Int. J. Nanoelectronics and Materials **3** (2010) 9-15

Investigation of low frequency dependence of output conductance in GaAs MESFET

A. Khoualdia, Z. Hadjoub, A. Doghmane*

Laboratoire des Semi-conducteurs, Département de Physique, Faculté des Sciences, Université Badji-Mokhtar, BP 12, Annaba, DZ-23000, Algeria.

Abstract

In this work, we experimentally investigate the effects of the extension of depletion regions in a GaAs MESFET on the frequency variation of the output conductance, g_d, as well as the maximal relative variation, Δg_{dmax}, at different polarisations of drain-source, V_{ds}, and gate-source, V_{gs}. It is found that, for weak depleted regions, the values of $g_d(f)$ are very small with a Δg_{dmax} which remains negligible. However, for large extensions, the values of $g_d(f)$ are very significant; they could reach 371.4 Ω^{-1} together with a Δg_{dmax} high value of about 2.7 dB at $V_{ds} = 1.5$V and $|V_{gs}| = 0.2$V. Moreover, Δg_{dmax} values undergo an increase when V_{ds} increases. Hence, maximal variation of the dispersion gets higher when the regions become more depleted. Therefore, the widening of space charge region introduces frequency dispersion of g_d that may limit potential GaAs MESFET applications in several fields in Micro- and nano-devices.

Keywords: GaAs MESFET, output conductance, frequency dispersion, depletion region.
PACS: 83.30.Tv; 73.61.Ey; 73.40.Sx; 71.55.Eq

1. Introduction

Field effect transistors are playing a very important role in all modern electronic applications: amplification, signal generation, mixers, switching, etc. Among these devices, GaAs MESFET (MEtal Semiconductor Field Effect Transistors) are receiving a great deal of interest in space applications. However, the output conductance, g_d, of these types of transistors depends on frequency, structure characteristics and polarisation conditions [1-5]. Such dependences lead to some difficulties in the design of several analogical and integrated circuits as well as in propagation delay in digital circuits [4]. The output conductance, g_d, as a function of frequency, f, in GaAs MESFETs, was found to be dispersive, several years ago. However, this phenomenon which was thought to be attributed to the presence of deep defects in the depletion region between the semi-insolator substrate and the active region [6-8] is still not well understood. The influence of the geometry or the dimensions of the devices on $g_d(f)$ [9] as well as the effects of doping in the regions beneath ohmic contacts and the buried p-layer on g_d (f) [10] were investigated.

---

*) For correspondence; E-mail: a_doghmane@yahoo.fr.

In this work, we investigate the influence of space charge regions, SCR, widths on the dispersion of the output conductance in MESFETs in different operating regimes. The maximum relative dispersion of output conductance, Δg_{dmax}, is also calculated for different SCR widths. All experimental investigations were carried out on a GaAs MESFET, of the type MGF30, in a large frequency interval ranging from 10 Hz to 10^7 Hz and at different drain-source bias, V_{ds}, and gate-source bias, V_{gs}.

2. Investigation of weak SCR widening

2.1 Description of g_d(f) Variation

Figure 1 shows the variation of the output conductance as a function of the frequency, g_d(f), for weak SCR widths at V_{gs} = 0 V and different drain-source polarisations V_{ds} equal to: 0.1 V (■ ■ ■), 0.3 V (● ● ●) and 0.5 V (▲ ▲ ▲). It can be seen that, whatever the considered frequency is, the g_d(f) value gets greater as the V_{ds} bias becomes more important. For instance, at a constant frequency value f = 10 Hz, it can clearly be noticed that for V_{ds} = 0.5 V we have g_d = 71.4 Ω^{-1} whereas for V_{ds} = 0.1 V it becomes six (06) times smaller. Moreover, g_d(f) dispersion remains negligible in the whole investigated frequency range [10 Hz – 10^7 Hz], except a slight dependence for V_{ds} = 0.5 V. Therefore, for small SCWs, the g_d(f) values remains low.

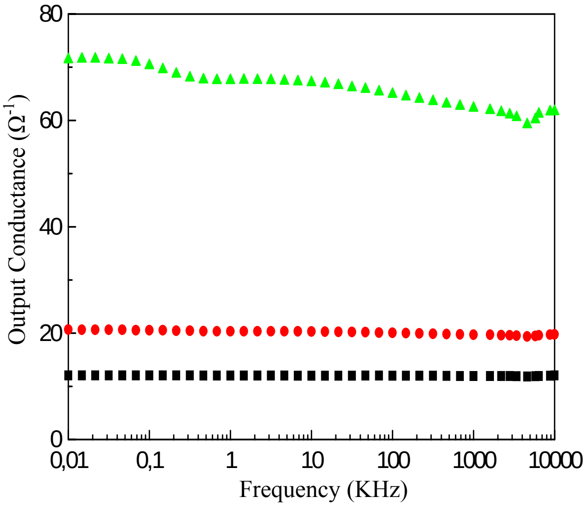

Fig. 1: Frequency variation of g_d for weak SCR at V_{gs} = 0 V and V_{ds} equal to: 0.1 V (■ ■ ■), 0.3 V (● ● ●) and 0.5 V (▲ ▲ ▲).

2.2. Influence of SCR widths on Δg_{dmax}

The maximum relative dispersion of the output conductance, Δg_{dmax}, is quantified and expressed, in decibels, via the following relation [11]:

$$\Delta g_{d\,\max} = 20\log\left|1+\left(\frac{\Delta g_{d1}}{g_{d\,\min}}\right)\right| \tag{1}$$

with $\Delta g_{d1} = g_d(f_1) - g_{dmin}$, where, $f_1 = 10$ Hz, is the frequency of the first measurement and g_{dmin} is the minimal output conductance at a given frequency; it depends on bias conditions. In order to evaluate the maximal relative dispersion, Δg_{dmax}, for weak SCR at $V_{ds} = 1$V and different frequencies, we calculate Δg_{dmax} at several $|V_{gs}|$ polarizations, [0.2 V – 0.6 V], corresponding to different SCR widening.

The obtained results for GaAs MESFET of the type MGF30 are shown in Figure 2 in terms of Δg_{dmax} as a function of $|V_{gs}|$ at $V_{ds} = 1$ V and different frequencies: 10 Hz (■ ■ ■), 22 Hz (● ● ●), 32 Hz (▲ ▲ ▲), 100 Hz (▼ ▼ ▼), 215 Hz (♦ ♦ ♦), 464 Hz (+ + +) and 1000 Hz (x x x). It can be noticed that the dependence of Δg_{dmax} on V_{gs} is almost constant for the considered polarisations. Therefore, no output conductance dispersion is observable. Nevertheless, for weak frequencies, the Δg_{dmax} values are greater than those obtained for higher frequencies. Hence, for small SCR widening, the measured Δg_{dmax}, at a given frequency, is constant and remains independent from bias V_{gs}.

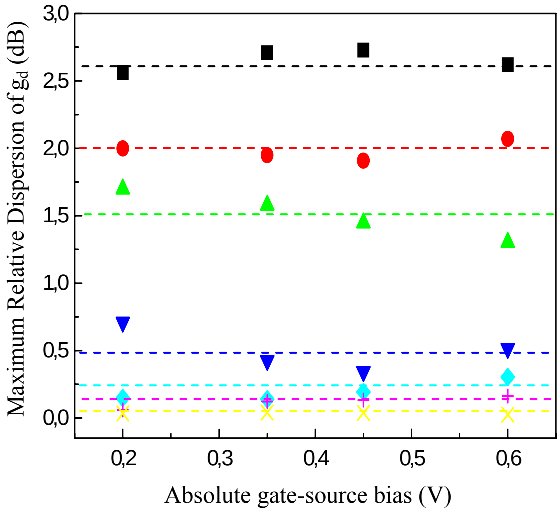

Fig. 2: Dependence of maximal relative dispersion of g_d on $|V_{gs}|$ bias at $V_{ds} = 1$V and different frequencies: 10 Hz (■ ■ ■), 22 Hz (● ● ●), 32 Hz (▲ ▲ ▲), 100 Hz (▼ ▼ ▼), 215 Hz (♦ ♦ ♦), 464 Hz (+ + +) and 1000 Hz (x x x).

3. Investigation of strong SCR widening

3.1. Description of $\Delta g_{dmax}(f)$ dispersion

Figure 3 illustrates the experimental dependence of maximal relative dispersion of output conductance on frequency for stronger extended space charge regions at $|V_{gs}| = 0.2$ V with different V_{ds} values: 1.5 V (● ● ●), 1.8 V (▲ ▲ ▲) and 2 V (■ ■ ■). All the curves show a similar behaviour: an initial decrease followed by a saturation region.

- *Decreasing region* (10 Hz – 200 Hz): Δg_{dmax} decreases as the frequency increases. Note that the decreasing slope varies from one curve to the other. This is better illustrated by the insert in figure 3, in terms of slope values deduced from the decreasing parts of the curves as a function of V_{ds}. It can clearly be seen that the absolute values of such slopes are inversely proportional to drain-source bias, V_{ds}. This phenomenon could be attributed to electron displacements that reach their upper limit velocity in this type of bias.

- *Saturated region* (200 Hz – 1000 Hz): the output conductance seems to take a constant value that could be due to the fact that, at these frequencies, surface states in depletion regions could not follow the high frequency signal.

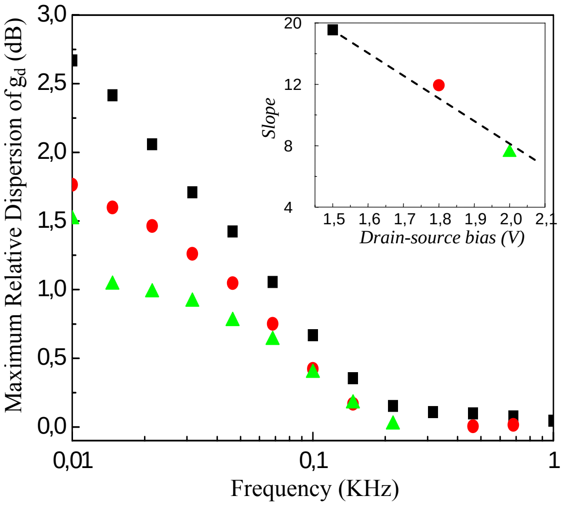

Fig. 3: Frequency dispersion of maximal relative dispersion of g_d at $|V_{gs}| = 0.2$ V with different V_{ds} values: 1.5 V (■ ■ ■), 1.8 V (● ● ●) and 2 V (▲ ▲ ▲).

3.2. V_{ds} influence on Δg_{dmax}

The investigation of Δg_{dmax} as a function of V_{ds} polarisations at different frequencies: 10 Hz (■ ■ ■), 22 Hz (● ● ●), 46 Hz (▲ ▲ ▲), 100 Hz (▼ ▼ ▼), 215 Hz (♦ ♦ ♦) and 464 Hz (+ + +) for constant V_{gs}, corresponding to different SCR widths, is shown in figure 4. It is clear that for $V_{ds} < 0.4$ V, we notice that: (i) Δg_{dmax} values are very small ($\Delta g_{dmax} < 0.2$ dB) and (ii) Δg_{dmax} is almost constant in the whole frequency range.

However, when V_{ds} increases, the SCR extension in the channel becomes not only important but shows inhomogeneous distribution as well. This leads to an increase in Δg_{dmax} that becomes more important for low frequencies; it reaches its highest value of 2 dB at a f = 10 Hz.

4. Evaluation of relative dispersion Δg_{dmax}

Some typical results of Δg_{dmax}, for different SCR widths, obtained at different V_{ds} and V_{gs} are regrouped in Table 1. We notice two distinct phenomena, according to weak or strong space charge region widths:

- *Weak SCR widths*, the following observations can be made:

(i) low Δg_{dmax} values, not exceeding 0.54 dB,
(ii) weak $g_d(f)$ values, less than 71.43 Ω^{-1},
(iii) an increase of 125 % when V_{ds} increase by 400%
(iv) an increase of $g_d(f)$.

- *Strong SCR widening*, we notice:

(i) high Δg_{dmax} values which reach 2.7 dB,
(ii) $g_d(f)$ increase when $|V_{gs}|$ increase,
(iii) an increase of Δg_{dmax} as $|V_{gs}|$ increase.

Therefore, we can deduce that for strong polarisation the values of both $g_d(f)$ and Δg_{dmax} are 800 % and 400% respectively than those of lower bias; These increase are related to space charge region widening.

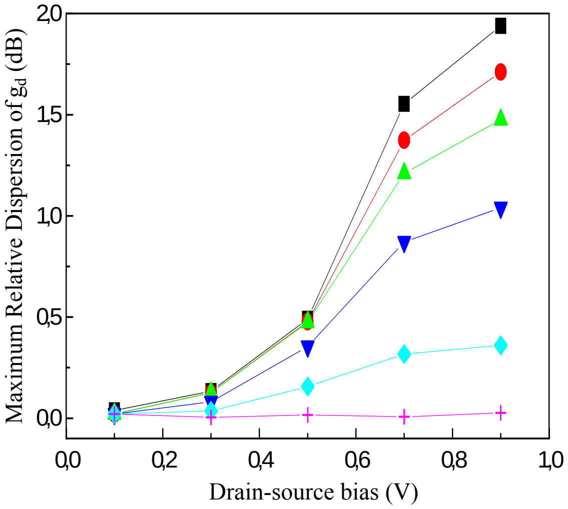

Fig. 4: Maximum relative dispersion of output conductance, Δg_{dmax}, as a function of V_{ds} for different frequencies: 10 Hz (■ ■ ■), 22 Hz (● ● ●), 46 Hz (▲ ▲ ▲), 100 Hz (▼ ▼ ▼), 215 Hz (♦ ♦ ♦) and 464 Hz (+ + +).

	V_{ds} , (V)	$\|V_{gs}\|$ (V)	g_d(f=10Hz) (Ω^{-1})	Δg_{dmax} (dB)
Weak SCR	0.1	0	12.1	0.04
	0.3	0	20.7	0.15
	0.5	0	71.4	0.54
Strong SCR	0.7	0	177.1	1.55
	0.9	0	232.0	1.93
	1	0.2	310.3	2.56
	1.5	0.2	371.4	2.70

Table 1: Results of g_d(f = 10 Hz) and Δg_{dmax} at weak and strong SCR idths

5. Discussion

For weak bias of drain-source and gate–source, i.e., ohmic regime, there exists a space charge region depleted from free electrons at the interfaces of (i) substrate/conducting channel and (ii) active layer/gate metallisation. The SCR widths remain weak with an almost uniform extension. For this bias, the device can be considered as a conductance that is controlled by the V_{gs} biasing. The obtained non-dependency of g_d on frequency (in fig. 1) at V_{gs} = 0 V and for low V_{ds} < 0.5 V is in agreement with reported data on small-signal output conductance whose physical mechanism was described by Canfield et al [4]. In fact, at these drain voltages, the electric field in the channel is not too high to scatter enough electrons into the channel-substrate and channel-surface trapping regions so that frequency dispersion in g_d is not observable.

The investigation of strong SCR widening, $V_{ds} > 0.5$ V, (Fig. 4 and table 1) puts into evidence the dispersion character of output conductance with frequency and polarization. When the electric field between the drain and source is increased, more of the electrons in the channel gain enough kinetic energy to be scattered over the potential barriers. Hence, any increase in V_{ds} leads to the extension of space charge regions into the active layer. This leads to enhanced values of both $g_d(f)$ and Δg_{dmax} of 800 % and 400%, respectively, as found above. The importance of such extension in SCR evolves along the channel with a greater appearance under the gate-drain side [11- 13]. Such behaviors were also reported in literature [3, 7] for certain devices for which the dispersive behaviour of output conductance of MESFETs is represented in terms of the parameters of multiple deep level traps located in the device channel-substrate depletion region, and a single deep level trap located at the drain-substrate depletion region. It should be noted that GaAs MESFETs are still receiving a great deal of interest to further clarify our understanding in order to master even more their enumerable micro- and nano-device applications [14, 15].

6. Conclusion

From this investigation concerning the influence of SCR widths on $g_d(f)$, it was put into evidence that, for weak widths of space charge regions, the very small values of $g_d(f)$ are associated with a negligible Δg_{dmax} of less than 0.54 dB. Whereas, for extended SCR, the $g_d(f)$ considerably increase by factors which reach 800% correlated to an identical important increase in Δg_{dmax} which may become 2.7 dB. Therefore, SCR widening introduces frequency dispersion of the output conductance that may limit potential GaAs MESFET applications in several fields in modern microelectronic devices.

Acknowledgment

This work was partially carried out at LAAS/CNRS in Toulouse. Prof. J. Graffeuil is gratefully acknowledged for his fructuous discussions and for providing Laboratory facilities

List of Symbols:

f:	Frequency
g_d:	Output conductance
Δg_{dmax}:	Maximal relative variation of output conductance
g_{dmin} :	Minimal output conductance at a given frequency
MESFET:	MEtal Semiconductor Field Effect Transistors
SCR:	Space Charge Region
V_{ds}:	Drain-source bias
V_{gs}:	Gate-source bias

References

[1] Y. Ohno, S. Ohkubo, K. Kunihiro, Y. Takahashi, IEEE Solid-States Electron. **43** (1999) 1339

[2] K. Kunihiro, M. Nogome, Y. Ohno, IEEE Tech. Dig, GaAs IC Symp. (1996) 179

[3] J. Conger, A. Peczalski, M. S. Shur, IEEE. J. Solid-State Circuits **29** (1994) 71

[4] P. C. Canfield, S. C. F. Lam, D. J. Allstot, IEEE J. Solid-State Circuits **25** (1990) 299

[5] S. S. Islam, A. F. M. Anwar, R. T. Webstar, IEEE. Trans. Electron Devices **51** (2004) 846

[6] J. M. Golio, M. G. Miller, G. N. Maracas, D. A. Johnson, IEEE. Trans. Electron. Devices **37** (1990) 1217

[7] S. Choi, M. B. Das, IEEE Trans. Electron. Devices **41** (1994) 1725

[8] J. Ladvanszky, M. Valtonen, TKK, CT-**21** (1994)

[9] W. Mickani, P.C. Canfield, E. Finchem, B. Odekirk, Tech. Dig. GaAs IC Symp. (1989)

[10] S. Nakajima, M. Yanagisawa, E. Tsumura, T. Sakurada, IEEE. Trans. Electron. Devices **47** (2000) 2255

[11] Khoualdia, Z. Hadjoub, A. Doghmane, Phys. Chem. News **41** (2008) 36

[12] Y. Hasumi, T. Oshima, N. Matsunaga, H. Kodera, Electron. Commun. Japan. **89** (2006) 20

[13] Z. Hadjoub, A. Khoualdia, K. Cheikh, A. Doghmane, IEEE ICTON-MW'07. FrP. **8** (2007) 1

[14] Y. Hasumi, N. Matsunaga, T. Oshima, H. Kodera, IEEE. Trans. Electron. Devices **50** (2003) 2032

[15] N. Sengouga, N. A. Abdeslam, Solid-State Electronics **52** (2008) 1039