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Investigation of Low-Frequency Noise Behavior of $In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As$ Metamorphic High Electron Mobility Transistors

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1. Introduction

InP-based high electron mobility transistors (HEMTs) have much better microwave and noise characteristics compared with those of GaAs-based (p-)HEMTs due to improved transport properties of the $In_xGa_{1-x}As$ (x~0.53) channel layer [1]. To exploit the excellent device characteristics of InP-based HEMTs, metamorphic buffer growth techniques have been extensively studied to grow InAlAl/InGaAs HEMT structures (closely lattice-matched to InP) on GaAs substrates, and InAlAl/InGaAs metamorphic HEMTs (MM-HEMTs) having a microwave performance (f_T ~ 200 GHz) comparable to that of the InAlAl/InGaAs HEMT grown on InP substrates was demonstrated [2]. Low-frequency noise characteristics of InP-based HEMTs are also know to be better than those of GaAs-based (p-)HEMTs [3]. The low-frequency noise characteristics of transistors are one of the most important device parameters, especially when they are used for circuit applications including oscillators that require low phase noise characteristics. However, to the best of our knowledge, there has been no report on the low-frequency noise characteristics of MM-HEMTs grown on GaAs substrates. In this paper, we first report on the low-frequency noise characteristics of $In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As$ MM-HEMTs grown on GaAs substrates.

2. Experiments and Results

The epitaxial layer structure of the MM-HEMT is shown in Fig. 1. The structure had a 2DEG density of $4x10^{12}/cm^2$ and a mobility of 8,500 $cm^2/V \cdot sec$ at room temperature. MM-HEMTs having two 0.5x50 μm^2 gates were fabricated. The normalized maximum transconductance and drain saturation current (@Vgs = 0V) were 620mS/mm and 0.7A/mm, respectively. Figure 2 shows the current and power gain characteristics of the MM-HEMTs as a function of the frequency measured at V_{gs}=-0.8V and V_{ds}=1.0V. The current gain transition frequency (f_T) and the maximum oscillation frequency (f_{max}) were 53 GHz and 170 GHz, respectively.

$In_{0.53}Ga_{0.47}As$	Si=4E18/cm^3	30nm
$In_{0.52}Al_{0.48}As$	undoped	25nm
$In_{0.52}Al_{0.48}As$	Si=4.5E12/cm^2	2nm
$In_{0.52}Al_{0.48}As$	undoped	3nm
$In_{0.6}Ga_{0.4}As$	undoped	23nm
$In_{0.52}Al_{0.48}As$	undoped	4nm
$In_{0.52}Al_{0.48}As$	Si=1.3E12/cm^2	2nm
$In_{0.52}Al_{0.48}As$	undoped	30nm
$In_xAl_{1-x}As$(x=0->0.52)	undoped	1200nm
Semi-insulaing GaAs Substrate		

Fig. 1. Epitaxial layer structure of the $In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As$ MM-HEMT.

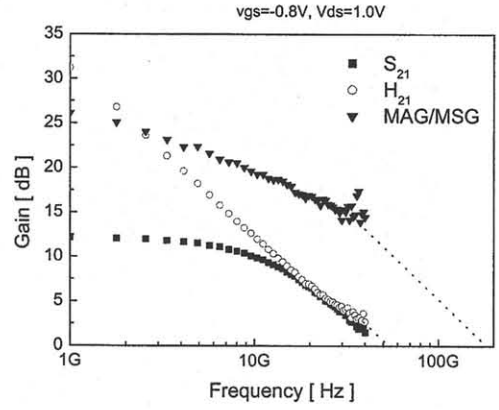

Fig. 2. S_{12}, h_{21}, and MSG/MAG of the MM-HEMT as a function of the frequency.

Low-frequency noise characteristics of the MM-HEMTs were measured for temperatures between 200 K and 400 K and for frequencies from 1 Hz to 53 kHz. Figure 3 shows the input noise spectral density (S_{iv}) of the MM-HEMTs as a function of the frequency with the temperature as a parameter. The noise spectra showed pure $1/f$ noise characteristics with the Hooge parameter (α_h) and the frequency exponent (γ) of ~$3.7x10^{-5}$ and ~1.0, respectively.

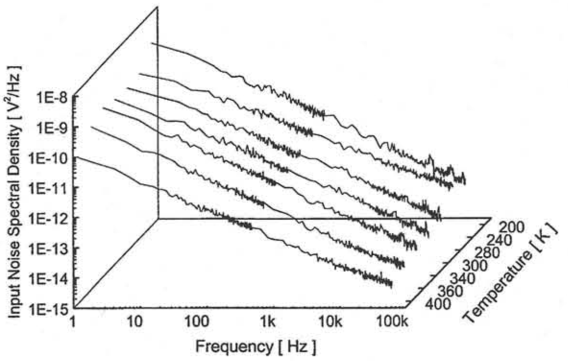

Fig. 3. Low-frequency input noise spectral density of the MM-HEMT as functions of the temperature and the frequency.

Dependence of the input *1/f* noise spectra on the gate and drain bias voltages were measured. Figures 4 and 5 shows the S_{iv}(@1kHz) as a function of the drain and gate biases, respectively. While the S_{iv}(@1kHz) decreased as the drain bias was increased from ohmic to saturation region, it showed a reduced dependence on the gate bias in the saturation region. Transconductance of the MM-HEMT was measured for the same temperature and frequency ranges. The maximum transconductance frequency dispersion was less than 1%, which was extremely low considering that the value was typically more than 10% for most of the (p-)HEMTs reported. The pure *1/f* noise spectra and the low transconductance frequency dispersion characteristics reveal that the MM-HEMT epi structure has an insignificant level of deep traps, indicating the quality of the $In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As$ MM-HEMT epi structure. Comparison of low-frequency noise characteristics of the $In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As$ MM-HEMT and the $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$/InP HEMT (ref. 3) is shown in Table 1.

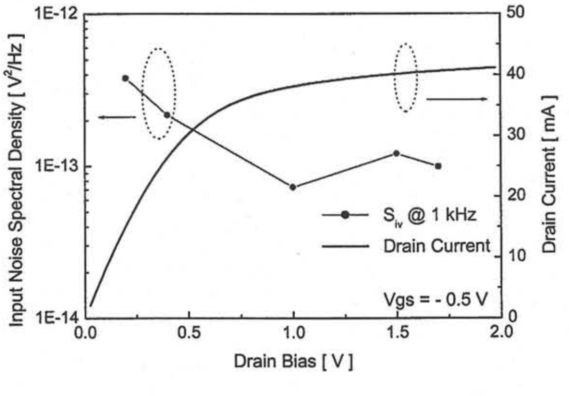

Fig. 4. Dependence of input noise spectral density of the MM-HEMT on the drain bias voltage (@Vgs=-0.5V).

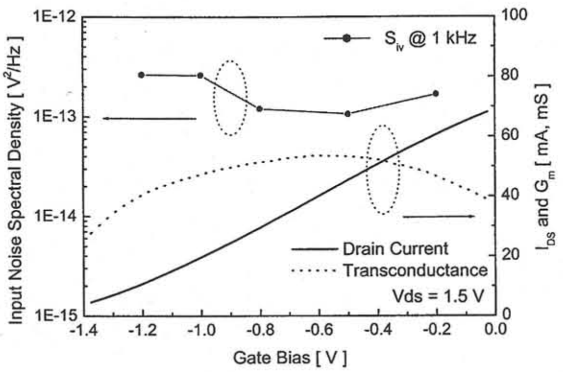

Fig. 4. Dependence of input noise spectral density of the MM-HEMT on the gate bias voltage (@Vds=1.5V).

Table 1. List of the low-frequency noise performance of the $In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As$ MM-HEMT and the state-of-the-art InAlAs/InGaAs/InP HEMTs (ref. 3).

Parameters	$In_{0.52}Al_{0.48}As/$ $In_{0.60}Ga_{0.40}As$ MM-HEMT	$In_{0.52}Al_{0.48}As/$ $In_{0.53}Ga_{0.47}As$/InP HEMT
Siv (@1kHz)	0.8×10^{-13} V²/Hz	1.0×10^{-13} V²/Hz
Hooge Parameter	3.7×10^{-5}	3.2×10^{-5}
Frequency Exponent	1.0	n/a
g-r noise bulges	none	@ 0.1 & 100 kHz
g_m dispersion	<1%	n/a

3. Conclusions

$In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As$ MM-HEMTs grown on GaAs substrates having comparable low-frequency noise characteristics to those of the state-of-the-art $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ HEMTs grown on InP substrates have been demonstrated. The results indicate a great potential of the $In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As$ MM-HEMT grown on a GaAs substrate for millimeter-wave circuit applications requiring low phase noise characteristics.

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