Microwave Noise Parameters of Pseudomorphic GaInAs HEMT's Under Optical Illumination

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***Abstract*—The microwave behavior of pseudomorphic high electron-mobility transistors (pHEMT's) under optical illumination is investigated in this paper. The influence of light on the small-signal equivalent circuit is derived from scattering-parameter measurements. The evolution of the noise parameters versus gate-to-source voltage and their sensibility to illumination is also demonstrated.**

***Index Terms*—High electron-mobility transistor, noise parameters, optical effects.**

I. Introduction

The optical control of microwave semiconductor devices has been widely investigated over these last years [1], [2]. The gain control of amplifiers, frequency tuning or locking in oscillators, or the phase shifting in phase shifters represent some typical examples where an optical signal is used to control the operation of a microwave circuit. The optical effects in GaAs MESFET's [3]–[6] and in high electron-mobility transistors (HEMT's) [7]–[9] have been theoretically and experimentally studied over the last decade, including their static and dynamic behaviors. However, there is a lack of data concerning their noise characteristics at microwave frequency. This paper reports for the first time on the evolution of the noise parameters of a pseudomorphic HEMT (pHEMT) under illumination.

II. Experiment

The GaAlAs/GaInAs/GaAs pHEMT was fabricated by Philips Microwave Limeil (D02AH) and features four gate fingers of 0.2-μm length and 30-μm width. The device, which is a standard microwave transistor, was not designed for optical application, and the light coupling efficiency should be small. Illumination was provided by a fiber-coupled light-emitting diode (LED) (Honeywell HFE4000) ($\lambda = 0.85$ μm), making the doped GaAlAs layer transparent for optical energy. The emitted output power varies from 0 to 35 μW, and the distance between the fiber and the device is adjusted using a micropositioner in order to obtain the optimum light coupling.

An external gate resistance ($R_g = 1$ MΩ) was added in the gate bias circuit [5] so that the increase of the gate current under illumination causes an appreciable change in the gate-to-source voltage $V_{\rm gs}$ and yields a large photoresponse in the drain current [10]. In the following, we use the external gate–source voltage $V_{\rm gse}$, which includes the voltage drop across the 1-MΩ resistor. The relative photoresponse defined as the incremental change of the drain current between illumination and dark conditions divided by the dark current value is shown in Fig. 1 for an optical power fixed at 35 μW. It can be seen that the device is more sensitive when biased close to pinchoff and for small drain-to-source voltage $V_{\rm ds}$. The variations against $V_{\rm ds}$ observed for $V_{\rm gse} = -0.6$ V are in agreement with the results published in [9]. For $V_{\rm gse} = -1.2$ V or $V_{\rm gse} = -1.8$ V, the lowering of the photoresponse against $V_{\rm ds}$ could be attributed to a two-dimensional effect caused by the channel longitudinal field [9].

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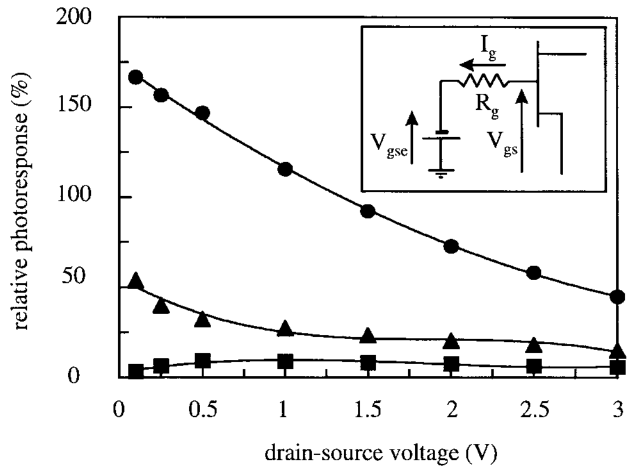

Fig. 1. Relative photoresponse of the transistor against $V_{\rm ds}$. ■ $V_{\rm gse} = -0.6$ V, ▲ $V_{\rm gse} = -1.2$ V, ● $V_{\rm gse} = -1.8$ V.

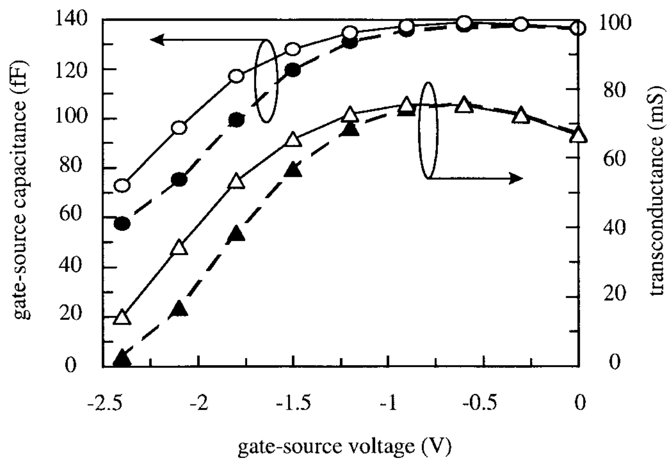

Fig. 2. Gate–source capacitance and transconductance against $V_{\rm gse}$. Open symbols: under illumination (full line: least-square fitting), dark symbols: without illumination (dashed line: least-square fitting).

S-parameter measurements were performed on-wafer from 100 MHz to 40 GHz and the small-signal equivalent circuit of the transistor was derived using the technique described in [11]. Fig. 2 shows the results obtained on the gate-to-source capacitance $C_{\rm gs}$ and on the transconductance g_m. It is clear that the larger increase of both $C_{\rm gs}$ and g_m is obtained when the device is biased near pinchoff. Despite the fact that the incident light power is small, the increase in $C_{\rm gs}$ and g_m is 27% and 400%, respectively, resulting in an increase of the transition and maximum oscillation frequencies under illumination. The small decrease of g_m for $V_{\rm gse} > -0.7$ V is attributed to a parallel conduction of the drain current in the doped GaAlAs layer. As can be seen in Fig. 2, illuminating the transistor has the same effect as applying a forward bias between the source and gate [3], [4]. It should be noted that the curves are the same whether or not the device is illuminated if the variations of the equivalent-circuit elements are plotted against the dc drain current. It should also be noted that the other intrinsic elements of the equivalent circuit are less sensitive to illumination than $C_{\rm gs}$ and

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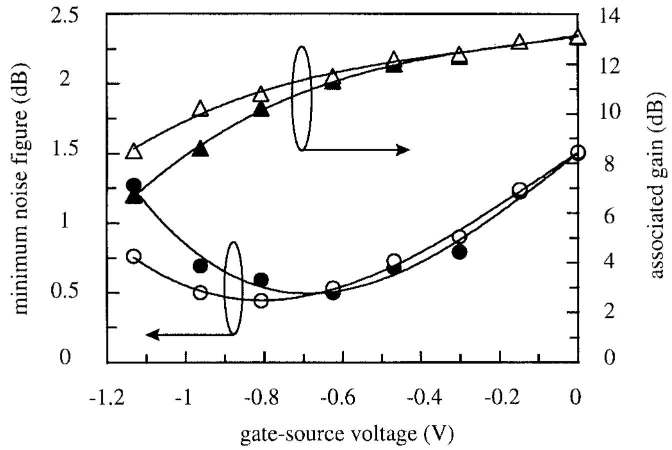

Fig. 3. Minimum noise figure and associated gain against $V_{\rm gse}$ at 12 GHz. Open symbols: under illumination, dark symbols: without illumination (full line: least-square fitting).

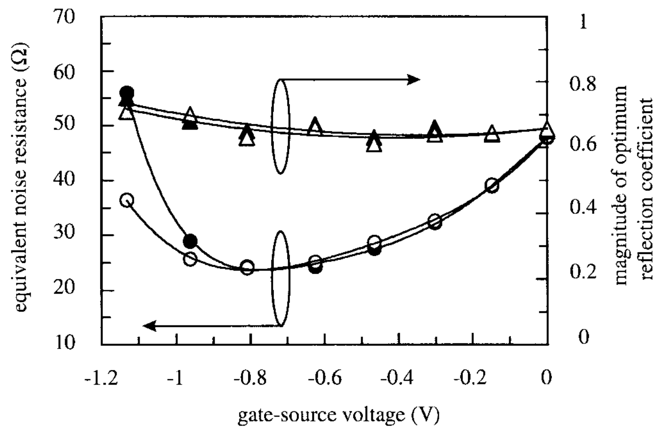

Fig. 4. Equivalent noise resistance and optimum reflection coefficient against $V_{\rm gse}$ at 12 GHz. Open symbols: under illumination, dark symbols: without illumination (full line: least-square fitting).

g_m (except the output resistance $R_{\rm ds}$) due to their smaller variations with the applied gate voltage.

The four noise parameters (minimum noise figure $F_{\min}$, equivalent noise resistance R_n, and optimum reflection coefficient $\Gamma_{\rm opt}$ -magnitude and phase-) together with the associated gain G_a have been measured at $V_{\rm ds} = 2$ V between 8–20 GHz using a dedicated test set and based on the multiple impedance technique [12]. The minimum noise figure and associated gain are plotted in Fig. 3 against $V_{\rm gse}$ at 12 GHz. Compared to Fig. 2, the $V_{\rm gse}$ excursion is not the same because in the device used for noise investigation there is a slight difference in the gate leakage current ($\approx 1\ \mu$A), which translates into a large difference in the external gate–source voltage as a consequence of the voltage drop across the 1-MΩ resistor. The increase of the minimum noise figure for $V_{\rm gse} > -0.7$ V is attributed to an increase of diffusion noise in the channel, while the increase of $F_{\min}$ and decrease of G_a near pinchoff is due to a decrease of g_m. A reduction of 0.5 dB in $F_{\min}$ and an augmentation of 2 dB in associated gain are reported at $V_{\rm gse} = -1.15$ V under illumination for an incident optical power of 35 μW. This reduction of $F_{\min}$ at a given $V_{\rm gse}$ is attributed to the external photovoltaic effect [2]. The photogenerated carriers collected at the gate yield a photovoltage when flowing across the external resistor, which is equivalent to a shift of the pinchoff voltage. The photoresponse of the transistor yields to an increase of the shot noise generated at the Schottky barrier. Nevertheless, the increase of the gate current is small, and the shot-noise source remains negligible with respect to the induced-gate thermal noise. As a consequence, the minimum value of $F_{\min}$ remains unchanged (providing the measurement accuracy is only ± 0.15 dB) whether or not the device is being illuminated. It can, therefore, be concluded that the microwave noise figure beyond 4 GHz is not sensitive to any possible filling of the trapping centers due to the illumination.

The equivalent noise resistance R_n is represented in Fig. 4 at $V_{\rm ds} = 2$ V and $f = 12$ GHz. A decrease of 35% for R_n with illumination is also observed near pinchoff where the device is operated in the most light-sensitive condition. The optical effects on the optimum reflection coefficient are less pronounced (see Fig. 4), which is consistent with the small variation of $|\Gamma_{\rm opt}|$ against $V_{\rm gse}$ that are usually observed when performing-noise parameter measurement versus bias. Therefore, it can be inferred from these results that a microwave low-noise optically controlled amplifier could be easily designed without any degradation of its minimum noise figure as long as the gate photocurrent range is below a given value (typically 1 μA), which depends on the operating frequency.

III. Conclusion

In conclusion, the optical effects in pHEMT's have been investigated. In spite of the small power delivered by the optical source, the device with an external resistance in the gate shows a strong sensibility when biased near pinchoff. Since illuminating the transistor is equivalent to apply a forward gate-to-source voltage, the sensibility of the intrinsic elements of the equivalent circuit and of the noise parameters is strongly related to their variations against $V_{\rm gse}$. Consequently, a 0.5-dB $F_{\min}$ reduction can be observed under illumination providing the gate voltage is conveniently taken.

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