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A Low Distortion pHEMT with Newly Developed Composite Channel Structure

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1. Introduction

The high-data rate wireless communication systems with digital modulation scheme, such as FWA, require a high gain and a low distortion amplifier. A pseudomorphic HEMT is an attractive candidate for these communication systems because of its high gain characteristics and larger current handling capability.

This paper clarified, for the first time, that the distortion characteristics of pHEMT are strongly dominated by a g_m dip, that is nonlinearity of g_m, which comes from hole accumulation under the gate, using device simulator, IM3 measurement and the Volterra series analysis. And based on these analyses, we achieved the IM3 improvement of 4 dB at 14 GHz by suppression of the g_m dip in our newly developed composite channel structure.

2. Design Guidelines for Linearity Improvement

Fig. 1 shows a cross sectional view of the double-hetero pHEMT we fabricated and analyzed in this work. We adopted buried gate structure and double-hetero structure. Our conventional pHEMT used non-doped $In_{0.2}Ga_{0.8}As$ as channel layer. We measured its S-parameters at various bias points along a power-matched load line and extracted g_m values and the other equivalent circuit parameters. As can be seen in Fig. 2, the extracted g_m profile has an anomaly, that is, a dip around V_{gs} of 0 V. We simulated an impact of the g_m dip on the IM3 and made a comparison between two devices, with and without the g_m dip. Using the third order Volterra series analysis [1][2], we calculated the IM3 of two devices with the same equivalent circuit parameters except the g_m, that is, with and without dip. The calculation result indicated that the one without the g_m dip has 5 dB better IM3 than the other.

To reduce the g_m dip and improve the IM3, we studied the mechanism of g_m dip. We supposed this g_m dip originated from a kink phenomenon of I-V characteristics. Several works have been reported that hole accumulations due to the impact ionization cause the kink phenomena [3]. We calculated the hole concentration at the channel layer under the gate, which is generated by the impact ionization, using device simulator. The profile of the hole concentration along the load line is plotted in Fig. 3. In the V_{gs} range from –0.4 to +0.4 V, intense hole accumulations almost coincides with that of the g_m dip. This result strongly suggests that holes generated by impact ionization cause g_m dip. The consideration above indicates the g_m dip and the distortion characteristics would be improved if there were no kink and no hole generation along the load line.

In order to suppress the hole generation without any degradation of power performance, we propose a new pHEMT with composite channel structure that consists of a upper $In_{0.2}Ga_{0.8}As$ layer and a lower GaAs layer.

3. Device Fabrication, Results and Discussions

To confirm the low distortion characteristic of the proposed structure, we fabricated three types of devices: the composite channel structure, the conventional $In_{0.2}Ga_{0.8}As$ channel structure and a GaAs channel structure. Each HEMT had a WSi/Au T-shaped gate, and the gate length was 0.25 μm, the total gate width was 300 μm.

These HEMTs' g_m profiles are compared in Fig. 4. The composite channel pHEMT has better linearity than the $In_{0.2}Ga_{0.8}As$ channel pHEMT. The GaAs channel HEMT also has better linearity, but lowest g_m value.

We measured power performance of these HEMTs at 14 GHz using on wafer measurement system. Fig. 5 shows P_{in}-P_{out} characteristics. The dependence of the IM3 on single carrier level output power is shown in Fig. 6. Compared with the $In_{0.2}Ga_{0.8}As$ channel pHEMT, the composite channel pHEMT exhibits 4 dB lower IM3 at the power level of 11 dBm that is the point where output power is backed off 10 dB from P_{1dB}. This result indicates that suppression of the hole generation using the composite channel structure improves the IM3 characteristics. Not only g_m linearity but also g_m value has a strong impact on IM3 [2]. The reason why the GaAs channel pHEMT has worst IM3 is its lowest g_m characteristic.

4. Conclusion

We demonstrated that the gm dip along the load line which is caused by hole accumulations has strong impacts on the distortion characteristics and suppressing the gm dip improves the linearity. Based on these analyses, we developed a composite channel pHEMT and confirmed the low distortion characteristics of proposed structure.

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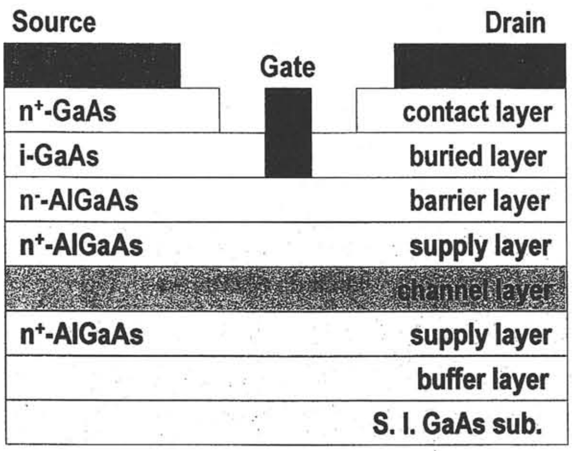

Fig. 1 Cross sectional view of our HEMTs.

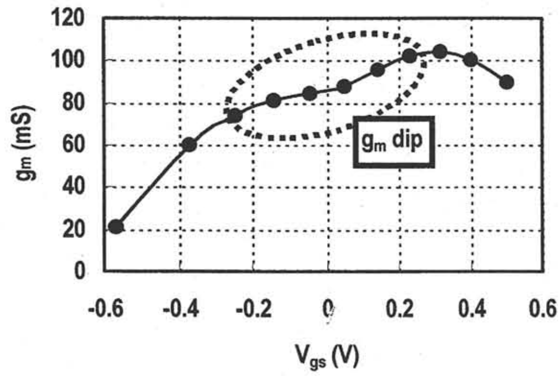

Fig. 2 Transconductance (g_m) profile of the conventional $In_{0.2}Ga_{0.8}As$ pHEMT along the power-matched load line. V_{ds} = 6 V, I_{ds} = 45%I_{max}.

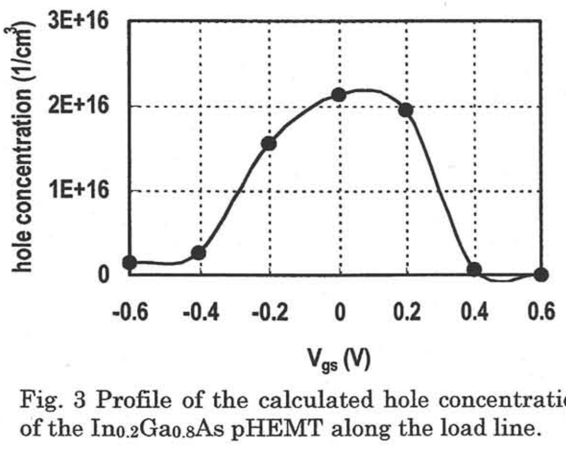

Fig. 3 Profile of the calculated hole concentration of the $In_{0.2}Ga_{0.8}As$ pHEMT along the load line.

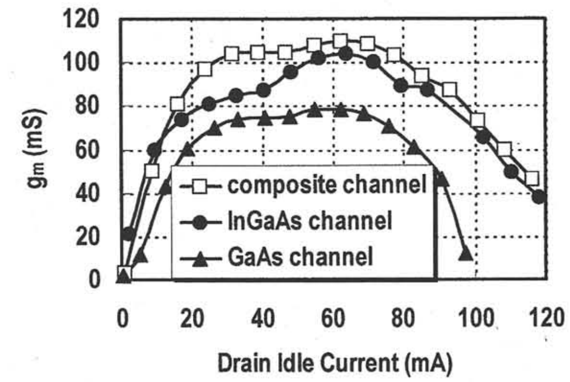

Fig. 4 Comparison of the g_m profiles.

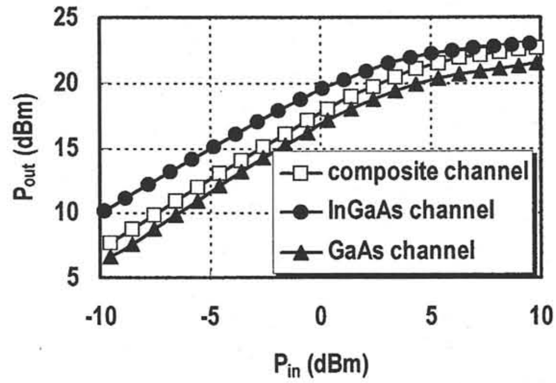

Fig. 5 P_{in}-P_{out} characteristics at frequency of 14 GHz. V_{ds} = 6V, I_{ds} = 45%I_{max}.

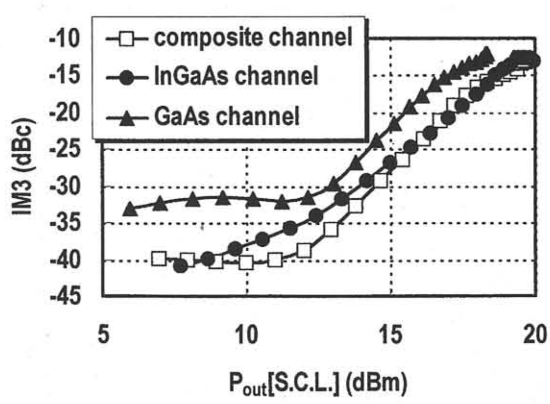

Fig. 6 The dependence of the IM3 on single carrier level output power at carrier frequency of 14 GHz and offset frequency of 10 MHz.