Temperature Effects of Low Noise InGaP/InGaAs/GaAs PHEMTs

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Abstract

The temperature-dependent DC characteristics and noise performance of $In_{0.49}Ga_{0.51}P/In_{0.15}Ga_{0.85}As/GaAs$ low noise pseudomorphic high electron mobility transistors (PHEMTs) with the gate dimensions of 0.25 ×160 μm^2 were investigated at 12 GHz with temperature ranging from 300K to 450K. It is found that the variation of the turn-on voltage for drain-to-gate Schottky diode was -1.05 mV/K and reverse voltages, at a fixed 0.5 mA/mm of gate current, was -6 mV/K. The temperature-dependence of pinch-off voltage was -1.01 mV/K and leakage current was 0.043 μA/K. Comparisons of noise performance including minimum noise figure and associated gain between $In_{0.49}Ga_{0.51}P/In_{0.15}Ga_{0.85}As$ and $Al_{0.25}Ga_{0.75}As/In_{0.15}Ga_{0.85}As$ low noise PHEMTs were also made. It is found that the high temperature performance of $In_{0.49}Ga_{0.51}P/In_{0.15}Ga_{0.85}As$ PHEMT is much better than that of $Al_{0.25}Ga_{0.75}As/In_{0.15}Ga_{0.85}As$ due to the less effects of deep level traps by absence of DX-center and lower leakage current by higher Schottky barrier and valence band discontinuity.

1. Introduction

The low noise devices play very important roles in wireless systems. As we know, the InP-based HEMT's show the best noise performance [1], but it is very difficult for their fabrication processes as compared to those of GaAs-based HEMT's. This encourages the development of GaAs-based low-noise AlGaAs/InGaAs/GaAs pseudomorphic HEMT's in these applications [2]. However, several disadvantages still exist, for example, in the viewpoint of achieving precise control of gate recess etching and reliability for thermal stress.

As compared to AlGaAs gated PHEMTs, InGaP-related devices with the following advantages: higher InGaP energy gap, higher valence band discontinuity [3], no deep-complex (DX) center [4], excellent etching selectivity between InGaP and GaAs [5][6], and good thermal stability, are developed recently [6]. As mentioned above, InGaP-based devices are the better choice than AlGaAs-based [7] in low noise applications, such as low noise MMIC. To mention noise performance of low noise devices, thermal effects are one of the most important issues to result in the degradation of low noise device performance. Therefore, the development of thermal-related reliability in InGaP-based devices is the furthest and most important issues.

Recently, super low noise InGaP gated PHEMT devices have been demonstrated with 0.46 dB minimum noise figure and 13 dB associated gain at 12 GHz, with the gate dimension of 0.25 × 160 μm^2 [7]. However, the temperature-dependent of InGaP PHEMTs device parameter and noise performance are still limited. In this paper, we will discuss the temperature effects on InGaP low noise devices for DC characteristics and noise performance. Furthermore, the noise performance between InGaP and AlGaAs low noise devices in different temperatures ranging from 300K to 450K will be also compared. Due to better temperature-dependent noise performance, InGaP/InGaAs/GaAs low noise PHEMT is more promising for low noise applications.

2. Experimental

$In_{0.49}Ga_{0.51}P/In_{0.15}Ga_{0.85}As/GaAs$ low noise PHEMTs, as shown in figure 1, were grown by metal-organic chemical vapor deposition (MOCVD) with composed of an $GaAs/Al_{0.25}Ga_{0.75}As/GaAs$ buffer layer, an undoped $In_{0.15}Ga_{0.85}As$ channel layer, an undoped $In_{0.49}Ga_{0.51}P$ spacer layer, n-type $In_{0.49}Ga_{0.51}P$ donor layer, an undoped $In_{0.49}Ga_{0.51}P$ Schottky layer, and a heavily-doped n-type GaAs cap layer. These layers were grown on (100)-oriented semi-insulating 4-inch GaAs substrate. The active part of the structure was a 145Å undoped $In_{0.15}Ga_{0.51}As$ channel. The Hall mobilities at room temperature and 77K are 5170 cm^2/V.sec and 18700 cm^2/V.sec, corresponding to the two-dimensional carrier densities 2.14×10^{12} cm^{-2} and 1.98×10^{12} cm^{-2}, respectively.

Devices were processed by conventional optical lithography technique. There are three major steps in this super low noise InGaP gated PHEMT fabrication: device isolation, ohmic contact, and Schottky contact. The etching of InGaP for the mesa was achieved using an HCl/H_3PO_4 (3:1) solution. The Au/Ge/Ni was evaporated to form the source and drain ohmic contacts by a 20-s 420℃ hot plate anneal. To form the InGaP gate, the

$HF/H_2O_2/H_2O$ solution was used for selectively removing the cap GaAs material. The Ti/Pt/Au was then deposited for the Schottky gate by lift-off. The gate dimension of the devices was 0.25 μm × 160 μm.

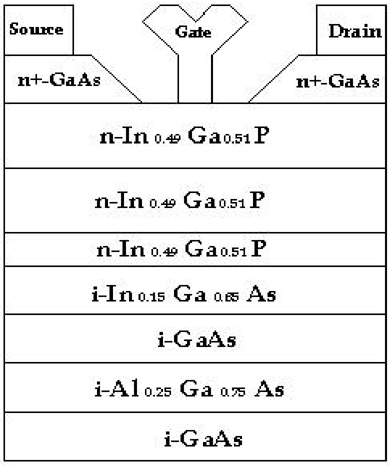

Figure1. Cross-sectional view of $In_{0.49}Ga_{0.51}P/In_{0.15}Ga_{0.85}As/GaAs$ low noise PHEMT structure.

We have measured the DC characteristics at different temperatures ranging from 300K to 450K, including 1) Schottky diode characteristics, 2) pinch-off voltage shift, 3) current-voltage characteristics, 4) the increment of gate leakage current following temperature increments and 5) thermal performance in noise exhibition. We have also measured the thermal performance in noise performance of AlGaAs PHEMT for comparison.

3. Temperature-dependent characteristics

As shown in figure 2, the temperature-dependent characteristics of the Schottky diode were measured. In forward bias, as revealed in the inset of figure 2, the turn-on voltage defined at forward current of 0.5 mA/mm were 0.675 and 0.52V at temperature of T = 300K and 450K, respectively. The temperature-dependent variational ratio of turn-on voltage was -1.05 mV/K. On the other side, the temperature-dependent characteristics of reverse currents were also examined. The reverse current increases with increasing operation temperature. Respectively, the reverse voltages measured at 80 μA are 9.1 and 8.2 V at 300K and 450K and the temperature-dependent variational ratio of reverse voltages was -6 mV/K. Due to the 1.92 eV of bandgap of the InGaP to be a Schottky layer in PHEMT devices, the reliable ΔE_V at $In_{0.49}Ga_{0.51}P/In_{0.15}Ga_{0.85}As$ is to be 0.377 eV [3]. Such a high ΔE_V can prevent the holes generated by thermal effects and impact ionization to pass into the gate to be leakage current, and the higher Schottky barrier of InGaP, is same reasons for reducing leakage current when devices are in operation. As mentioned above, we can find such small temperature-dependent Schottky diode characteristics of -1.05 mV/K in forward bias and -6 mV/K in reverse bias.

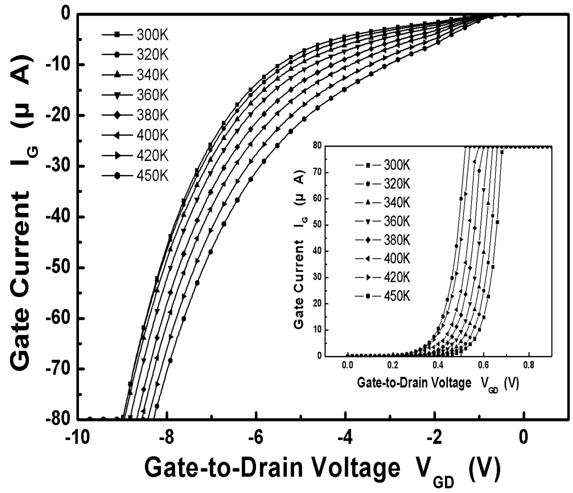

Figure2. The reverse-bias characteristics of gate-to-drain Schottky diode：Inset is for forward-bias.

The temperature-dependent characteristics of pinch-off voltages, as shown in figure 3, were measured at V_{DS} = 2 V and I_{DS} = 2 mA/mm under the devices' operation. The temperature-dependent variational ratio of pinch-off voltage was -1.01 mV/K

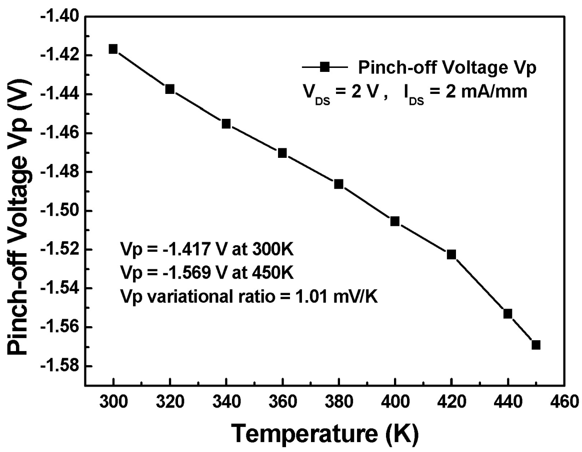

Figure 3. Temperature-dependent characteristics of pinch-off voltage：Measure at V_{DS} = 2 V and I_{DS} = 2 mA/mm.

We measured minimum noise figure at 12 GHz, which DC bias is V_{DS} = 2 V and I_{DS} = 10 mA. The V_{GS} with I_{DS} = 10 mA is near – 0.75 V, as shown in figure 4. Hence the temperature-dependent variational ratio of leakage current with V_{GS} = – 0.75 V was a significant factor to evaluate thermal effects of noise performance.

As shown in figure 5, the temperature-dependent variational ratio of leakage current was 0.043 μA/K at V_{GS} = – 0.75 V. The temperature-dependent characteristics of reverse gate-to-drain voltage (V_{GD}) and gate-leakage current (I_G), with fixed – 0.5 mA/mm of gate current and – 9 V of gate-to-drain voltage, were measured as shown in figure 6 and related variations were 0.258 μA/K of I_G and -6 mV/K of V_{DG} , respectively.

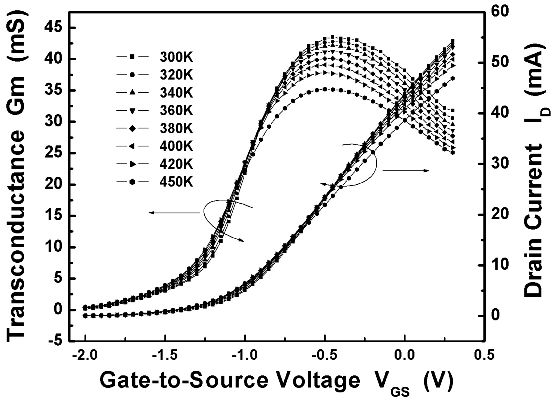

Figure 4. Temperature-dependent transfer curves of low noise InGaP PHEMTs：Measured at VDS = 2 V.

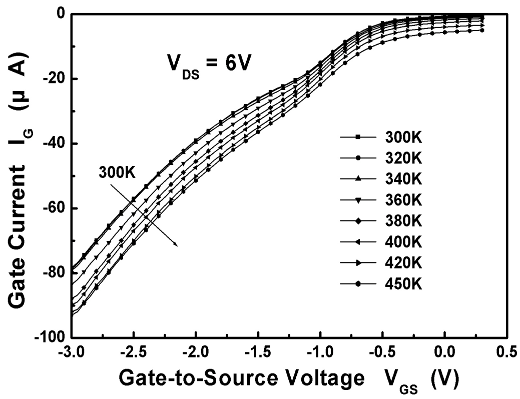

Figure 5. Temperature-dependent characteristics of gate current I_G with temperature ranging from 300K to 450K at V_{DS} = 6 V.

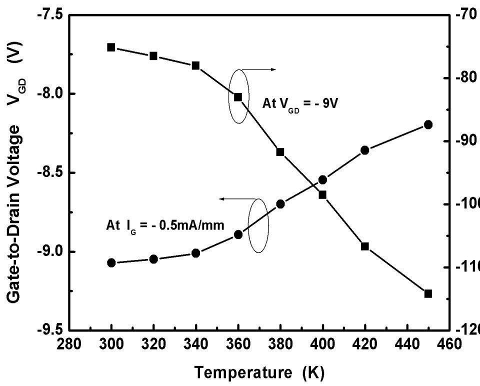

Figure 6. Temperature-dependent characteristics of reverse gate-to-drain voltage (V_{GD}) and gate-leakage current (I_G) at a fixed - 0.5 mA/mm of gate current and - 9 V of gate-to-drain voltage, respectively.

The current-voltage characteristics were measured as shown in figure 7. A significant drop in high drain current is essentially due to the decreased channel mobilities caused by phonon scattering and a significant degradation of the Schottky diode performance [8]. On the other hand, a slight increment in low drain current is primarily due to pinch-off voltage shifts towards further negative V_{GS} values caused by thermal effect. The curve of V_{GS} = -0.6 V was with two phenomena, one is a slight increment of drain current at from V_{DS} = 0 V to 3.5 V and the other is a significant drop of drain current at V_{DS} > 3.5 V.

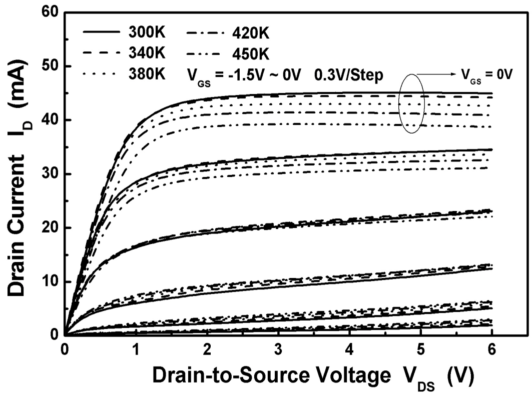

Figure 7. Temperature-dependent current-voltage characteristics of low noise InGaP PHEMTs.

4. Noise performance

The noise performance of low-noise InGaP gated PHEMTs were better than AlGaAs [7]. The minimum noise figure (NF_{min}) and associated gain (G_a) of InGaP and AlGaAs were measured at 12 GHz, which DC bias is V_{DS} = 2 V and I_{DS} = 10 mA, with different temperature ranging from 300K to 450K. The NF_{min} and G_a of InGaP and AlGaAs at 300K and 450K were shown in Table 1. The temperature-dependent NF_{min} and G_a was be normalized by the NF_{min} and G_a at 300K, as shown in figure 8. Both kinds of PHEMTs – InGaP and AlGaAs are conventional single heterojunction PHEMTs with gate dimensions are 0.25 × 160 μm^2. Furthermore, we examined the reliability of temperature-dependent noise performance between InGaP and AlGaAs. We found temperature-dependent variations of NF_{min} and G_a of AlGaAs was much higher than InGaP when measured temperature was increased slightly from 300K to 320K, i.e. the increment was 20K. This means AlGaAs PHEMT is more sensitive to temperature. The noise performance of InGaP PHEMTS, at temperatures ranging from 300K to 450K, was all better than that of AlGaAs.

Table 1.NF_{min} and G_a of InGaP and AlGaAs at 300K and 450K, at 12 GHz.

	InGaP		AlGaAs	
	300K	450K	300K	450K
NF_{min} (dB)	0.46	1.76	0.53	1.88
G_a (dB)	13	10.63	12.87	10.33

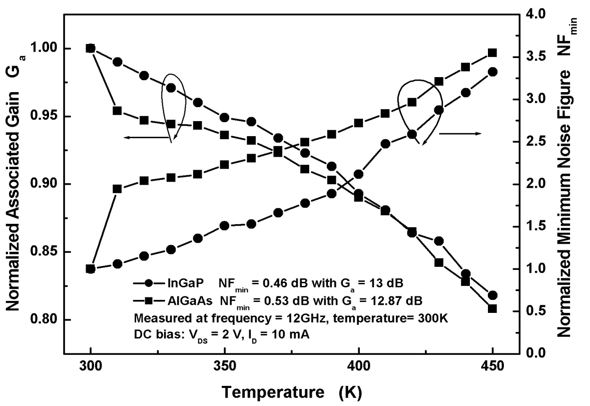

Figure 8. The temperature-dependent performance of normalized minimum noise figure and associated gain at 12 GHz. Both gate dimensions of InGaP and AlGaAs are 0.25 × 160 μm^2

5. Conclusion

In summary, experimental results of temperature-dependent DC characteristics, minimum noise figure and associated gain of low noise InGaP PHEMTs have been demonstrated. Comparison of the noise performance between InGaP and AlGaAs PHEMT has also been made. Small variations of DC characteristics of temperature effects on InGaP devices, as mention above, are observed due to the advantages of InGaP essential attribution. Subsequently, the temperature-dependent noise performance of low noise InGaP PHEMT is proved better than that of AlGaAs.

Hence, the InGaP/InGaAs/GaAs low noise PHEMTs are not only having better noise performance than AlGaAs, but also having higher stability of temperature-dependent characteristics. As the results show, InGaP /InGaAs/GaAs PHEMTs are promising for low noise MMIC applications which require excellent good thermal stability.

Acknowledgment

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