Nonlinear Effects in AlGaN/GaN HFET's Under Large-Signal RF Conditions

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Field-Effect Transistors based upon the AlGaN/GaN heterostructure are predicted to be capable of producing RF output power on the order of 10-12 W/mm of gate periphery [1] and spot experimental results indicate performance in agreement with the theoretical predictions, with approximately 10 W/mm RF power [2,3] obtained in C-band and X-band. Power-added efficiency, with good gain, also approaches the theoretical expectations, at least through C-band. However, the RF performance of these devices is often limited by a series of physical effects that prevent the devices from producing predicted performance. The limiting effects are caused by nonlinear charge dynamics under large-signal terminal voltage and current conditions.

There are several locations within the HFET, as shown in Fig.1, where nonlinear charge behavior affects the dc and RF performance of the device. The high power and high frequency performance of the device is dependent upon the ability of the transistor to carry a large channel current. Therefore, both the change density and charge transport characteristics of the 2DEG that forms the conducting channel of the device ultimately determine device performance. Any physical effect that limits either charge density, or charge transport will degrade performance.

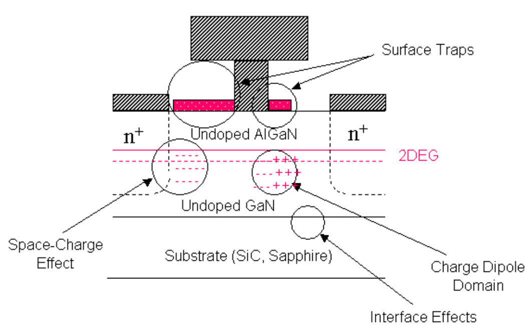

Fig. 1 HFET Structure Indicating Locations of Physical Effects Limiting RF erformance

Of the possible sources of nonlinear behavior, the AlGaN surface is fundamental. The movement of charge into and out of a high density of surface charging states can deplete the conducting channel, thereby reducing the current as the states become increasingly charged. Although the surface charge cannot respond to high frequency excitation on a real time basis, a premature saturation condition, where the channel current decreases with increasing RF drive can result. The decreasing channel current results in decreased RF output power and power-added efficiency, accompanied by a premature saturation in gain. The operation of the device becomes nonlinear at relatively low RF drive and the dynamic range is limited.

The degree to which this phenomenon is affected by surface traps is dependent upon surface conditions, the density of surface traps, and the proximity of the surface to a high density of electrons. The effect can be minimized by the introduction of layers intended to screen the surface from the 2DEG. Surface passivation also can minimize, although not eliminate the phenomenon.

The dipole domain that forms in the conducting channel of field-effect transistors also can produce performance limitations as the transistor is driven to large-signal conditions. The electric field associated with the domain can achieve high magnitude values, on the threshold of breakdown. Under large voltage swings the breakdown threshold can be exceeded and a pulse of charge will be generated. A surge in conduction current, in phase with the voltage, is generated. The phenomenon limits the RF voltage, thereby producing a reduction in performance. The charge generation also produces an inductive delay in the current-voltage characteristics. The inductive delay increases with increasing RF drive and introduces dispersion effects.

Nonlinear charge dynamics associated with high injection conditions at the source also can limit performance. Space-charge suppression of the electric field in the source region between the source contact and gate can occur under high injection conditions. Space-charge effects occur due to the high current density at which these devices are operated (e.g., $J_{ds}>10^6$ A/cm), and the lack of background impurity doping that would resist space-charge effects. This effect is illustrated in Fig. 2, which shows a simulation of the source region of an AlGaN/GaN HFET under high current injection conditions.

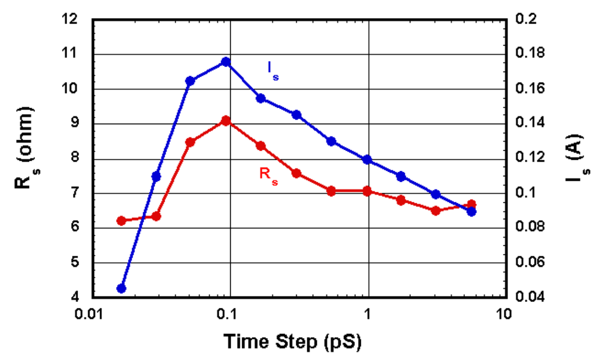

Fig. 2 HFET Source Resistance Modulation Due to High Current Density

The source resistance is modulated in response to the current density and is characterized with a highly nonlinear current dependent characteristic. The modulation increases rapidly once the threshold for space-charge limited current flow are achieved, and the source resistance increase can become significant. It is observed that a relatively small variation in source resistance can have a significant effect upon the large-signal performance of the device. The source resistance will be modulated in response to the current, and will, therefore, vary throughout the RF cycle. This phenomenon can produce the premature saturation conditions observed in experimental data.

REFERENCES

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