ENHANCEMENT-MODE PSEUDOMORPHIC INVERTED HEMT FOR LOW NOISE AMPLIFIER

K.Ohmuro, H.I.Fujishiro, M.Itoh, H.Nakamura and S.Nishi

Semiconductor Technology Laboratory, Oki Electric Industry Co., Ltd.
550-5 Higashiasakawa-cho, Hachioji-shi, Tokyo 193, Japan
(Phone: 0426-63-1111)

ABSTRACT

The noise characteristics of pseudomorphic inverted HEMT (P-I-HEMT) were reported for the first time in this paper. The P-I-HEMTs were fabricated in enhancement-mode. Compared with pseudomorphic HEMT, P-I-HEMT shows a lower noise figure, especially at small drain voltage and small drain current. It was concluded that the P-I-HEMT structure is suitable for fine gate low noise FETs.

INTRODUCTION

HEMT structures, especially pseudomorphic HEMT (P-HEMT) structures are used for low noise FET devices due to their high electron mobility and good carrier confinement (1). A layer structure suppressing short channel effects with superior carrier confinement is thought to be very advantageous to fine gate low noise devices. In this respect, inverted HEMT structure, which has a GaAs layer located on an AlGaAs, is a prime candidate of low noise fine gate devices (2). To maximize the merits of inverted HEMT, improving g_m by increasing 2DEG concentration and/or by shortening the gate to channel distance are essential.

In order to increase the 2DEG concentration, InGaAs strained layer was inserted into the hetero-interface of inverted HEMT to make its energy band gap larger. This structure is called pseudomorphic inverted HEMT (P-I-HEMT) (3). To shorten the gate to channel distance, P-I-HEMT is used in enhancement-mode (with positive V_{th}). In this P-I-HEMT, our simulation study shows excellent carrier confinement and suppression of short channel effects, so it is expected to have an improved noise property.

In this paper, the microwave and noise properties of P-I-HEMTs were studied for the first time, and it is observed that the P-I-HEMT is suitable for a low noise device. Its characteristics were compared with that of the P-HEMT fabricated by the same process.

FABRICATION PROCESS

The P-I-HEMT and P-HEMT structures are grown by MBE. The cross sectional view of the P-I-HEMT is indicated in Fig.1. They have an $In_{0.2}Ga_{0.8}As$ channel of 100Å thickness. In the P-I-HEMT and the P-HEMT, electron mobilities are almost the same value of 6500 cm^2/Vs at room temperature, and 2DEG concentrations are $1.3\times10^{12}cm^{-2}$ and $1.6\times10^{12}cm^{-2}$ at 77K, respectively. The fabrication process is the modified one that reported earlier (1). In enhancement-mode devices, source resistance tends to increase due to the existing space between gate electrode and source n^+ region. To prevent this problem, the stepped recess gate structure was formed using the combination of dry and wet etching (4). The GaAs is etched anisotropically using electron-cyclotron-resonance-type dry etcher with Cl_2 gas first, then recess-etched by wet etchant isotropically. The 0.2μm gate electrode was fabricated in the inner recess. The gate cross section is shown in Fig.2. The upper part of the gate is wider than the lower part to reduce gate resistance.

DC CHARACTERISTICS

The I-V characteristics of the P-I-HEMT and the P-HEMT are shown in Fig.3. For both devices, the gate length, width and V_{th} are 0.2μm, 10μm and approximately 0V, respectively. The maximum values of g_m (g_{mmax}) of P-I-HEMT and P-HEMT are 570 and 520 mS/mm, respectively. Comparing the pinch-off characteristics in sub-threshold region, the superior performance of the P-I-HEMT to the P-HEMT is observed. From Fig.4, drain conductance (g_d) of the P-I-HEMT is recognized to be much smaller than that of the P-HEMT. Moreover g_d of the P-I-HEMT maintains low

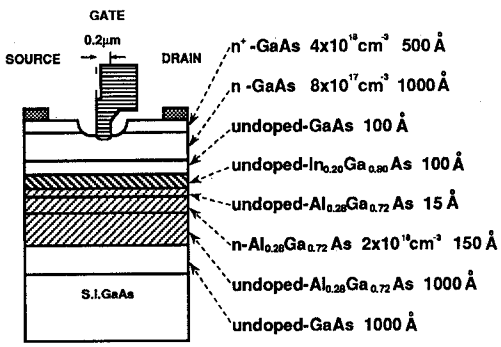

Fig.1 Schematic cross section of pseudomorphic inverted HEMT.

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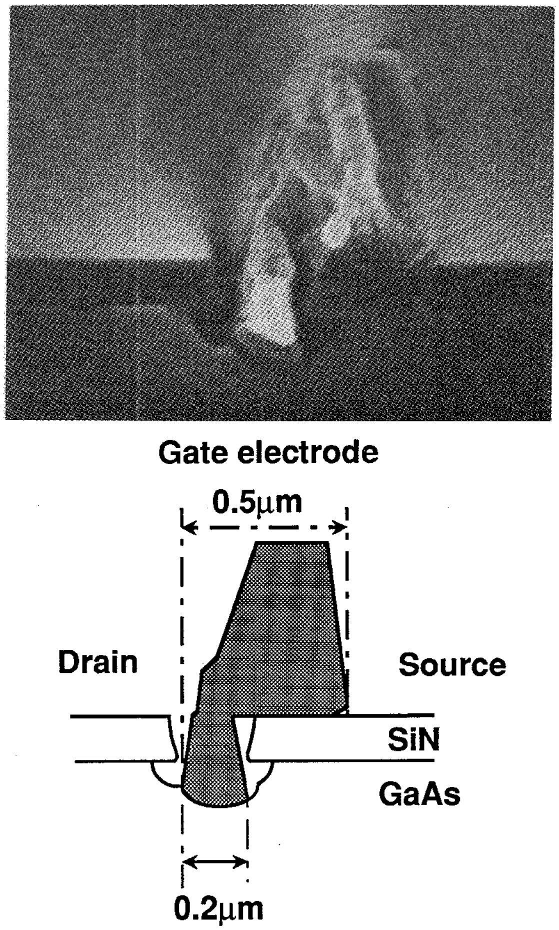

Fig.2 Cross sectional SEM photograph of 0.2μm mashroom shaped gate electrode.

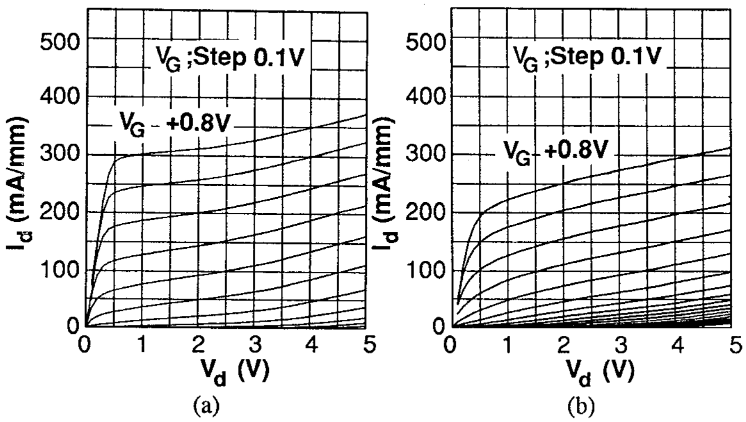

Fig.3 I-V characteristics of (a)pseudomorphic inverted HEMT and (b)pseudomorphic HEMT.

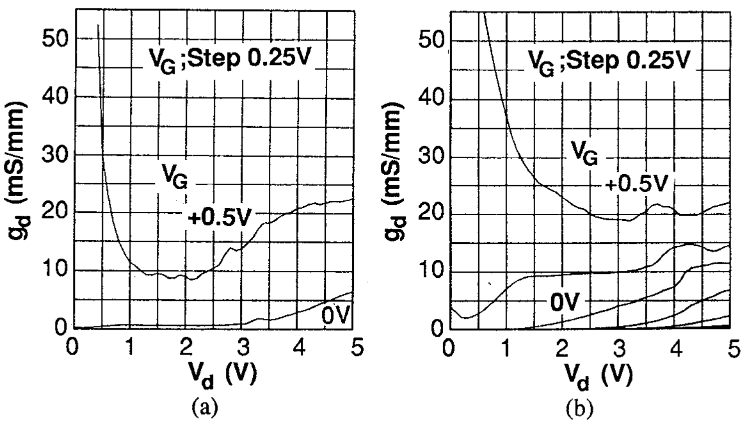

Fig.4 Drain conductance versus drain voltage of (a)pseudomorphic inverted HEMT and (b)pseudomorphic HEMT.

value at small drain voltages, which comes from the good drain current saturation at small drain voltages. For example, at a drain voltage of 2V and gate voltage of 0.5V, g_d of the P-I-HEMT is 9mS/mm, whereas that of P-HEMT is 23mS/mm. From these results, P-I-HEMT has smaller short channel effects and thus is a suitable structure for short gate devices, and is advantageous in low drain currents. In Fig.5, the K-value (i.e. extracted from $I_d=K(V_g-V_{th})^2$, which represents the g_m in small I_d region) is indicated as a function of V_{th}. As V_{th} becomes more positive, K-value of P-I-HEMT increases more sharply than that of P-HEMT. This is because the distance between gate and channel becomes smaller in P-I-HEMT than in P-HEMT as Vth goes positive, and that becomes larger as Vth goes negative. In the P-I-HEMT and the P-HEMT, K-values are 600mS/Vmm and 430mS/Vmm at V_{th}=0V, respectively.

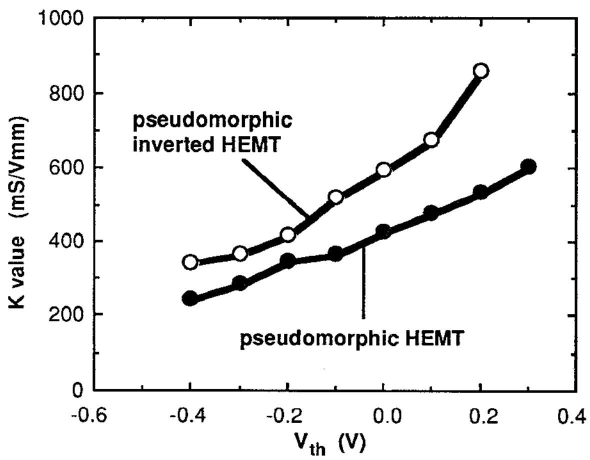

Fig.5 K-value versus threshold voltage.

S PARAMETER MEASUREMENTS

The cut-off frequency (f_T) was extracted from the on-wafer scattering parameters measured from 0.5GHz to 40GHz with 150μm-wide FETs. Fig.6 shows the comparison of f_T versus log Id in both devices. A steeper rise in f_T with

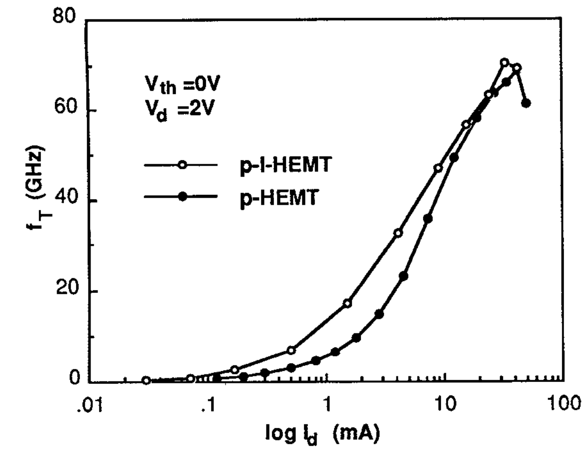

Fig.6 Cut-off frequency versus drain current.

increasing Id was observed in the the P-I-HEMT. Furthermore, the f_T at smaller drain currents is higher in the P-I-HEMT than in the P-HEMT, so the P-I-HEMT is expected to have good noise characteristics at small drain currents. This is due to the good pinch-off characteristic in P-I-HEMT. The maximum f_T is approximately 70GHz for both devices.

In Fig.7, f_T versus Vg for P-HEMTs and P-I-HEMTs of different V_{th} were plotted. In P-I-HEMTs, f_T peak value increases as V_{th} goes positive. P-I-HEMTs, therefore, have higher f_T in enhancement-mode than in depletion-mode.

Some equivalent circuit constants were extracted from the measured S-parameters. The g_m/g_{ds} (the bias condition of 100mA/mm) in RF region were 16.1 for P-I-HEMT and 10.7 for P-HEMT, respectively. Although these values are smaller than DC values, P-I-HEMT has higher g_m/g_d value than the other and has the ability of high gain.

NOISE CHARACTERISTICS

Noise parameter measurements were performed using NP4. Measured devices are 150µm-wide FET with three-feeds to reduce gate resistance. The frequency dependence of minimum noise figures(Fmin s) and associated gains(Gass) at Id=15mA, Vd=2V for P-HEMT and P-I-HEMT are shown in Fig.8. Fmin s are about 0.1dB smaller and the Gass are 1dB larger for the P-I-HEMT than for the P-HEMT. The F_{min} s at 12GHz and 18GHz are 0.56dB (Gas 11.0dB) and 1.01dB (Gas 10.9dB) for the P-I-HEMT, and 0.66dB (Gas 10.1dB) and 1.14dB (Gas 9.9dB) for the P-HEMT.

At small drain voltages, P-I-HEMTs have superior characteristics than P-HEMTs, because the former shows good current saturation at low drain voltages as shown in Fig. 3. Fig.9 shows Fmin s and Gass versus Vd at 12GHz and Id=15mA. In V_d region smaller than 1V, degradation of noise characteristics is not so fierce in the P-I-HEMT as in the P-HEMT. Fmin s at 0.6V and 0.4V are 0.66dB and 1.01dB for the P-I-HEMT, and are 0.98dB and 2.71dB for the P-HEMT, respectively. These lower Fmin s in small Vd region for the P-

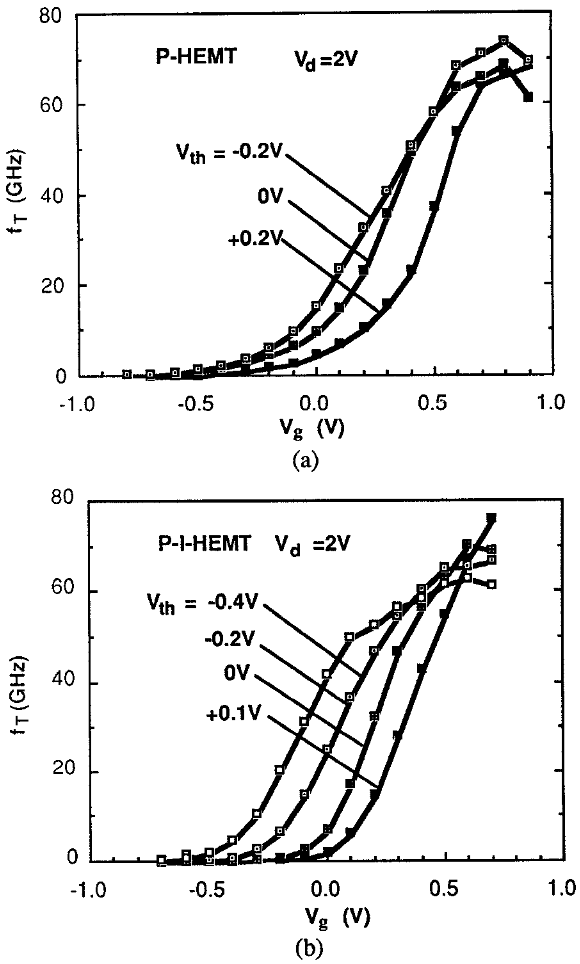

Fig.7 Cut-off frequency versus gate voltage for (a)pseudomorphic HEMT and (b)pseudomorphic inverted HEMT of different threshold voltages.

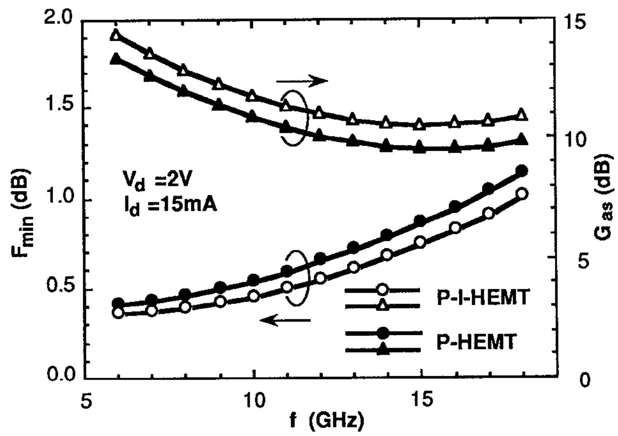

Fig.8 F_{min} and G_{as} versus frequency.

I-HEMT are thought to be due to early drain current saturation and small gd in this region. Lower noise characteristics are seen for the P-I-HEMT than its counterpart also in the Vd region from 1V to 4V. In this region, P-I-HEMTs have better pinch-off characteristic than P-HEMTs.

At small drain currents, P-I-HEMTs have superior characteristics than P-HEMTs, because of the good pinch-off characteristics in this region. Fig.10 shows Fmin s and Gass versus Id at 12GHz and Vd=2V. Little degradation of Fmin is seen down to Id=5mA in the P-I-HEMT, whereas Fmin of the P-HEMT degrades at small Id. So the P-I-HEMT is proved to be useful in small drain currents. Moreover, the P-I-HEMT maintains low Fmin in Id region from 5mA to 20mA, so it can be used with a wide margin about drain current.

From these results, enhancement-mode P-I-HEMTs show better noise characteristics at small drain currents and for small drain voltages than P-HEMTs, so they are advantageous for low noise devices with low power consumption. There is still room to make a much lower Fmin by reducing Cgs. Here, Cgs has become high owing to the rather large overhang of the gate electrode. When Cgs is reduced by narrowing the upper part of the gate electrode, noise characteristics could be improved.

Noise characteristics of P-I-HEMTs, as they do not show the obvious short channel effects even at this gate length, are expected to be further improved by adopting it to devices of under 0.2μm gate length. In addition, the use of enhancement-mode low noise FET will have the merit of simplifying the power supply circuit, especially in the MMICs.

CONCLUSIONS

Enhancement-mode pseudomorphic inverted HEMTs (P-I-HEMTs) were fabricated and the properties were compared with a pseudomorphic HEMTs (P-HEMTs). Dry/wet recess etching process was adopted to reduce source resistance.

In DC characteristics of enhancement-mode FET, the P-I-HEMT has better pinch-off property, smaller g_d, and higher g_m than its counterpart. In RF characteristics, the P-I-HEMT has steeper increase of f_T with Id, and has a higher value of f_T at low drain currents. The maximum f_T is approximately 70GHz. The g_m/g_d value is higher in P-I-HEMT than the other.

In the noise measurement, the P-I-HEMT exhibits a lower noise figure (F_{min} at 18GHz is 1.0dB) than the P-HEMT, and little noise degradation in wider drain voltage region from 1V to 4V. Furthermore, it has far better noise characteristics even at small Vd and Id, and hence has the capability of realizing low noise devices with low power consumption.

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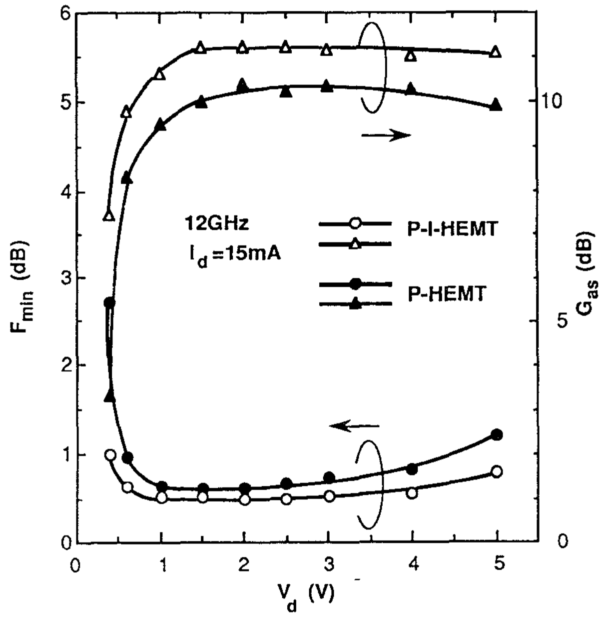

Fig.9 F_{min} and G_{as} versus drain voltage.

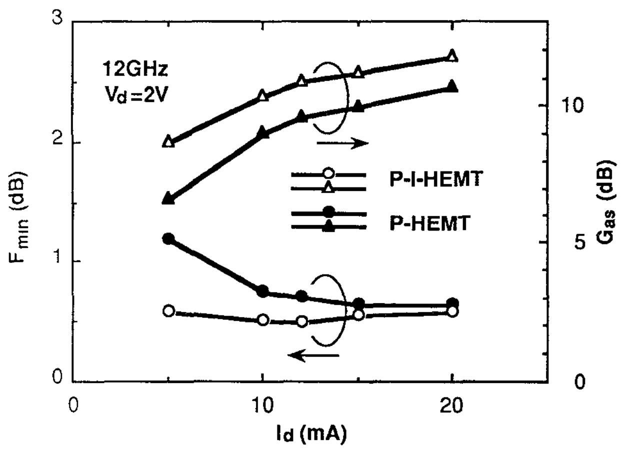

Fig.10 F_{min} s and G_{as}s versus drain current.

REFERENCES

(1) M. Itoh et al., "Effect of InGaAs Well Width on Low-Noise Performance in AlGaAs/InGaAs Pseudomorphic HEMT," Extended Abstracts of the 21st Conference on Solid State Devices and Materials, Tokyo, 1989, pp.285-288.

(2) S. Nishi et al., "High performance inverted HEMT and its application to LSI," Inst. Phys. Conf. Ser., No.83, Int. Symp. GaAs and Related Compounds, pp.515-520: 1986.

(3) H.I.Fujishiro et al., "0.2μm gate pseudomorphic InGaAs/AlGaAs inverted HEMTs," Inst. Phys. Conf. Ser. No 112, Chapter 7, Int. Symp. GaAs and Related Compounds, pp.453-458: 1990.

(4) H. Tsuji et al., "A Sub-10ps/gate Direct-Coupled FET Logic Circuit with 0.2μm-Gate GaAs MESFET," Japanese Journal of Applied Physics, Vol. 29, No. 12, December, 1990, pp.L2438-L2441.