Compound Source MBE를 이용한 InGaP/InGaAs p-HEMT 구조의 성장 및 특성 분석

김 정 훈, 강 신 재, 조 성 준, 송 진 동, 이 용 탁, 송 종 인
광주과학기술원 정보통신공학과
전화 : (062) 970-2262 / 팩스 : (062) 970-2204

Growth and Characterization of InGaP/InGaAs p-HEMT Using Compound Source MBE

J. H. Kim, S. J. Kang, S. J. Jo, J. D. Song, Y. T. Lee, J. I. Song
Dept. of Information and Communications Kwang-Ju Institute of Science and Technology
E-mail : jeonghun@geguri.kjist.ac.kr

Abstract

DC and low frequency noise characteristics of InGaP/InGaAs pseudomorphic HEMTs (p-HEMTs) grown by compound source MBE are investigated for temperature range of 150K to 370K. Equivalent input noise spectra(S_{iv}) were measured as a function of frequency and temperature. S_{iv} was measured to be 3.4 X 10^{-12} V^2 / Hz at 1kHz for 1.3 X 50㎛^{2} InGaP/InGaAs p-HEMT at room temperature. Measurements of the low-frequency noise spectra of the p-HEMT as a function of temperature show that the trap with an activation energy level around 0.589 eV is a dominant trap that accounts for the low-frequency noise behavior of the device. The normalized extrinsic g_m frequency dispersion of the p-HEMT was as low as 2.5% at room temperature, indicating that the device has well-behaved low-frequency noise characteristics. Sub-micron (0.25X50㎛^{2}) gate p-HEMT showed f_T and $f_{\max}$ of 40GHz and 108GHz, respectively.

I. Introduction

In many circuit applications including high performance oscillators or decision circuits, low phase noise characteristics are required[1-2]. The ultimate phase noise performance of these circuits depends on the low frequency noise characteristics of the transistors used. Being a mature device technology, AlGaAs/InGaAs p-HEMT suffers from inferior low frequency noise characteristics due to the high concentration of *DX* centers in AlGaAs barrier layer, resulting in abnormalities such as threshold voltage shift, persistent photoconductivity, and *I-V* collapse. $In_{0.49}Ga_{0.51}P/In_xGa_{1-x}As$ heterojunction system has been attracting much attention for use in circuit applications that require low phase noise characteristics due to its low deep trap density and excellent surface and interface characteristics.

Various devices have been fabricated based on the InGaP/InGaAs system including high electron mobility transistors (HEMTs), heterojunction bipolar transistors (HBTs). Recently, InGaP/InGaAs p-HEMTs have been fabricated and characterized by several authors[3-4]. Record RF performance for this material system is obtained for 0.1㎛ devices with f_T =106GHz and $f_{\max}$ =188GHz [4].

In this paper we present DC, RF and low-frequency noise characteristics of InGaP/InGaAs p-HEMT grown by compound source MBE system and their relationship with deep trap levels in InGaP barrier layer. In addition, we present the temperature-dependent transconductance frequency dispersion characteristics of the transistor associated with the deep trap levels.

II. Epitaxial layer growth and device fabrication

$In_{0.49}Ga_{0.51}P/In_{0.25}Ga_{0.75}As$ p-HEMT structures were grown by V80H-10K compound source MBE system. Dominant sources of group V are As_2 and P_2 generated from GaAs and GaP compound cells, respectively. All the epi layers were grown at the substrate temperature of 500°C and with a group V/III ratio of approximately 10. Room temperature Hall mobility and density of two-dimensional electron gas in the channel were 2,500~3,000 $cm^2/v \cdot sec$ and $1.6 \sim 2.0 \times 10^{12}/cm^{-2}$, respectively. The rather low mobility of the p-HEMT structure is attributed to the degradation of InGaP/InGaAs hetero-interface due to the long growth interrupt that is necessary for switching group V sources at the interface. The mobility of the p-HEMT structure was improved to ~5,000 $cm^2/v \cdot sec$ by the use of $Al_{0.22}Ga_{0.78}As$ spacer between InGaAs channel and InGaP barrier layer that can move the growth interrupt region away from the InGaAs channel. Transistors having a 1.3×50 μm^2 gate and 0.25×50 μm^2 gate were fabricated conventional optical lithography and E-beam lithography, respectively, for characterization including low frequency noise characteristics.

Mesa etching was performed by subsequent etching of GaAs cap, InGaP barrier, InGaAs channel, and GaAs buffer layers. A $H_2SO_4/H_2O_2/H_2O$ solution was used for the etching of GaAs and InGaAs layers, while the InGaP layer was etched using HCl/H_3PO_4 solution. Ohmic contacts were realized by E-beam evaporation of Ni/Au/Ge/Ni/Au (300/1,000/300/300/1,000Å) layers followed by 400°C, 30 sec rapid thermal annealing. After the gate lithography gate recess etching was carried out using $H_2SO_4/H_2O_2/H_2O$ solution that has an etching selectivity greater than 100 against InGaP. Subsequently, Ti/Pt/Au (300/300/4,000Å) gate metal was e-beam evaporated and lifted off. Finally, a Ti/Au (300/4,000Å) layer was used for probing pads required for device characterization.

III. Results and discussion

DC characteristics of the fabricated p-HEMT for temperatures between 150K and 370K were measured using HP4155 parameter analyzer and RF characteristics are measured using HP8510C network analyzer. Dependence of the $I-V$ characteristics of the p-HEMT on temperature is presented in Fig. 1. Drain saturation current and transconductance vs. gate voltage characteristics with temperature as a parameter are shown in Fig. 2. Variation of drain saturation current and transconductance vs. gate voltage characteristics with temperature as a parameter are shown in Fig. 3. The dc characteristics of the p-HEMT showed no significant abnormalities associated with the deep trap including I-V collapse and persistent photoconductivity for temperature as low as 150K. Dependence of the f_T and f_{max} of the $0.25X50\mu m^2$ InGaP/InGaAs p-HEMT on gate bias is presented in Fig. 4.

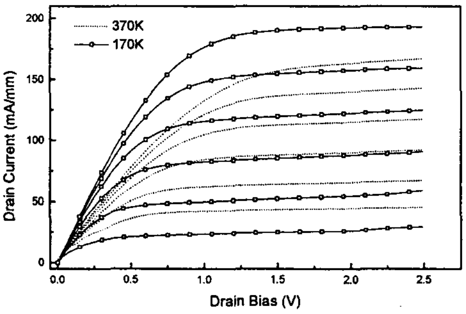

Fig 1. I-V characteristics of InGaP/InGaAs p-HEMT having a $1X50\mu m^2$ gate

$1/f$ noise, which is attributed to the fluctuation of the carrier number or mobility, is one of the dominant low-frequency noise sources in electronic devices[5]. As the frequency is increased, the $1/f$ noise decreases and other white Gaussian noise terms become dominant. However, when deep traps are present in semiconductor devices, additional noise components usually called *generation-recombination*($g-r$) noise are superimposed on the $1/f$ noise spectra. The low-frequency noise associated with deep traps usually appears as a Lorentz-shape spectrum. The low-frequency input noise spectral density S_{iv} of HEMT operating in saturation can be expressed as

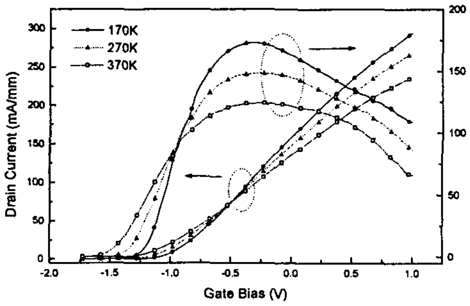

Fig. 2. I_{dss} and g_m characteristics of InGaP/InGaAs p-HEMT at different temperatures.

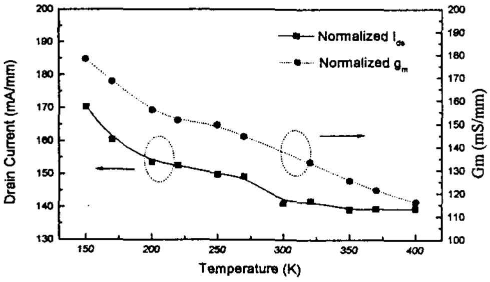

Fig. 3. I_{dss} and g_m characteristics of InGaP/InGaAs p-HEMT as a function of temperature.

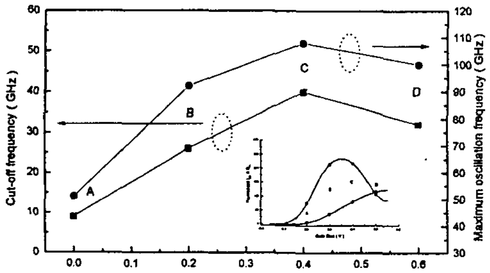

Fig. 4. f_T and f_{max} as a function of gate bias

$$S_{iv}=\frac{\overline{v_{ng}^2}}{\Delta f}=\frac{\alpha_h\, q\, v_{av}}{f^{\gamma}\, l_g'}\left(\frac{I_{dss}}{g_m^2}\right) \qquad (1)$$

$$+4kT\left(\sum_{r=1}^{r=n}\frac{\rho_r(\tau_r/\tau_0)}{1+\omega^2\tau_r^2}+\frac{P}{g_m}+r_{ss}+r_{gg}\right)$$

where α_h and v_{av} are the Hooge parameter and average carrier velocity, ρ_r, τ_r, τ_0 are the equivalent resistance, the time constant representing the r-th component of $g-r$ noise, and the reference time constant, P is the constant representing the thermal noise at the drain, and r_{ss} and r_{gg} are the source and gate parasitic resistances, respectively [6-7]. In low frequency range thermal noise terms are negligible and the $1/f$ noise and $g-r$ noise are dominant.

The temperature dependence of the input noise spectral density was investigated under saturation bias condition (V_{gs}=0.0V, V_{ds}=2.0V) for temperatures between 150K and 370K. From the input noise spectral density of the p-HEMT measured at 300K and Eq.(1) without contributions of $g-r$ noise and thermal noise, γ and α_h were extracted to be 1.20 and 1.45X10^{-5}, respectively. As shown in Fig. 5, pure $1/f$ noise spectra were found in InGaP/InGaAs p-HEMT from 1Hz to 52kHz for most of the temperatures. However, Lorentz-shape spectra superimposed on the $1/f$ noise were observed for temperatures around 270K. The detailed input noise spectra around 270K shift of the peak position in Lorentz-shape spectra due to the change of the time constant of the deep trap was observed as the temperature was changed. The activation energy of the trap extracted from the Arrhenius plot was 0.589 eV, which is reported to be associated with phosphorus vacancy and related complexes[8].

Transconductance of p-HEMT is affected by activation of traps which is dependent on temperature as well as frequency due to the response time of the associated traps. The measurement results are shown in Fig. 6 for the InGaP/InGaAs p-HEMT's operated at V_{gs}=0.0V, V_{ds}=2.0V. The dispersion of g_m was low at low and high temperatures and reached maximum at temperature around 250K, which has a very similar trap activation tendency observed in low-frequency

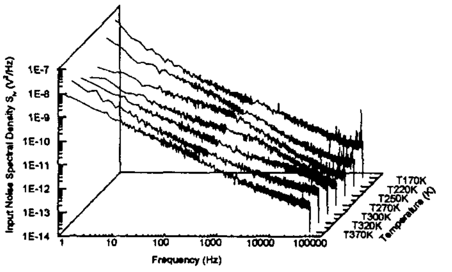

Fig 5. Equivalent input noise spectral density of InGaP/InGaAs p-HEMT under various temperatures.

noise measurements. The normalized extrinsic g_m frequency dispersion of the p-HEMT was as low as 2.5% at room temperature.

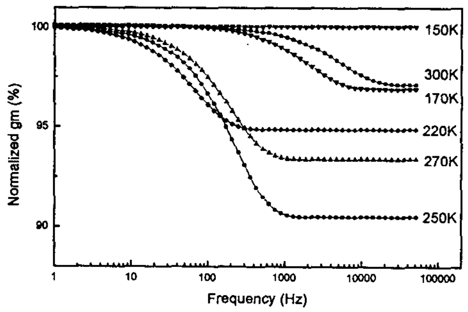

Fig. 6. gm dispersion characteristics of InGaP/ InGaAs p-HEMT

IV. Conclusions

DC, RF and low-frequency noise performance of InGaP/InGaAs p-HEMT is characterized and its relationship with deep traps in InGaP barrier layer has been investigated using excess noise and transconductance frequency dispersion measurements. InGaP/InGaAs p-HEMT has relatively large S_{iv} at 1kHz, due to unoptimized ohmic and InGaP/InGaAs interface. However it has small $g-r$ noise bulge and low extrinsic g_m frequency dispersion as compared with those of typical AlGaAs/InGaAs p-HEMT. These measurements results indicate the potential of the InGaP/InGaAs p-HEMT grown by compound source MBE for use in low phase noise applications.

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