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E-6-5

Frequency Dispersion in Drain Conductance of InAlAs/InGaAs HEMTs and Its Correlation with Impact Ionization

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Introduction

0.1-μm-gate $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ HEMTs [1] are promissing devices for ultrahigh-speed systems such as 40 Gbit/s optical communication systems[2]. Frequency dispersion (FD) of device parameters is undesirable in wideband analog and digital ICs. It is said that the change of the crosspoint in eye pattern with various duty cycles in logic ICs results from FD of device parameters [3]. Thus, it is very important to characterize FD of device parameters. In the case of InAlAs/InGaAs HEMTs, it has been reported that drain conductance (g_d) at high frequency is much lower than that at low frequency (negative dispersion), and there have been many arguments on the origin of FD [4, 5].

In this paper, we investigated the FD in g_d of 0.1-μm-gate InAlAs/InGaAs HEMTs under various bias conditions in a frequency range from 9kHz to 500MHz using a network analyzer. The substrate current was also monitored from the backside of the wafer. Fine correlation between FD and the substrate current is observed for the first time.

Frequency Dispersion in Drain Conductance

Figure 1 shows the device structure of the tested 0.1-μm-gate InAlAs/InGaAs HEMT on an InP substrate. The HEMT structure was grown by MOCVD. By introducing InP etch-stopper technology [6], the threshold voltage scatter was reduced successfully. The kink effect and FD in transconductance (g_m) dispersion was also significantly reduced [7]. The typical g_m and g_d at DC are 1200 and 20 mS/mm, respectively. Figure. 2 shows the I-V characteristics of the device. Kink in I-V characteristics was not observed in this device.

Figure 3 shows the frequency dependence of g_d normalized by g_d at 500MHz. In the intermediate gate voltage ranging from -0.2 to +0.2V, the FD is large and negative. g_d at high frequency (>100MHz) is about half of that at low frequency (<1MHz). On the other hand, at low and high gate voltages (-0.4 or 0.4V), the FD is reduced and is flat or slightly positive.

In order to characterize the magnitude of FD, we define the standard deviation (σ) of the ratio $R(f)=g_d(f)/g_d(500MHz)$ as follows,

$$\sigma = \sqrt{\frac{\sum_f \left(R(f) - \langle R(f)\rangle\right)^2}{n-1}}.$$

Figure 4 shows dependence of σ and substrate current on drain-source voltage (V_{ds}) at the gate-source voltage (V_{gs}) of 0V. In the figure, the monitored substrate currents are also plotted. The non-linear substrate current in a semi-insulating InP substrate is considered to be due to the hole current generated by impact ionization [8]. It is clear that the increase of σ coincides with the increase of substrate current. This result suggests a correlation between FD and impact ionization in the channel.

Figure 5 shows dependencies of σ on V_{gs} for various V_{ds}. The gate bias region where the FD is negative is also indicated in the figure. With higher V_{ds}, the negative dispersion becomes clearer. The impact ionization current is expressed by,

$$I_{impact} = A\left(V_{gs} - V_{th}\right)^{\alpha} \exp\left(\frac{-B}{V_{ds} - V_{gs} + V_{th}}\right),$$

where V_{th} is threshold voltage of the device, and A, B, and α are constants. This equation means that the impact ionization current has a peak in its dependence on V_{gs} when V_{ds} is constant, and that V_{gs} giving the maximum impact ionization current increases with increasing V_{ds}. The same dependencies of FD in g_d are observed in Fig. 5. The σ also has a peak in its dependency on V_{gs} and the peak of σ moves to high V_{gs} with increasing V_{ds} as shown in Fig. 5. The results shown in Fig. 4 and 5 strongly suggest that the origin of the FD is related to impact ionization.

Conclutions

The frequency dispersion of 0.1-μm-gate InAlAs/InGaAs HEMTs on an InP substrate has been investigated. g_d at high frequency (>100MHz) is about half of that at low frequency (<1MHz). It has been found, for the first time, that negative FD in g_d is associated with an increase of substrate current. These results strongly suggest that holes generated by impact ionization contribute to the increase in g_d in the low frequency range.

Acknowledgments

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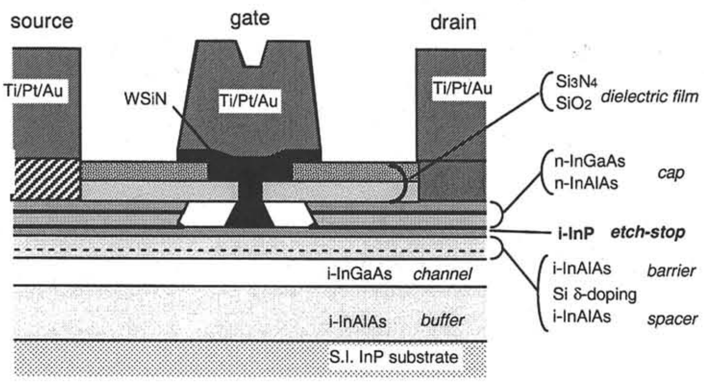

Figure. 1 Device structure of 0.1-μm-gate InAlAs/InGaAs HEMT.

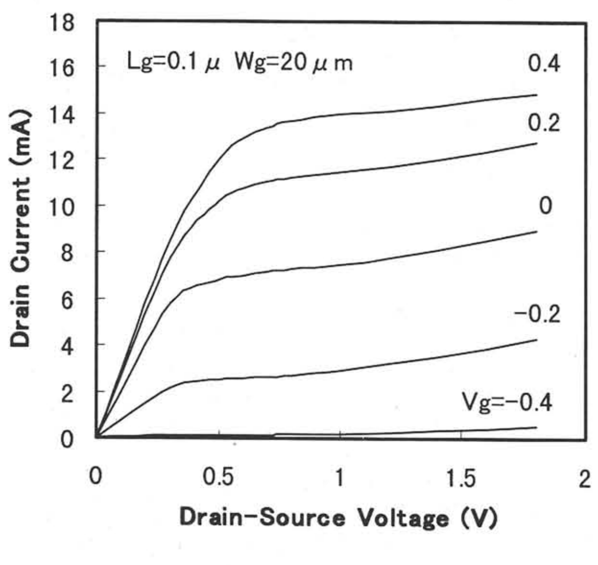

Figure. 2 I-V characteristics of tested device.

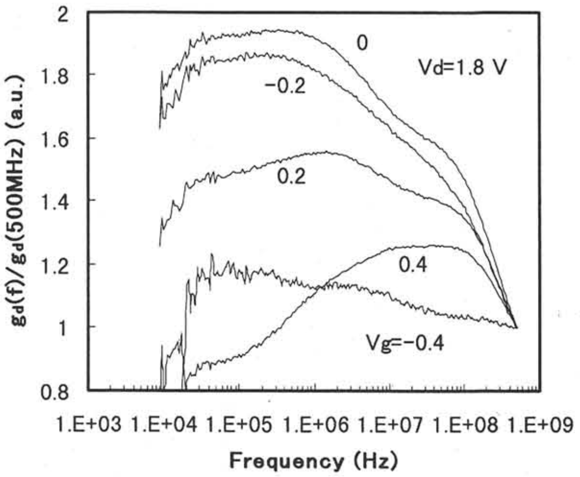

Figure. 3 Frequency dependence of normalized g_d at various gate voltage.

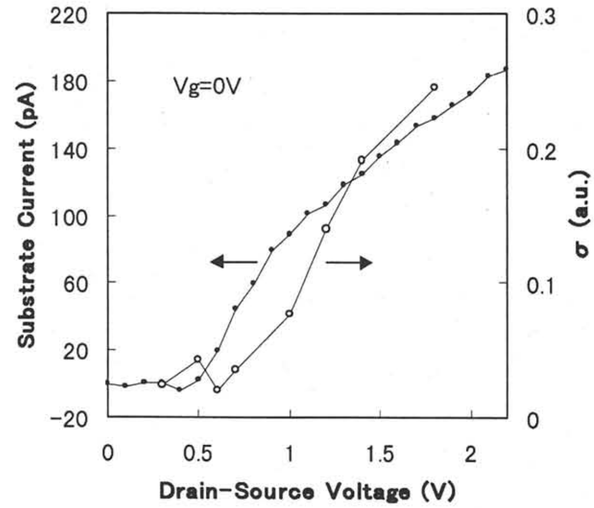

Figure. 4 Dependence of substrate current and standard deviation of normalized g_d on drain-source voltage.

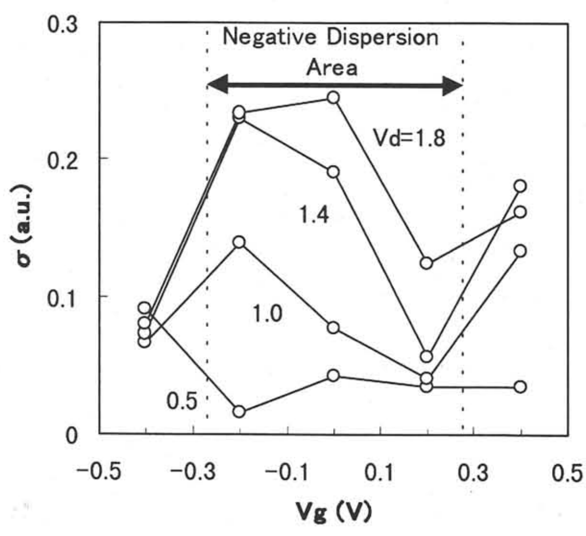

Figure. 5 Dependence of standard deviation of normalized g_d on gate-source voltage for various drain-source voltage.