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AlGaN/GaN HFET: Nonlinearity Analysis With Nonlinear Source Resistance

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ABSTRACT

The impact of nonlinear source resistance and RF channel breakdown on AlGaN/GaN HFETs RF and linearity performance has been studied.It has been demonstrated that a nonlinear source resistance is generated in these devices due to the onset of space-charge limited (SCL) transport in the gate-source region. Under high current injection conditions, SCLC transport will be in action and due to this the source resistance becomes a function of the injected charge resulting in a rapid increase and limiting device performance. The nonlinear source resistance is generated when the magnitude of the channel current exceeds the threshold for space-charge limited current. It has been manifested that the nonlinear source resistance modulation reduces the linearity of the device, even under prudent RF drive conditions.

Key words: AlGaN/GaN hetrostructure field-effect transistors, Surface charge limited current(SCLC).

1. NEED OF DEVICE

The primary goal of developing new RF power amplifier technology is to achieve high linearity and optimum efficiency to reduce the power consumption of base station. Practical amplifiers do not have good linearity performance. To achieve linear performance circuit linearization techniques, such as digital predistortion, feed forward linearization, envelope elimination and restoration, require additional circuitry design and complex digital signal processing work, and also increase the overall complexity and cost.

AlGaN/GaN HFET microwave power amplifiers are of interest for use in base station transmitters for cellular systems at S- and C-band and for radar transmitters. These amplifiers are able to produce RF output power which is an order of magnitude greater than Si and GaAs based devices. The nitride-based devices also have inherent advantages for linear operation. This implies that AlGaN HFET's are strong candidate for transmitter and receiver high dynamic range modules for various communication systems.

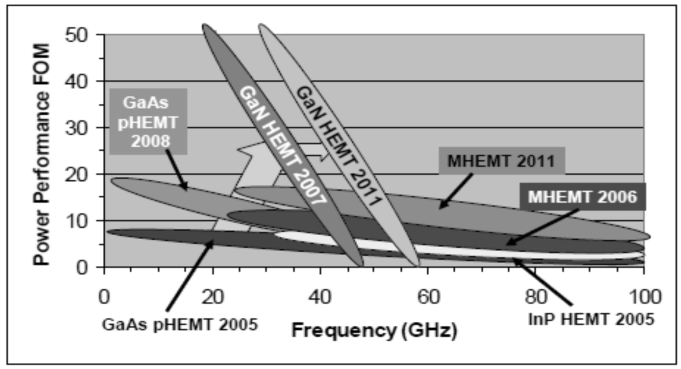

Figure 1: The expected frequency and power ranges where various HEMT device technologies are expected to be dominant. Power performance FOM is MMIC power density W/mm times small signal gain per stage at the frequency of operation (after ITRS 2005[1])

2. DEVICE OVERVIEW

HFET (hetero-junction field effect transistors) are also known as HEMT (high electron mobility transistor)/ TEGFET (two dimensional electron gas field effect transistor)/ SDHT (selectively doped heterojunction transistor). AlGaN/GaN HFETs are promising RF transistors for use in high-power and high-frequency circuit applications. HFETs possess a combination of high current density capability and high breakdown voltage due to the desirable physical properties of the materials, like high critical electric field for breakdown, high carrier density in the channel, high electron mobility and saturated carrier velocity, lower dielectric constant, and improved thermal conductivity when epitaxially grown on semi-insulating SiC substrates. These parameters permit the HFET to operate at high RF voltage and current that result in high power operation [2], [3], [12] at high frequency. The AlGaN/GaN material system forms a hetero-junction which results in the establishment of a two-dimensional electron gas (2DEG) channel at the material interface with high charge densities. The electrons are confined in the quantum well and form a conducting channel. Due to the separation of the conducting channel formed in the 2DEG from the undoped GaN layer, the electron-impurity scattering in the channel is drastically reduced, resulting in a significantly improved electron mobility and thus on resistance. Also, electron saturation velocity in GaN is very high. High charge carrier speed permits high current density capability for an AlGaN/GaN device.

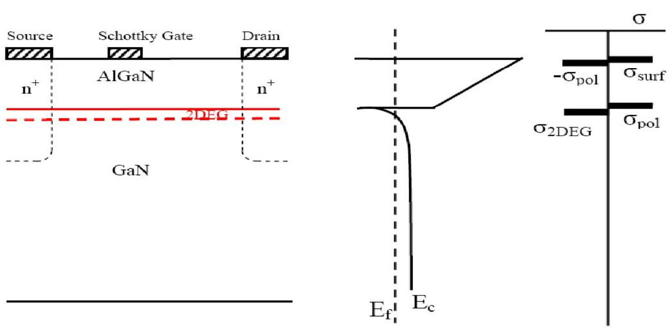

Figure 2: (a) Cross section of an AlGaN/GaN HFET; (b) Corresponding energy band diagram; (c) Corresponding space charge components in the device [4]

3. SOURCE RESISTANCE MODULATION

At very low electric fields (approximately about 10-25 kV/cm) in the HFET's source access region an early "quasi-saturation" phenomenon [14] occurs . This effect, at high current driving condition introduces a source resistance modulation effect and degrades the transconductance (gm) when the device enters into open channel operation. Source resistance modulation limits the device's performance by introducing nonlinearity and suppression of saturation current.

3.1 Quasi Saturation Effect [5]

This effect results a source resistance modulation effect at high current driving condition and degrades the transconductance (gm) when the device enters into open channel operation. There are several possible explanations to this effect,

A. *Self Heating [6,7,8]*

In the two-dimensional electron gas (2DEG) region of the device between source and drain, penetration depth of the UV light which is very shallow (~0.2mm), helped in measurement of temperature rise (ΔT). Visible light gave the average change in temperature (ΔT) in the SiC substrate, and that of the GaN layer, at the same roundabout position. Measured ΔT in the 2DEG is consistently over twice the average GaN-layer value. Transport properties like thermal and electrical are simulated and identified a hotspot as the predominating factor in the self-heating, located at the gate edge in the 2DEG. There is no apparent improvement in electron transport at low field when, for example, low thermal conductivity sapphire substrates are replaced with high thermal conductivity SiC. This depicts that self-heating is not the reason causing velocity pre-saturation.

B. *Rough Interface Scattering* [13]

Interface scattering affects charge transport. When drain source voltage is increased while keeping 2DEG concentration constant, the interface scattering get reduced to sustainable level but degradation of transconductance (gm) still exist. As electrons move faster under higher electric field, the probability of being scattered by surface roughness is reduced. Thus this factor is trivial in the pre-saturation effect.

C. *Non-equilibrium phonon emission and absorption*

The effect of non equilibrium longitudinal optical phonons on hot-electron energy distribution, drift velocity, mean energy, and power dissipation is considered for bulk GaN subjected to electric fields in a range up to 100 kV cm^{-1}. Particularly, the suppression of the high-energy tail of the hot-electron distribution due to the phonon accumulation is resolved. The saturated electron drift velocity at high electric field decreases as the electron gas density increases. Values around 10^7 cm s^{-1} are reached at an electric field of 100 kV cm^{-1} for an electron gas density of 10^{18} cm^{-3}. This factor was assumed to be main reason causing pre saturation but many simulation using ensemble Monte Carlo methods [5, 9] resulted that hot optical phonon did cause a suppression of transconductance (gm) at high current drive [10]. However, the simulation mobility and velocity are still overestimated [5].

D. *Injection Limited Effect [11]*

Injection limited effect can also be said as space charge limited effect. High current injection conditions during RF operation set up conditions for space-charge-limited current (SCLC) transport within the device. Once threshold current level is passed, the channel resistivity in the source and drain neutral regions becomes a function of the injected charge which leads to the nonlinear behavior of the source resistance. With a positive bias on one of the contacts (referred to as the drain) the barrier for carrier injection on the source side is lowered. Because of the lack of doping in the intrinsic region, space charge limited transport occurs. The space charge components present in the AlGaN/GaN HFET structure include: charges due to spontaneous and piezoelectric polarization at the AlGaN/GaN interface and the AlGaN surface; charges due to ionized surface states; charges due to ionized donors in the AlGaN barrier layer; charges due to the electrons in the two-dimensional electron gas channel; and charges due to the ionized traps in the GaN buffer layer.

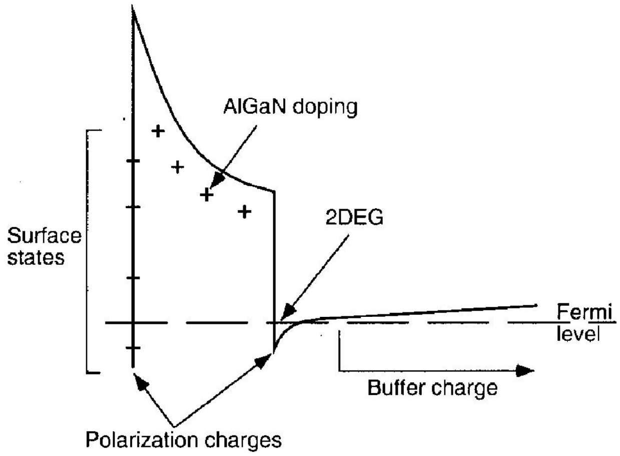

Figure 3: Schematic conduction band diagram for an AlGaN/GaN HFET with space charge components in the device [11]

4. CONCLUSION

The inherent superior material quality enables AlGaN/GaN devices to operate within extreme conditions that introduce second order physical mechanisms such as nonlinear source resistance and surface electron hopping conduction. Nonlinear source resistance originates from SCL effect when conduction current reaches the threshold current value. This effect diminishes devices performance by suppression transconductance and introduces nonlinearity. The lack of background doping and high current operation make this effect very important in AlGaN/GaN power amplifiers. Nonlinear source resistance magnitude can significantly increase under even modest power drive conditions. The nonlinear source resistance is found to limit the gain, output power, and also linearity behavior.

REFERENCES

[1] "Radio frequency and analog/mixed-signal technologies for wireless communications," International technology roadmap for semiconductors,2005 edition.

[2] U. K. Mishra, Shen Likun, T. E. Kazior and Yi-Feng Wu., "GaN-based RF power devices and amplifiers. "Proceedings of the IEEE 96(2), pp. 287-305. 2008.

[3] R. Trew, D. Green and J. Shealy. "AlGaN/GaN HFET reliability." Microwave Magazine, IEEE 10(4), pp. 116-127. 2009.

[4] E. T. Yu, G. J. Sullivan, P. M. Asbeck, C. D. Wang, D. Qiao, and S. S. Lau,"Measurement of piezoelectrically induced charge in GaN/AlGaN heterostructure field-effect transistors," Applied Physics Letters, vol. 71, pp. 2794-2796, 1997.

[5] Tomas Palacios, Siddharth Rajan, Arpan Chakraborty, Sten Heikman, Stacia Keller, Steven P.DenBaars, "Influence of the Dynamic Access Resistance in the gm and f_T Linearity of AlGaN/GaN HEMTs" *IEEE Transaction on Electron Devices*, 52, 10, 2005, pp.2117.

[6] M. Kuball, S. Rajasingam, A. Sarua, M. J. Uren, T. Martin, B. T. Hughes, K. P. Hilton, and R. S. Balmer, Appl. Phys. Lett. **82**, 124 (2003).

[7] N. Braga, R. Mickevicius, R. Gaska, X. Hu, M. Shur, M. A. Khan, G. Simin, and J. Yang, J. Appl. Phys. **95**, 6409 (2004).

[8] M. A. Khan, X. Hu, A. Tarakji, G. Simin, J. Yang, R. Gaska, and M. Shur, Appl. Phys. Lett. **77**, 1339 (2000).

[9] S Gokden, N Balkan, B K Ridley, "Effect of non-drifting hot phonon on high-field drift velocity in GaN/AlGaN" Semicond. Sci. Technol. 18, 2003, pp 206-211

[10] Yuh-Renn Wu, Madhusudan Singh, Jasprit Singh, "Sources of Transconductance Collapse in III-V Nitrides-Consequences of Velocity-Field Relations and Source/Gate Design" IEEE Transaction on Electron Devices, 52, 6, 2005, pp.1048.

[11] J. P. Ibbetson, P. T. Fini, K. D. Ness, S. P. DenBaars, J. S. Speck, and U. K. Mishra,"Polarization effects, surface states, and the source of electrons in AlGaN/GaN heterostructure field effect transistors," Applied Physics Letters, vol. 77, pp. 250-252,2000.

[12] Schimizzi, Ryan "Performance and Reliability Modeling of AlGaN/GaN Hetero-junction Field Effect Transistors" http://www.lib.ncsu.edu/resolver/1840.16/7975

[13] Hou, Danqiong "A Physics-Based AlGaN/GaN HFET Compact Model for Implementation in Circuit Simulators" http://www.lib.ncsu.edu/resolver/1840.16/7973

[14] Liu, Yueying "Analytical Physics Based AlGaN/GaN HFET Large Signal Model and Nonlinearity Analysis with Nonlinear Source Resistance" http://www.lib.ncsu.edu/resolver/1840.16/3208

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