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Effect of Temperature on DC and RF Characteristics of Cryogenic InP HEMTs

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Abstract

We measured the DC and RF characteristics of InP-based 75-nm-gate InAlAs/InGaAs HEMTs at 300, 220, 150, 100, 77 and 16 K. Cutoff frequency f_T and maximum oscillation frequency f_{max} increase with decreasing temperature. The increase of f_{max} with decreasing temperature is more than that of f_T. The f_{max} largely increases between 150 and 100 K. Furthermore, the increase of f_T and f_{max} values is very small between 77 and 16 K.

1. Introduction

InP-based InAlAs/InGaAs HEMTs are one of the best devices for cryogenic low-noise amplifiers (LNAs) [1]. Operating the InP HEMTs cryogenically can improve their DC and RF performance levels due to the suppression of phonon scatterings [2]. In our previous works, we measured the DC and RF characteristics of 30-nm-gate InP HEMT at 300, 77 and 16 K [3] and gate length L_g dependence of the DC and RF characteristics at 300 and 16 K [4].

In this work, we measured the DC and RF characteristics of 75-nm-gate InP HEMTs at 300, 220, 150, 100, 77 and 16 K. We clarified the effect of temperature on improvement of DC and RF performance.

2. Experiments

On-wafer DC and RF measurements were carried out at 300, 220, 150, 100, 77 and 16 K. Cryogenic temperature measurements were carried out using a specially designed cryogenic probing system consisting of a vacuum chamber, a helium-gas closed cycle cryostat and probes. The S-parameters were measured in the frequency range from 0.25 to 50 GHz in 0.25 GHz steps using an HP8510C vector network analyzer and on-wafer probes from Picoprobe. Cutoff frequency f_T values were obtained by the extrapolation of the current gain $|h_{21}|^2$ with a slope of -20 dB/decade in the frequency range from 20 to 50 GHz. On the other hand, maximum oscillation frequency f_{max} values were obtained by the extrapolation of Mason's unilateral power gain U_g from 30 to 50 GHz.

3. Results and Discussion

Figure 1 shows the current-voltage (*I-V*) characteristics of a 75-nm-gate HEMT at 300 and 16 K. This HEMT showed good pinch-off characteristics. Note that good pinch-off behaviors were observed at all the measured temperatures. The kink phenomenon was seen in the *I-V* characteristics at 16 K. Figure 2 shows the gate-source voltage V_{gs} dependence of drain-source current I_{ds} and transconductance g_m. The I_{ds} decreases with decreasing temperature. On the other hand, the maximum g_m increases with decreasing temperature from 300 to 77 K. The decrease in g_m at 16 K results from the kink phenomenon.

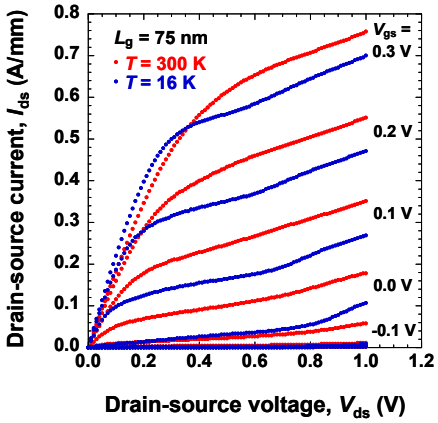

Fig. 1 Current-voltage (*I-V*) characteristics of 75-nm-gate HEMT at 300 and 16 K.

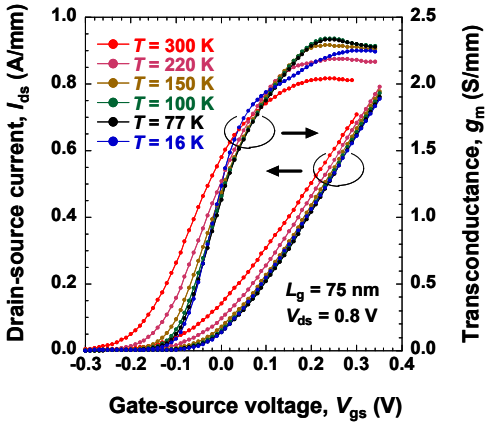

Fig. 2 Gate-source voltage V_{gs} dependence of drain-source current I_{ds} and transconductance g_m under drain-source voltage V_{ds} of 0.8 V at 300, 220, 150, 100, 77 and 16 K.

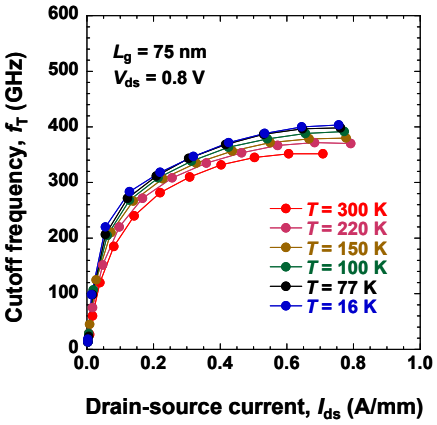

Fig. 3 Drain-source current I_{ds} dependence of cutoff frequency f_T under drain-source voltage V_{ds} of 0.8 V at 300, 220, 150, 100, 77 and 16 K.

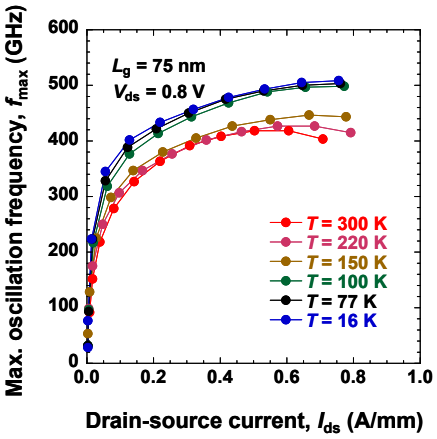

Fig. 4 Drain-source current I_{ds} dependence of maximum oscillation frequency f_{max} under drain-source voltage V_{ds} of 0.8 V at 300, 220, 150, 100, 77 and 16 K.

Figure 3 shows the I_{ds} dependence of f_T under a V_{ds} of 0.8 V. The f_T value gradually increases with decreasing temperature between 300 and 77 K. The increase of f_T value is very small between 77 and 16 K. Figure 4 shows the I_{ds} dependence of f_{max} under a V_{ds} of 0.8 V. The f_{max} value also increases with decreasing temperature. Here, the f_{max} largely increases between 150 and 100 K. On the other hand, the increase of f_{max} value is very small between 77 and 16 K. This phenomenon is the same as that of f_T. Figure 5 shows the temperature dependence of the peak f_T value under V_{ds} of 0.6, 0.8 and 1.0 V. The increase of the peak f_T is large between 300 and 77 K. Below 77 K, the increase of the peak f_T is very small. Figure 6 shows the temperature dependence of the peak f_{max} under V_{ds} of 0.6, 0.8 and 1.0 V. The peak f_{max} value increases between 300 and 77 K. Especially, the large increase of the peak f_{max} is seen between 150 and 100 K. On the other hand, the increase of the peak f_{max} is very small below 77 K, which is the same phenomenon as that of the peak f_T.

4. Conclusions

In conclusion, we measured the DC and RF characteristics of 75-nm-gate InP HEMTs at 300, 220, 150, 100, 77 and 16 K and clarified the effect of temperature on improvement of DC and RF performance. The maximum g_m increases with decreasing temperature between 300 and 77 K. At 16 K, the decrease in g_m is seen, which results from the kink phenomenon. The f_T and f_{max} values increase with decreasing temperature. The increase of f_{max} is more than that of f_T. The f_{max} largely increases between 150 and 100 K. Furthermore, the increase of f_T and f_{max} values is very small between 77 and 16 K.

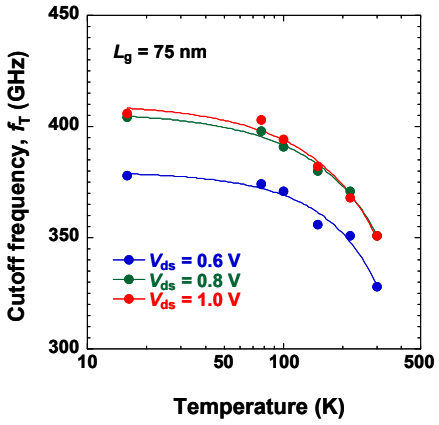

Fig. 5 Temperature dependence of peak cutoff frequency f_T under drain-source voltage V_{ds} of 0.6, 0.8 and 1.0 V.

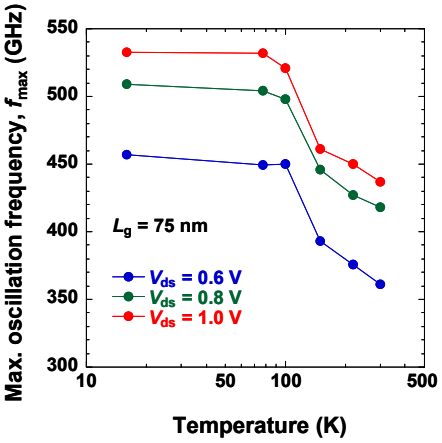

Fig. 6 Temperature dependence of peak maximum oscillation frequency f_{max} under drain-source voltage V_{ds} of 0.6, 0.8 and 1.0 V.

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