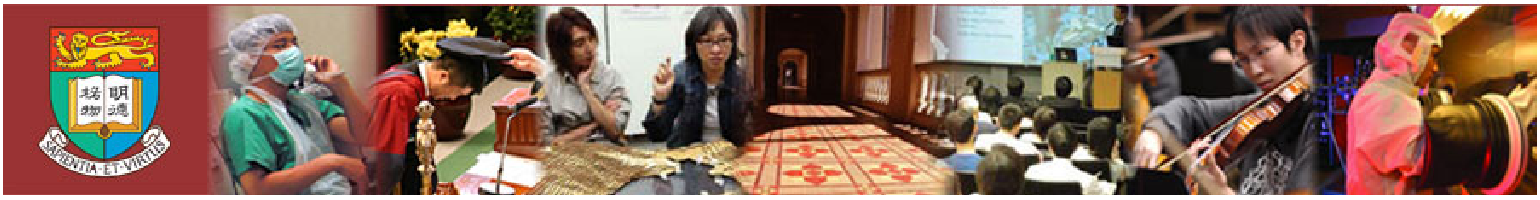

Title	CCl4-doped semi-insulating InP as a buffer layer in GaInAs/InP high electron mobility transistors
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CCl_4-doped semi-insulating InP as a buffer layer in GaInAs/InP high electron mobility transistors

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The application of CCl_4-doped semi-insulating InP as a buffer layer in a pseudomorphic $Ga_{0.2}In_{0.8}P/Ga_{0.47}In_{0.53}As$/InP high electron mobility transistor (HEMT) grown by metalorganic chemical vapor deposition is reported. This Al-free InP-base HEMT with a gate length of 1.3 μm has extrinsic transconductances of 420 and 610 mS/mm at 300 and 77 K, respectively. A cutoff frequency of 15 GHz and a maximum oscillation frequency of 40 GHz are obtained. The results demonstrate the CCl_4-doped semi-insulating InP is a promising buffer layer for InP-based HEMT. © *1996 American Institute of Physics.* [S0003-6951(96)02234-6]

Recently, Gardner *et al.*[1,2] have demonstrated the semi-insulating (SI) property of CCl_4-doped InP grown by low temperature metalorganic chemical vapor deposition (MOCVD). The resistivity of the CCl_4-doped InP layer could exceed 10^{12} Ω cm under proper growth conditions.[2] The CCl_4-doped InP layer with such a good SI property can replace the conventionally undoped AlInAs layer or Fe-doped InP layer in InP-based devices and circuits. The semi-insulating InP layer providing carrier confinement and current blocking can be used for Schottky barrier enhancement or as the buffer layer in InP-based high electron mobility transistors (HEMTs) and the isolation layer in integrated circuits. Among these applications, the use of SI InP as a HEMT buffer layer may offer some advantages over conventional buffer layers. It is well known that Al containing undoped AlInAs usually used as a buffer layer in InP-based HEMTs is responsible for trap-related anomalous phenomena such as the kink effect, deep levels, and high output conductance.[3,4] An Al-free CCl_4-doped InP buffer layer can hopefully eliminate the above effects. Compared to the resistivity of 10^7–10^9 Ω cm for MOCVD grown Fe-doped InP layers,[5] the resistivity of the CCl_4-doped InP layer can be much higher.[2]

In this letter, we present a promising use of CCl_4- doped semi-insulating InP as a buffer layer in a pseudomorphic $Ga_{0.2}In_{0.8}P/Ga_{0.47}In_{0.53}As$/InP HEMT grown by MOCVD. It is shown that the kink effect usually present in the InP-based HEMT is eliminated using the CCl_4-doped InP buffer layer.

Epitaxial growth was performed in a commercial (Aixtron) MOCVD reactor. Trimethylgallium, trimethylindium, tertiarybutylphosphine, and tertiarybutylarsine were used as the precursors. The CCl_4-doped InP buffer layer was grown at a CCl_4 flow rate of 5 cc/m at temperature of 500 °C. The carbon to indium ratio in the gas phase was 0.038, while the V/III ratio was 60. The thickness of the buffer layer is 2000 Å. The HEMT structure and growth condition are similar to those reported earlier[6] except the thickness of undoped GaInAs channel is 400 Å. Since the CCl_4-doped InP buffer is a wide gap material, the HEMT is a double heterostructure device. According to Gardner *et al.*,[1,2] the resistivity of the CCl_4-doped InP layer depends on both the CCl_4 flow rate and the growth temperature. The resistivity of CCl_4-doped InP buffer layer was measured to be 1×10^7 and 10^{10} Ω cm for CCl_4 flow rates of 5 and 10 cc/m, respectively, which is similar to Gardner's results. The higher CCl_4 flow rate gives a higher resistivity at a given growth temperature, but it reduces the growth rate due to the etching effect. So the low CCl_4 flow rate of 5 cc/m was used in this work. The fabrication process is similar to that reported earlier,[6] and the HEMT has a gate length of 1.3 μm and a gate width of 25 μm. The cross section of the HEMT with the epitaxial layered structure is shown in Fig. 1.

Figure 2 shows the typical current–voltage characteristics at 300 and 77 K in darkness. Excellent pinch-off characteristics are observed. The kink effect related to the quality of the buffer layer is commonly observed, especially at 77 K, in InP-based HEMT with either an undoped AlInAs buffer[3,4] or an undoped InGaAs buffer layer.[6] In our devices, no kink effect is observed at 300 K. The kink effect in the $I-V$ curve at 77 K is hardly noticeable indicating that the CCl_4-doped InP is a promising buffer layer for HEMTs. The drain–source breakdown voltage of 2.5 V is a little bit low due to the low breakdown voltage of the Schottky gate for this sample. The drain current is slightly photosensitive. There is

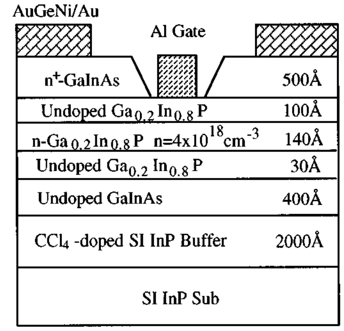

FIG. 1. Cross section of GaInP/GaInAs/InP HEMT with the layered structure.

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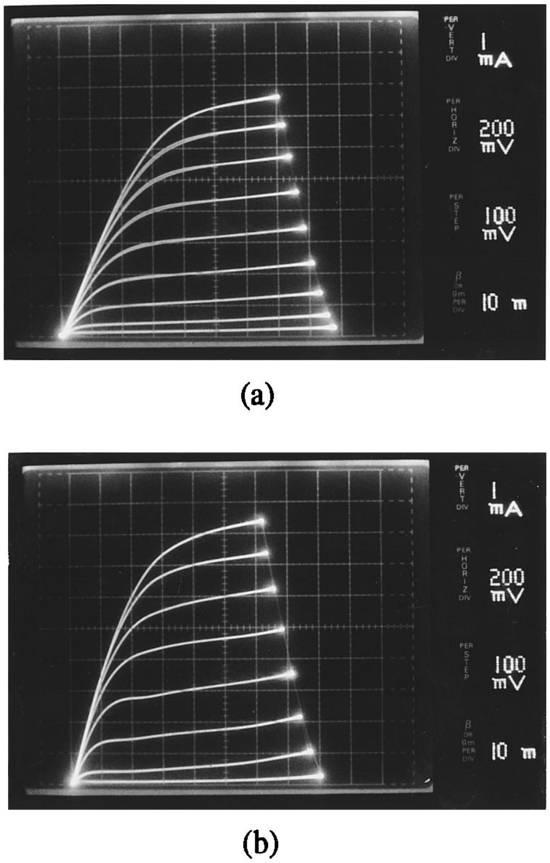

FIG. 2. Drain I–V characteristics of GaInP/GaInAs/InP HEMT with CCl_4-doped InP buffer layer at (a) 300 and (b) 77 K in darkness.

a 3% increase in drain current but no kink effect observed under illumination. The transfer characteristics and the transconductance (g_m) as a function of the gate bias (V_{gs}) are shown in Fig. 3 at the drain–source bias of 1.5 V. The threshold voltages of −0.85 and −0.75 V were measured at 300 and 77 K, respectively. The maximum extrinsic g_m of 420 and 610 mS/mm are obtained at 300 and 77 K. These data are comparable to those of the InP-based HEMTs with undoped AlInAs (Refs. 7 and 8) and undoped (Ref. 9) buffer layers with a similar gate length.

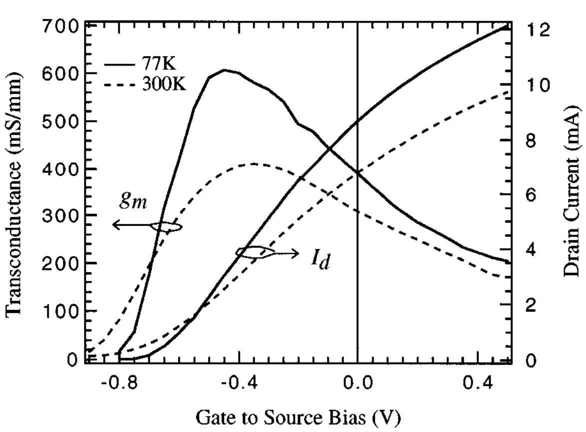

FIG. 3. Drain current (I_d) and transconductance (g_m) as a function of gate–source bias at 300 and 77 K.

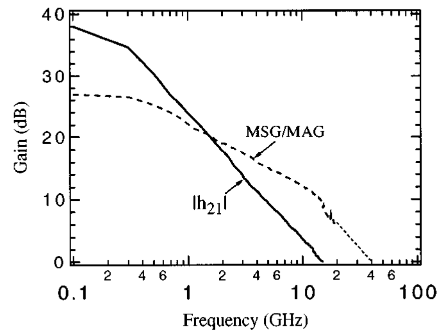

FIG. 4. Current gain ($|h2|$) and maximum stable gain/maximum available grain (MSG/MAG) as a function of frequency at V_{ds} of 1.5 V and V_{gs} of −0.4 V.

Microwave measurements were made with an HP8510B network analyzer and cascade microwave probes in the frequency range from 100 MHz to 20 GHz at 300 K. Figure 4 shows the current gain and maximum stable gain/maximum available gain versus frequency at V_{ds} of 1.5 V and V_{gs} of −0.4 V. The cutoff frequency and the maximum oscillation frequency are 15 and 40 GHz, respectively. The microwave performance can be improved by optimizing the HEMT layer structure and reducing the gate length.

The electron Hall mobility for the HEMT sample was measured to be 4400 and 8400 $cm^2/V\,s$ at 300 and 77 K, respectively. The value of the electron mobility at 77 K is not as high as expected and the reason is unclear at present.

In conclusion, a pseudomorphic $Ga_{0.2}In_{0.8}P/Ga_{0.47}In_{0.53}As/InP$ high electron mobility transistor grown by MOCVD using a CCl_4-doped semi-insulating InP buffer layer is reported for the first time. The dc and rf performance of the HEMT demonstrates that CCl_4-doped semi-insulating InP is a promising buffer layer for InP/InGaAs HEMTs, although the electron mobility and the breakdown voltage of the Schottky gate need to be improved.

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