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Low-Noise Performance of Pseudomorphic InGaAs/InAlAs HEMTs

Issei Watanabe [1], Akira Endoh [1,2], Takashi Mimura [1,2] and Akifumi Kasamatsu [1]

[1] National Institute of Information and Communications Technology
4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan
Phone: +81-42-327-7944 E-mail: issei@nict.go.jp
[2] Fujitsu Laboratories Ltd.
10-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0197, Japan

Abstract

We achieved a low minimum noise figure (NF_{min}) of 0.6 dB and an associated gain of 4.7 dB at 50 GHz for a pseudomorphic $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT with a gate length of 35 nm when biased at a drain-source voltage of 0.4 V and a gate-source voltage of -0.2 V. This NF_{min} is one of the lowest values for InGaAs/InAlAs HEMTs ever reported in the 50 GHz band.

1. Introduction

InGaAs/InAlAs high electron mobility transistors (HEMTs) are the promising electron devices not only for future ultra-high-speed wireless communications but also expansion of radio spectrum resources in millimeter- (30-300 GHz) and sub-millimeter-wave (300 GHz-3 THz) frequency bands; this is because these HEMTs can demonstrate a high current-gain cutoff frequency (f_T), a maximum oscillation frequency (f_{max}) and a low noise figure (NF). In fact, extremely high f_T of up to 710 GHz and f_{max} above 1 THz have been reported [1, 2]. In our previous works, a high f_T of 520 GHz, a high f_{max} of 425 GHz and a low minimum NF (NF_{min}) of 0.8 dB at 90 GHz were simultaneously obtained in a pseudomorphic $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT with a gate length (L_g) of 35 nm [3, 4]. In this study, we measured on-wafer noise performance at a frequency of 50 GHz and investigated the effect of DC bias on the noise performance of the 35-nm-gate $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT.

2. Device Fabrication

The epitaxial structure of the $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT consists of a 200-nm-thick $In_{0.52}Al_{0.48}As$ buffer, an 8-nm-thick pseudomorphic $In_{0.7}Ga_{0.3}As$ channel, a 3-nm-thick $In_{0.52}Al_{0.48}As$ spacer, a Si-planar doped sheet (N_D = 5×10^{12} cm^{-2}), a 6-nm-thick $In_{0.52}Al_{0.48}As$ Schottky barrier, a 3-nm-thick InP etching stopper, a 20-nm-thick Si-doped $In_{0.53}Ga_{0.47}As$ cap (N_D = 2×10^{19} cm^{-3}) and a 10-nm-thick Si-doped $In_{0.7}Ga_{0.3}As$ cap (N_D = 2×10^{19} cm^{-3}). This structure was grown on a conventional (100)-oriented three-inch semi-insulating InP substrate by metal-organic chemical vapor deposition (MOCVD). The 8-nm-thick $In_{0.7}Ga_{0.3}As$ channel was used to enhance electron mobility and saturation velocity. We then fabricated HEMTs by using a simple, self-aligned one-step-recessed gate procedure [3, 4]. Source and drain electrodes were formed using non-alloyed Ti/Pt/Au ohmic contacts and the gap between these electrodes was set to be 2 μm. We evaporated a 20-nm-thick SiO_2 film to improve adhesion of a tri-layer EB resist (ZEP/PMGI/ZEP), define a gate footprint, and mechanically support T-shaped Ti/Pt/Au gates. The Schottky gates with widths of 50 μm×2 were also formed after replicating the gate-foot pattern onto the SiO_2 film using CF_4 reactive ion etching and removing the Si-doped InGaAs cap layers using a highly selective citric acid-based etchant.

3. Device performance

The on-wafer DC and radio-frequency (RF) characteristics of the HEMT were measured using a vector network analyzer (Keysight Technologies; N5247A), a DC power analyzer (Keysight Technologies; N6705B) and on-wafer probes. Fig. 1 shows the typical gate-source voltage (V_{gs}) dependence on drain-source current (I_{ds}) and transconducatnce (g_m) of the 35-nm-gate $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT. The drain-source voltage (V_{ds}) was changed from 0.2 V to 0.8 V in 0.2-V-steps. This HEMT was well pinched off. As the V_{ds} increased from 0.2 V to 0.8 V, the maximum g_m (g_{m_max}) increased from 1.05 S/mm to 1.80 S/mm.

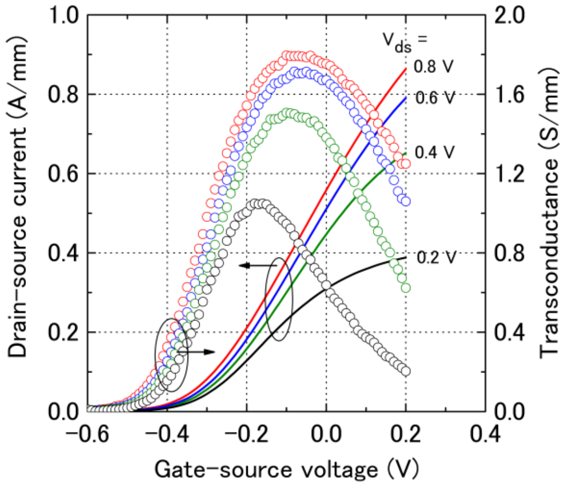

Fig. 1 V_{gs} dependence on I_{ds} and g_m of $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT with L_g = 35 nm and W_g = 50 μm×2.

The on-wafer noise performance on the HEMT was investigated using a source-pull noise measurement system in our laboratories. The NF_{min} was determined by using a noise source (NoiseCom; NC346V), an automatic impedance tuner (Focus Microwave; iCCMT-5060), and a noise receiver set in the vector network analyzer. On the other hand, the associated gain (G_a) was also measured by using the vector network analyzer when the impedance of the input tuner was tuned to be just 50Ω. The NF_{50}, where the noise figure measured when the input and output impedances were tuned to be 50Ω, was 0.9 dB when biased at V_{ds} = 0.4 V and V_{gs} = -0.2 V. With tuning the input impedance to minimize NF, the NF_{min} was determined to be 0.6 dB under the same bias condition, as shown in Fig. 2.

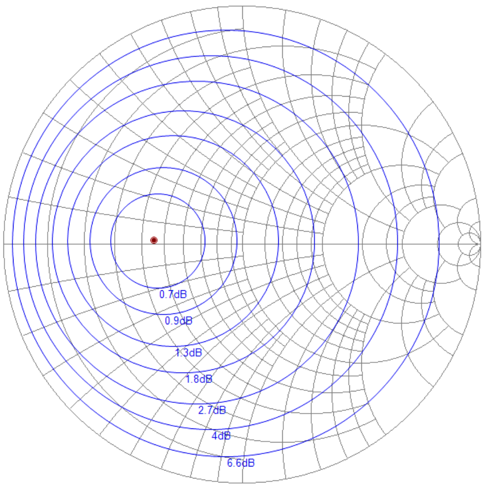

Fig. 2 Noise circles at 50 GHz for 35-nm-gate $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT biased at V_{ds} = 0.4 V and V_{gs} = -0.2 V.

Next, we investigated the effect of V_{ds} on the noise performance of the HEMT. Table I shows the results of DC, RF and noise performances on the HEMT. R_n and AvGain were respectively noise resistance and available gain.

Table I Results of DC, RF and noise performances on 35-nm-gate $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT.

V_{ds} (V)	0.20	0.40	0.60	0.80
V_{gs} (V)	-0.25	-0.20	-0.15	-0.10
I_{ds} (mA)	8.4	16.4	26.5	39.3
I_{gs} (μA)	-58	-78	-93	-106
$V_{ds}\times I_{ds}$ (mW)	1.7	6.6	15.9	31.4
g_m (mS)	86	128	160	180
G_a (dB)	2.0	4.7	6.2	7.4
NF_{50} (dB)	2.3	0.9	1.4	1.7
NF_{min} (dB)	1.0	0.6	0.8	0.9
R_n (Ohm)	9.4	3.7	7.7	10.0
AvGain (dB)	6.7	10.0	10.0	10.9

As the V_{ds} decreased from 0.8 V to 0.4 V, the NF_{min} decreased from 0.9 dB to 0.6 dB and we found that the NF_{min} had the minimum value of 0.6 dB at V_{ds} = 0.4 V. On the other hand, the DC power consumption ($V_{ds}\times I_{ds}$) decreased drastically from 31.4 mW to 6.6 mW as the V_{ds} decreased

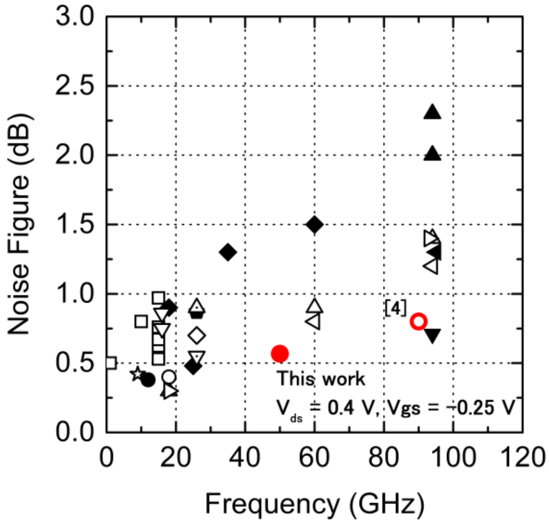

Fig. 3 Frequency dependence on noise figure for InGaAs/InAlAs HEMTs ever reported.

from 0.8 V to 0.4 V. Furthermore, the obtained NF_{min} is one of the lowest values for InGaAs/InAlAs HEMTs ever reported in the 50 GHz band, as shown in Fig. 3. These results indicate that the pseudomorphic InGaAs/InAlAs HEMTs are suitable for low noise and low power consumption performances for future millimeter- and sub-millimeter-wave wireless communications and sensing applications.

4. Conclusions

We measured on-wafer noise performance at 50 GHz and investigated the effect of DC bias on the noise performance of the 35-nm-gate $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ HEMT. The NF_{min} of 0.6 dB with associated gain of 4.7 dB and available gain of 10.0 dB was obtained when biased at V_{ds} = 0.4 V and V_{gs} = -0.2 V for the HEMT. Moreover, the obtained NF_{min} is one of the lowest values for InGaAs/InAlAs HEMTs ever reported in the 50 GHz band.

References

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