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Influence of frequencies on output admittance, conductance and susceptance of GaAs MESFETs

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In this paper, the influence of frequencies [10 Hz – 1 MHz] on the output admittance, conductance and susceptance of GaAs MESFETs is measured and analyzed under the following conditions: saturation regime, drain-source bias, V_{ds} = 1 V and variable gate-source bias - 0.45 V < V_{gs} < - 0.2 V. It was found that, for low frequencies, a very pronounced frequency dispersion of the output admittance is observed with a maximum being obtained for V_{gs} = - 0.45 V corresponding to an almost pinched off channel. The conductance shows an initial sharp decrease that reach a minimum for a frequency f ≈ 100 Hz; it then increases to saturate for f ≥ 1 KHz. Whereas, for the susceptance, the minimum is reached at different frequencies and the saturation appears at a null value for f > 10 KHz. These experimental results could be used for the quantification of deep traps in the energy gap of the semi-insulating substrate.

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1. Introduction

Frequency dispersion of electrical parameters of metal-semiconductor field-effect transistors, MESFETs, represents very attractive research activities in many laboratories all over the world. Gallium arsenide, GaAs, devices are being applied in many fields ranging from monolithic IC technological systems to wireless communications. This great success is mainly due to their numerous advantages: very encouraging electrical characteristics, very reliable electronic properties, etc. However, low frequency dispersion phenomena, usually showing strange behaviours, disturb their ideal operation and degrade their performances [1, 2]. It should be noted that several electrical parameters such as input capacitance or transconductance exhibit these anomalies whose origin have successfully been analysed [3]. However, the output admittance of GaAs MESFETs is less understood despite a number of reported research works [4-7].

In this context, we measure the output admittance at different frequencies of GaAS MESFETs. We investigate the influence of bias conditions on both conductance and susceptance. Analysis and quantification of the results are finally proposed in order to discuss the origin of dispersion mechanisms.

2. Experimental details and results

2.1. Measurement conditions

Experimental setup, fully automated, consists of a large band frequency impedance meter, a double channel d. c. potential generator for gate and drain transistor polarisation, multi-meters to measure potentials and drain currents and a microcomputer that commands all the set up. Experimental results are obtained, at room temperature, on a Mutchibichi GaAs MESFET device. Measurements are carried out in the frequency range [10 Hz – 1 MHz] at a drain-source bias V_{ds} = 1 V and at different values of gate-source bias 0.2 V < $|V_{gs}|$ < 0.45 V.

2.2. Output admittance

The output admittance is defined as the ratio of the change in drain current produced by a weak variation in V_{ds} when V_{gs} remains constant. This quantity, which greatly affects GaAs MESFET performances, is a complex number that admits amplitude as well as imaginary and real parts. Fig. 1 illustrates the obtained results of the effects of gate bias on the frequency on the output admittance amplitude, in the saturation regime, at different V_{gs} whose absolute values were chosen to be equal to 0.2V; 0.3V; 0.35V; 0.4V and 0.45V.

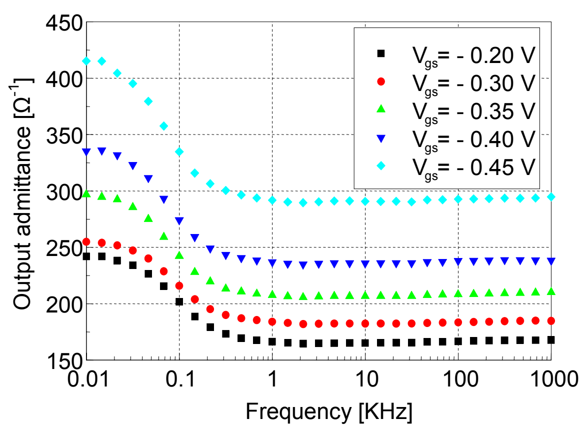

Fig. 1. Output admittance variations with frequency at drain-source bias V_{ds} = 1 V.

The main observations, in Fig. 1, can readily be formulated as follows:

(i) the most important dispersion of the output admittance is obtained for V_{gs} = - 0.45V corresponding to an almost pinched off channel.

(ii) at low frequencies, f < 1 KHz, we first notice some constancy in values whose extension depends on V_{gs} values; its becomes larger as V_{gs} gets weaker. Then, all the curves decrease sharply

(iii) at high frequencies, f > 1 KHz, a saturation region is obtained: each curve tends towards a constant value which increases with increasing $|V_{gs}|$

Hence, output admittance variations with frequency show an anomalous behaviour at low frequencies; this is generally attributed to the presence of deep-trap levels in GaAs. Such traps, usually more dense at interfaces, are the result of preparation techniques; they greatly influence frequency dispersion of output admittance and consequently device performances.

2.3. Conductance

The real part of the output admittance is known as conductance. Figure 2 represents the influence of frequency on the conductance, in the saturation regime under the same polarization conditions (applied to the gate and to the drain) as those of the output admittance. It is clear that all curves show:

(i) an initial linear decrease in conductance,

(ii) a valley with a minimum value around a frequency f = 100 KHz and

(iii) an increase in conductance followed by a saturation region for f $\geq$ 1 KHz

(iv) both the initial slope and the value of the saturation depend on the polarization of V_{gs}.

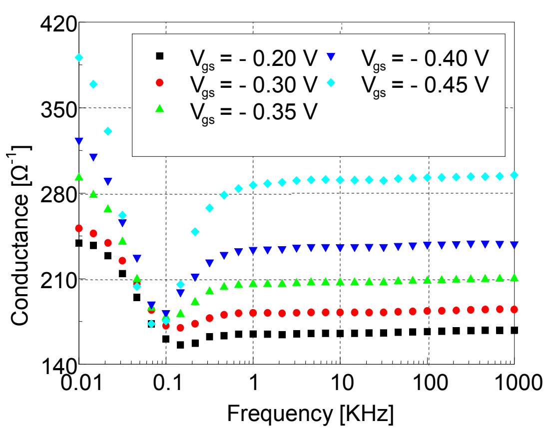

Fig. 2. Conductance variations with frequency at drain-source bias V_{ds} = 1 V.

These very important results show that, at low frequencies, the conductance values are very dispersive. Moreover, unlike admittance for which a single type of dispersion is obtained, it is fascinating to notice the coexistence of two varieties of dispersion: the first being negative for low frequencies f < 10 Hz and the second is positive appearing in the frequency range [10 Hz - 1 KHz]. These phenomena may be attributed to traps situated at the active layer/depletion zone interface. Therefore, the origin of these forms could be due to two opposite effects, capture and emission of charge carriers. In the case of negative dispersion, electrons are captured in traps but released in the case of positive dispersion. Hence, electron emission and capture equivalent to generation and recombination phenomena can be treated by Shockley-Read-Hall statistics. This would be of great importance in the determination of transport phenomena and the characteristics of trapping and recombination centers.

2.4. Susceptance

Susceptance, defined as the imaginary part of the output admittance, is also investigated. Fig. 3 illustrates susceptance dependence on frequency under the same biasing conditions as above. The general trends of the curves are similar to those obtained for conductance in Fig. 2. However, it should be noted that (i) the minimum is obtained at different frequencies and (ii) for f > 10 KHz all the curves are saturated at a null value. We also notice that susceptance could take negative values putting into evidence capacitive effects of space charge regions. It would be interesting to exploit these results in the quantification of the characteristics of the traps which are identified as deep centers in the energy gap of the semi-insulator.

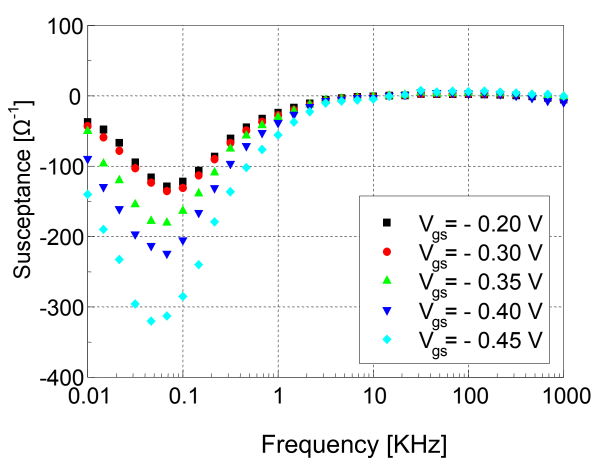

Fig 3. Frequency dispersion of susceptance at drain-source bias V_{ds} = 1 V.

3. Discussion

3.1. Output admittance analysis

In order to better quantify output admittance dispersion as a function of gate bias V_{gs}, we regroup in

Fig. 4 admittance values at f = 10 Hz and f = 1 MHz representing the limiting experimental (lower and upper) values and for variable gate polarisations up to channel pinch off.

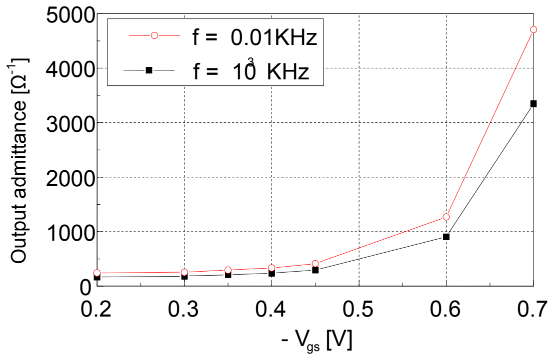

Fig. 4. Output admittance variation versus V_{gs} at two extreme frequencies f = 10 Hz and f = 1 MHz.

At weak bias V_{gs} < 0.4 V, it is easy to notice that admittance values, which remain inferior to 500 Ω^{-1}, are identical with only a slight increase when V_{gs} increases for both considered frequencies. Whereas, for V_{gs} > 0.4V, output admittance values undergo a sharp increase that overtakes 4000 Ω^{-1} at f = 1 MHz. Moreover, we notice some discrepancies in values measured at both frequencies. These differences become more important when V_{gs} gets higher. Hence, it can be concluded that frequency dispersion of output admittance is more pronounced for higher V_{gs}. For such polarisation of the device, the conducting channel is almost pinched off and depletion regions become larger. Thus, the reduced active region favours trapping phenomena at the active region/depletion region interface.

3.2. V_{gs} effects on minimal values

As shown above, both conductance and susceptance dispersion curves go through minimal values then saturate. To better illustrate such dependences, we plot in figure 5 minimal values of conductance (◦ ◦ ◦) and succeptance (▪ ▪ ▪) as a function of gate bias V_{gs}. It is clear that minimal values of conductance, with a mean value of about 190 Ω^{-1}, can be considered not to be dependent on V_{gs}. Whereas, for susceptance, after an initial constancy for $|V_{gs}|$ < 0.3 V, these minimal values undergo a rapid decrease (from – 120 Ω^{-1} down to – 350 Ω^{-1}) when $|V_{gs}|$ increase (from 0.2 V to 0.45 V). Therefore, it is safe to conclude that these minima, in general, are dependent on experimental conditions (frequency, bias, etc.).

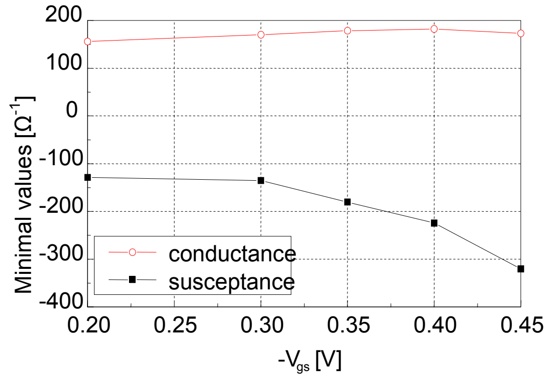

Fig. 5. Variations of minimal values of conductance (◦ ◦ ◦) and susceptance (▪ ▪ ▪) as a function of V_{gs}.

In the saturation regime, space charge regions are larger in the drain neighbourhood and the conducting region is very thin, leading to a very small distance between both space charge regions. Hence, traps are easily perturbed; they generate deep levels in the energy gap. These agitated traps could emit or absorb electrons that take part in the conduction mechanism and consequently to the variations in the capacitive effects of the output admittance. Deep-level traps were shown to be the origin of frequency dispersion of transconductance and drain conductance of GaAs MESFETs in the saturations regime [8]. For the low frequency anomalies, a proposition was made concerning a technique with an equivalent circuit to model the frequency dispersion of the transconductance, drain conductance and the device lag effect [9].

It is worth noting that the phenomenon of low frequency dispersion is not typical of only GaAs MESFETs; it can also affect other modern devices such as MODFETs, HJFETs, etc. In fact, some experimental results on the output admittance frequency dispersion characteristics of AlGaN/GaN MODFETs devices at different temperatures were reported [10]. Putting into evidence the presence of deep-level traps, it was shown that this phenomenon could be attributed to two types of trapping centers: the Silicon donor in the AlGaN, and either surface states in the gate-drain region or interface states at the AlGaN/GaN interface. Moreover, a large-signal HJFET model for drain-lag phenomena was developed [11] by expressing electron capture and emission in deep traps via a parallel circuit on the basis of SRH statistics.

Therefore, frequency dispersion phenomena obtained experimentally in this work with output admittance is a genuine mechanism that exists for trasconductance, output conductance, etc. Despite the great difficulties and the complication of the physical mechanisms responsible for such behaviors, it seems that the presence of deep-trap levels in the semi-insulating substrate and/or at different interfaces play an important role in frequency dispersion.

Hence, the development of a new model that takes into account all parameters would be of great necessity in order to accurately describe complicated dispersion phenomena of mostly used electrical parameters.

4. Conclusions

This investigation shows that frequency dispersion of output admittance in GaAs MESFETs occurs at low frequencies, f < 10 KHz. Both conductance and susceptance go through minimum values then saturate for f > 10 kHz. At high frequencies, the output admittance amplitude is almost equal to conductance with a null susceptance. Moreover, this phenomenon that appears when the transistor is operated in the saturation regime becomes more pronounced when $|V_{gs}|$ increase. It seems that, for such bias, the width of the active region favours trap excitation which are numerous at the active layer/substrate interface. Thus, these experimental results can be used for the quantification of trap states at such interfaces.

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References

[1] J. M. Golio, M. G. Miller, G. N. Maracas, D. A. Johnson, IEEE Trans. Electron Devices **37**, 1217 (1990).
[2] M. Lee, L. Forbes, IEEE Trans. Electron Devices **37**, 2148 (1990).
[3] J. Graffeuil, Z. Hadjoub, J. P. Fortea, M. Pouysegur, IEEE Solid State Electronics **29**, 1087 (1986).
[4] Q. Li , R. W. Dutton, IEEE Trans. Electron Devices **38**, 1285 (1991).
[5] Z. Hadjoub, A. Khoualdia, K. Cheikh, A. Doghmane, IEEE ICTON-MW'07. FrP.**8**, 1 (2007).
[6] G. Meneghesso, A. Paccagnella, G. Gasparetto, D. V. Camin, N. Fedyakin, G. Pessina, C. Canali, IEEE Conference, 256 (1997).
[7] A. Khoualdia, Z. Hadjoub, A. Doghmane, Phys. Chem. News **41**, 36 (2008).
[8] Y. Hasumi, N. Matsunaga, T. Oshima, H. Kodera, IEEE Trans. Electron Devices **50**, 2032 (2003).
[9] N. Matsunaga, M. Yamamoto, Y. Hatta, H. Masuda, IEEE Trans. Electron Devices **50**, 1194 (2003).
[10] G. A. Umana-Membreno, J. M. Dell, B. D. Nener, L. Faraone, G. Parish, Y.-F. Wu, U. K. Mishra, IEEE Conference, 252 (1999).
[11] K. Kunihiro, Y. Ohno, IEEE Trans. Electron Devices **43**, 1336 (1996).

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