Frequency Dependent Output Resistance and Transconductance in AlGaN/GaN MODFETs

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I. Introduction

Wide bandgap III-V nitride semiconductors are excellent candidates for high power applications and superior power performance of AlGaN/GaN MODFETs has been reported recently [1]. Circuits designed for power applications such as power amplifiers, oscillators and mixers, operate under large-signal conditions and their performance can deviate significantly from small-signal predicted characteristics in case of frequency dependent device properties. It is consequently very important to understand and if possible control and suppress such dispersion effects. The low frequency output resistance (R_{DS}) and transconductance (g_m) dispersion characteristics of GaAs MESFETs [2]-[3] and GaAs as well as InP-based MODFETs [4]-[5] have been addressed by various groups. However, the dispersion characteristics of AlGaN/GaN MODFETs are not well understood at this point and significant interest exists in this area in order to explain dispersion between DC predicted and high–frequency measured power characteristics. This paper addresses such issues by presenting experimentally evaluated frequency dependent properties of R_{DS} and g_m in AlGaN/GaN MODFETs.

II. Characterization System used for Frequency Dependent Properties of GaN-based MODFETs

Measurements of the frequency dispersion of the output resistance (R_{DS}) and transconductance (g_m) in this study were made by direct evaluation of the AC current and voltage components to determine these parameters [2]. Coaxial transmission lines were employed for signal and bias paths to avoid device oscillation problems and reduce interference. A sense resistor was used to extract the small-signal drain current without influencing the intrinsic device output characteristics. A function generator was employed at the output or input for exciting the device and measuring the output resistance or, transconductance repetitively. The signal across the sense resistor was monitored using a high-resolution oscilloscope and tests were performed in the frequency range of 50 Hz to 100 kHz under small-signal conditions (amplitude ~ 120 to 150 mV). The measurement system was calibrated using different resistive elements at various small signal levels. Measurement verification was also possible by comparing the R_{DS} and g_m values at 50 Hz with DC values obtained from the HP4145B semiconductor analyzer. These tests showed good agreement between measured data presenting further confidence regarding the testing methodology.

III. Measured Frequency Dependent Characteristics of AlGaN/GaN MODFETs

The AlGaN/GaN power MODFETs evaluated in this study were grown using RF-assisted MBE on sapphire substrates. The device structures consist starting from the substrate of an undoped GaN buffer, an NID $Al_{0.22}Ga_{0.78}N$ spacer, n-$Al_{0.22}Ga_{0.78}N$ donor layer and an NID $Al_{0.28}Ga_{0.78}N$ cap layer. The gate length for all devices was 0.25 μm and the gate finger width was 0.1 mm. The devices demonstrated excellent scalability in terms of large-signal power performance and a maximum output density of 1.3 W/mm was obtained at 10 GHz [6]. The frequency-dependent R_{DS} and g_m measurements were performed under a wide range of V_{DS} and V_{GS} bias conditions.

Fig. 1 shows the V_{DS} bias dependence of output resistance dispersion under the same V_{GS} bias condition of the 2-finger (0.25μm × 0.2 mm) device. As can be seen, the dispersion is insignificant in the ohmic region but as V_{DS} increases, the output resistance dispersion increases dramatically. The trend observed resembles that reported for GaAs MESFETs [2]. Under low drain-source bias levels, the current variation resulting for given V_{DS} change is dominated by the induced variation of carrier velocity and the impact of interface states at the undoped GaN buffer and 2DEG channel interface is insignificant. However, as the device enters the saturation regime, charge redistribution occurs in the channel and is affected by the occupation of the states. As a result, the frequency dependence of output resistance becomes more pronounced.

When the channel was modulated vertically with the help of V_{GS}, the dispersion increased as V_{GS} became more negative (see Fig. 2). This result can be explained by the fact that the channel is beyond thermal equilibrium condition as the gate voltage becomes more negative and free carrier injection into trapping states is enhanced. The injected charge results in an electrical field which modulates the shape of the channel leading therefore to more pronounced frequency dependence.

The measurement results for the frequency dependence of transconductance are shown in Fig. 3 and 4. The frequency dispersion of g_m appears to be much smaller than that of the output resistance over the same range of bias conditions. A similar observation has been previously reported by the authors for InP-based HFETs [4]. These results suggest that the influence of surface conditions which are often responsible for g_m dispersion is small in the AlGaN/GaN MODFETs reported here. The lateral (access) resistance does not consequently vary with frequency and the dispersion is therefore very small.

Consideration of the frequency dependent characteristics of R_{DS} and g_m shows that R_{DS} is reduced by ~ 6% to ~ 44% over the range of bias used for these studies while the g_m reduction ranges from ~ 4% to ~ 10%. It appears therefore that the key parameter effecting device performance when operation is considered from DC to high frequencies is R_{DS}.

Study of the large-signal output power characteristics of the devices showed that the measured RF output power was very close to values predicted from DC characteristics [6]. This good agreement was possible provided that the DC drain current used in the derivations was evaluated under large-signal conditions, as obtained during RF power measurements. Consideration of the good agreement between DC and RF power characteristics, as well as, the pronounced dispersion of R_{DS} but not g_m suggests the following mechanism of operation. As the frequency of operation increases from DC, the evaluated AlGaN/GaN MODFETs maintain their DC value of g_m but present lower output resistance R_{DS}. A suitable value of load impedance needs therefore to be employed in order to allow optimum large-signal operation, as for example occurring in case of load-pull power characterization of the AlGaN/GaN MODFETs. The DC drain current evaluated under high-frequency large-signal matching conditions accounts for the dispersion in R_{DS} characteristics leading to good agreement between DC and RF measured performance.

Overall, the frequency dependent characteristics of the output resistance (R_{DS}) and transconductance (g_m) of AlGaN/GaN MODFETs have been investigated experimentally. The results indicate that the frequency dispersion of transconductance dispersion is much smaller than that of the output resistance. These characteristics provide a better insight of device operation and DC versus HF small-signal and large-signal performances.

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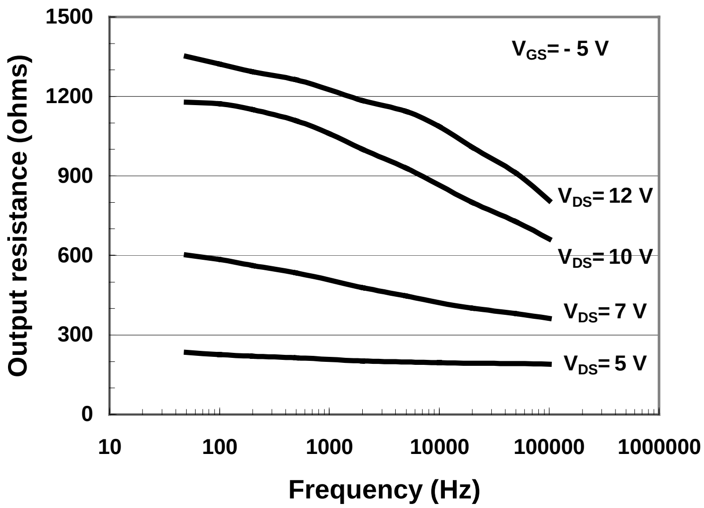

Fig. 1. Measured output resistance as a function of frequency for the 0.25 μm × 0.2 mm device under constant gate-source bias.

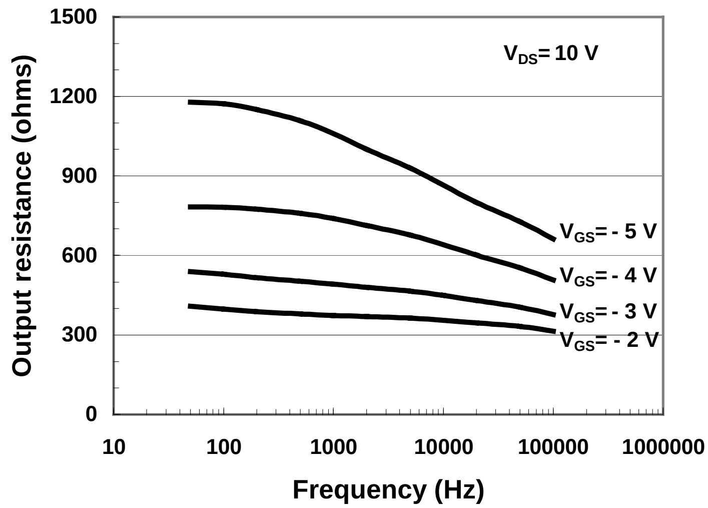

Fig. 2. Measured output resistance as a function of frequency for the 0.25 μm × 0.2 mm device under constant drain-source bias.

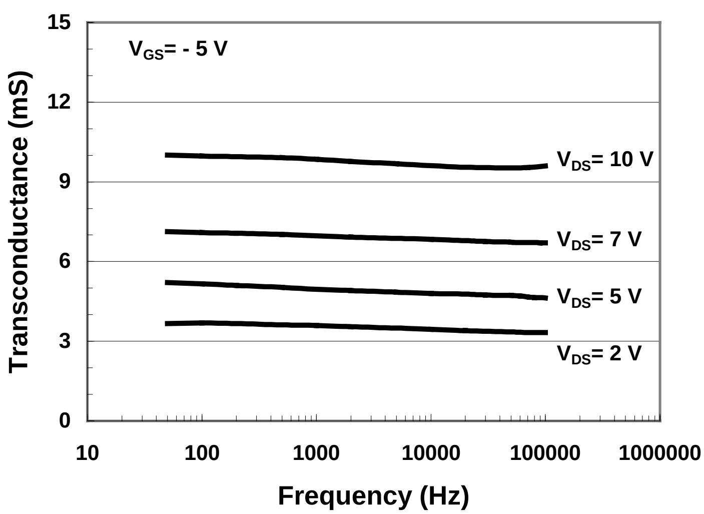

Fig. 3. Measured transconductance as a function of frequency for the 0.25 μm × 0.2 mm device under constant gate-source bias.

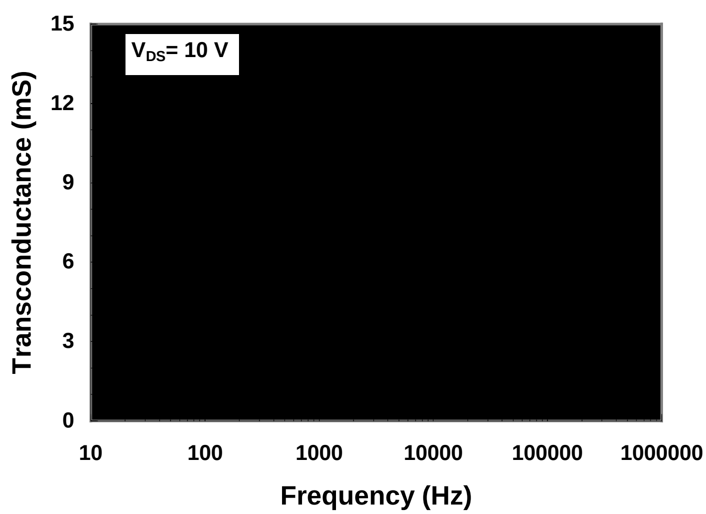

Fig. 4. Measured transconductance as a function of frequency for the 0.25 μm × 0.2 mm device under constant drain-source bias.

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