (OP_{1dB}) of 11.1 dBm with gain 16.2 dB when DC bias at $V_{ds} = 2.4 \text{ V}$, $I_{ds} = 28.6 \text{ mA}$ at 6 GHz as shown in Fig. 2. Compared with the conventional AlGaAs/InGaAs PHEMT data, the InGaP/InGaAs PHEMT developed has high $\Delta(\text{IP3} - \text{OP}_{1\text{dB}})$ and high IP3/ P_{DC} ratio as shown in Table 1 [6]. Furthermore, gate leakage current of the device is very low. Fig. 3 shows the gate current against reverse gate-source voltage with different drain source, the gate current is 36 μA/mm at $V_{ds} = 7 \text{ V}$, $V_{gs} = -0.8 \text{ V}$.

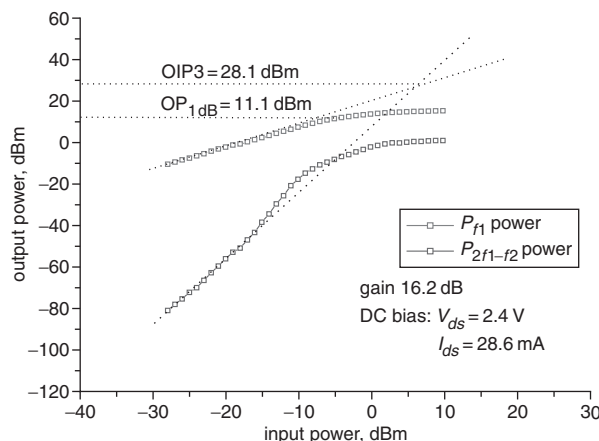


Fig. 2 Measured third-order products and fundamental power of $0.25 \times 300 \mu\text{m}$ InGaP/InGaAs PHEMT

Table 1: Comparison of noise figure and IP3 with AlGaAs/InGaAs PHEMT

Device type	gm (mS/mm)	Fmin [dB] $W_g = 160 \mu\text{m}$ at 6 GHz	IP3 with $W_g = 300 \mu\text{m}$ at 6 GHz			
			1 dB comp P_{out} [dBm]	IP3 [dBm]	$\Delta(\text{IP3} - P_{1\text{dB}})$ [dB]	IP3/ P_{DC}
InGaP/InGaAs double delta-doped	414.2	0.4	11.1	28.1	17.0	9.4
Double delta-doped PHEMT	432.0	0.6	12.7	23.0	10.3	1.6

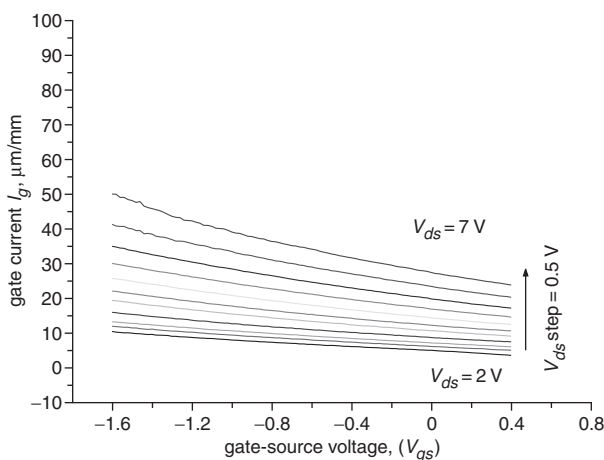


Fig. 3 InGaP/InGaAs PHEMT gate leakage current

Conclusion: An InGaP/InGaAs PHEMT with a very low noise figure, low third-order distortion, and low DC power consumption is developed.

The outstanding performance of the device is attributed to the use of high bandgap InGaP as the Schottky layer so as to improve the noise figure and reduce the gate leakage current, along with the use of AlGaAs as the spacer to improve the electron mobility and the use of dual delta doped layers to improve the device linearity. The developed InGaP/InGaAs PHEMT with very low noise figure and leakage current and very high OIP3 is of great use for wireless communication applications.

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References

- 1 Wu, C.L., Wang, J.C., and Chang, C.S.: 'Super low noise InGaP gated PHEMT', *IEEE GaAs Dig.*, 2001
- 2 Hur, K.Y., Hetzler, K.T., McTaggart, R.A., Vye, D.W., Lwmonias, P.J., and Hoke, W.E.: 'Ultralinear double pulse doped AlInAs/GaInAs/InP HEMTs', *Electron. Lett.*, 1996, **32**, (16)
- 3 Jkalainen, P.K., Witkowski, L.C., and Kao, Y.C.: 'Low-noise low DC power linear FET'. *European Microwave Conf. Proc.*, 1992, Vol. 1, (22), pp. 570–575
- 4 Okamoto, Y., Matsunaga, K., Kuzuhara, M., and Kanamori, M.: 'Novel InGaP/AlGaAs/InGaAs heterojunction FET for X-Ku band power applications', *IEEE MTT-S Int. Microw. Symp. Dig.*, 1997, **3**, pp. 1191–1194
- 5 Zheng, H.Q., Ng, G.I., Zhang, Y.Q., Radhakrishnan, K., Lee, K.Y., Chee, P.Y., Tse, M.S., Weng, J.X., and Yoon, S.F.: 'High linearity, current drivability and f_{max} using pseudomorphic GaAs double-heterojunction HEMT (DHHEMT)', *Semicond. Electron.*, 1996, pp. 12–14
- 6 Chu, S.L.G., Huang, J., Struble, W., Jackson, G., Pan, N., Schindler, M.J., and Tajima, Y.: 'A highly linear MESFET', *IEEE MTT-S Int. Microw. Symp. Dig.*, 1991, **2**, pp. 725–728