GaAs Power MESFET Performance Sensitivity to Profile and Process Parameter Variations

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ABSTRACT

Large signal performance sensitivities are calculated and compared for power GaAs MESFETs fabricated with uniform, ion-implanted, and lo-hi-lo doping profiles. Variations in RF power, power-added efficiency, gain, and device linearity are determined for the various devices as a function of process dependent parameters. It is demonstrated that the channel doping profile design and breakdown voltage have the most significant influence upon large-signal RF performance.

INTRODUCTION

The rapid development of the state of the art in monolithic microwave integrated circuits has intensified the need to develop sophisticated CAD tools for use in circuit and device design. Linear simulators suitable for the analysis and design of microwave/mm-wave circuits have been intensively developed and are currently in a relatively advanced state. Device simulators, conversely, have not received as much attention and are currently in a relatively primitive state of development. In particular, there is a need for large signal device models capable of describing the nonlinear characteristics of active devices. In order to obtain the maximum benefit from a device simulator, the device model should be capable of describing the performance of a device before fabrication. In this manner much time, effort and expense would be saved since device optimization studies could be performed before the device is actually fabricated. This consideration indicates a physics based model, rather than an equivalent circuit based technique.

A suitable analytic large signal GaAs MESFET model has been developed at NCSU [1]. In this paper this model is used to investigate the large signal RF performance sensitivities to various device design and process dependent parameters. The RF performances of power FETs with uniform, ion-implanted, and lo-hi-lo (buried channel) doping profile designs are considered and compared.

DEVICE MODEL

The analytic model used in this work is based upon efficient solutions to the basic semiconductor device equations. The model accepts as input data device geometry, doping profile, bias conditions, and RF drive information. It returns RF output power, power-added efficiency, gain, input/output impedances, and spectrum information. The model is capable of investigating the RF performance of a GaAs MESFET as a function of device design parameters without the need to first fabricate and characterize the device. Since the model is physics based, equivalent circuit techniques are not used, although equivalent circuit elements can be determined. The model has previously been used to investigate a C-band monolithic power amplifier [2] and parameter sensitivities of ion-implanted power FETs [3]. Excellent agreement between model predictions and experimental data was obtained.

RF PERFORMANCE COMPARISON

Two sets of simulations were performed in this work. In one set the three device types were designed so that each of the different doping profiles had an equal amount of charge under the gate region. In the second set of simulations each profile type was optimized to produce a maximum power-added efficiency. All devices had nominal gate lengths of 0.5 micron and gate widths of 1 mm.

The RF output power versus input power characteristic for the uniform doped, ion-implanted and lo-hi-lo optimized profile devices are shown in Figs 1,2 and 3, respectively. Also shown is the output power at the 2nd and 3rd harmonics when the output is terminated in a 50 ohm load. The uniform doped and lo-hi-lo profile devices produce the lowest linear power (by about 1 db), but the greatest saturated output power (also by about 1 db) when compared to the ion-implanted device. The harmonic outputs were similar in the uniform and lo-hi-lo devices and both devices produced significantly less harmonic power than the ion-implanted device. Since harmonic power is an indicator of nonlinear operation, this suggests that ion-implanted devices should produce the least linear operating range and most limited dynamic range.

The power-added efficiency and gain characteristic for the three devices are shown in Figs. 4 and 5. The lo-hi-lo profile device produces the greatest PAE_{max} of about 42% and the ion-implanted device produces the smallest PAE_{max} of about 33%. The ion-implanted device produces the greatest linear gain (about 11 db) and the uniform doped device produces the smallest linear gain (about 9db). The ion-implanted device saturates at an input power approximately 2 dbm before the other two devices. Once saturation is achieved, the ion-implanted device produces approximately 1 to 2 db less gain than the other devices at a given input power level. The lo-hi-lo device produces the greatest saturated gain.

PERFORMANCE SENSITIVITY STUDY

The sensitivity of the one db compressed power (P_{1db}) and power-added efficiency (PAE) was calculated for each device for variations in various design and process parameters. Each design parameter of interest was varied about its nominal value and the relative sensitivity of the RF performance parameter was calculated. Nominal values for the devices were determined by simulating an experimental ion-implanted device and scaling the other device designs accordingly.

The RF performance sensitivities for the uniform doped, ion-implanted, and lo-hi-lo profile devices are shown in Tables I, II, and III, respectively, for devices designed with equal charge under the gate. As indicated in the tables, both the PAE and P_{1db} are most sensitive to the conducting channel design under the gate. Both the doping density and channel thickness are important. The uniform doped and lo-hi-lo devices are very sensitive to the conducting channel thickness. All three devices are sensitive to doping density. This indicates that very tight tolerance must be maintained on the conducting channel design if optimum and repeatable performance is to be obtained. The ion-implanted device also shows a large sensitivity to gate-drain breakdown voltage. Although the other two devices do not indicate a similar sensitivity, the magnitude of the breakdown voltage must be considered. The nominal breakdown voltages for the uniform and lo-hi-lo devices were calculated by scaling from the measured breakdown voltage for the ion-implanted device based upon surface doping arguments. The values are relatively high compared to the ion-implanted device (21 v and 31 v, respectively, compared to 18 v). As the breakdown voltage is reduced significant increases in RF performance sensitivity is observed. For example, the PAE for the three devices is shown in Fig. 6 as a function of gate-drain breakdown voltage. The ion-implanted device is able to tolerate the lowest breakdown voltage before significant degradation in PAE occurs. Reducing the breakdown voltage below approximately 20 v for the ion-implanted device, 21 v for the lo-hi-lo device, and 23 v for the uniform doped device produce significant degradation in RF performance.

CONCLUSIONS

The RF performance and large signal performance sensitivities for GaAs MESFETs with uniform doped, ion-implanted, and lo-hi-lo doping profiles have been investigated. Optimized lo-hi-lo profile devices appear to produce the greatest power-added efficiency, saturated gain and most linear response. Ion-implanted devices produce the lowest PAE, saturated gain and the most nonlinear operation. The RF performance of the devices is most sensitive to the conducting channel design and the gate-drain breakdown voltage when the breakdown voltages are relatively low.

References

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2. M.A. Khatibzadeh, R.J. Trew, and I.J. Bahl,"Large-Signal Modeling of GaAs Power FET Amplifiers," 1987 IEEE MTT-S International Microwave Symposium Digest, pp. 107-110.

3. M.A. Khatibzadeh and R.J. Trew,"Sensitivity of the RF Performance of GaAs Power FETs to Process-Dependent Parameters," Proc. of the 1987 IEEE/Cornell Conference on Advanced Concepts in High Speed Semiconductor Devices and Circuits, pp. 209-218.

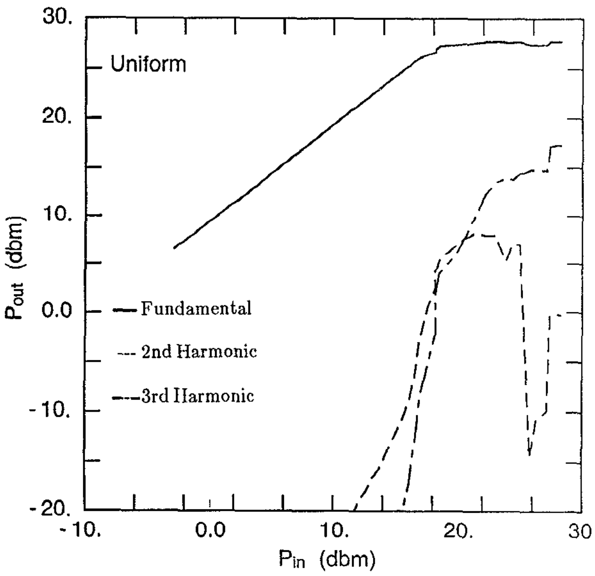

Fig. 1 Output Power versus Input Power for the Uniform Doped Device

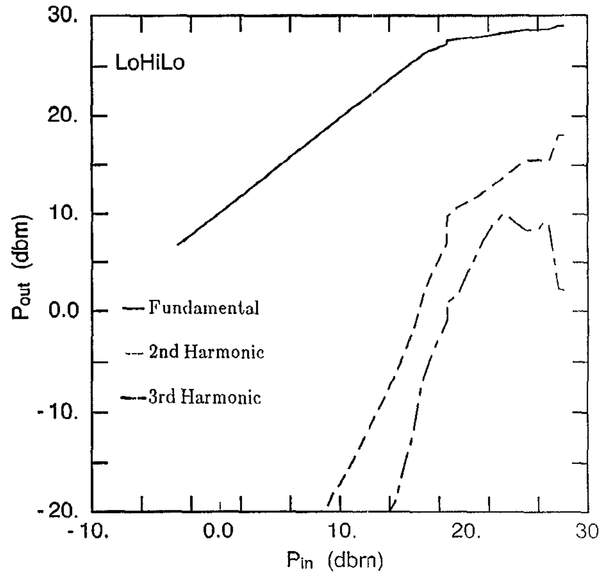

Fig. 3 Output Power versus Input Power for the Lo-Hi-Lo Profile Device

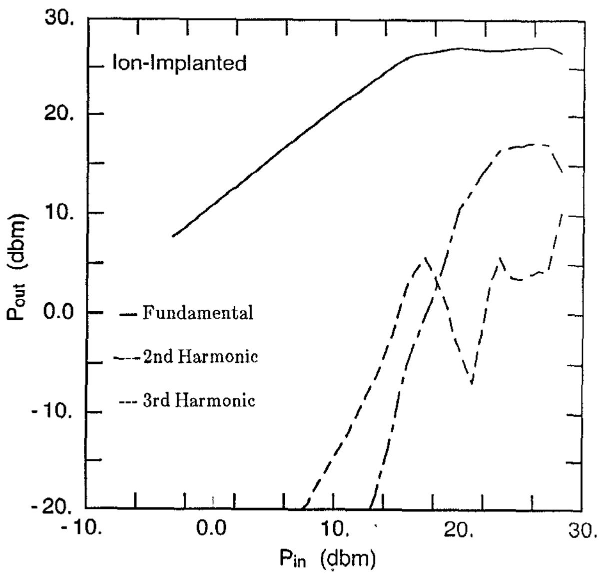

Fig. 2 Output Power versus Input Power for the Ion-Implanted Device

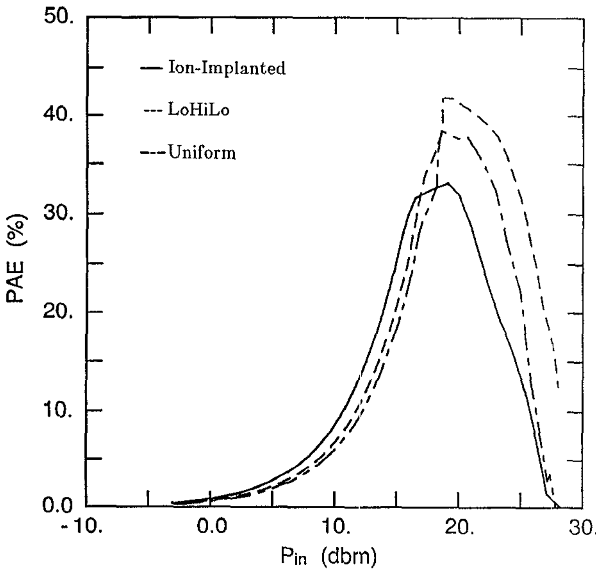

Fig. 4 Power-Added Efficiency versus Input Power for the Devices

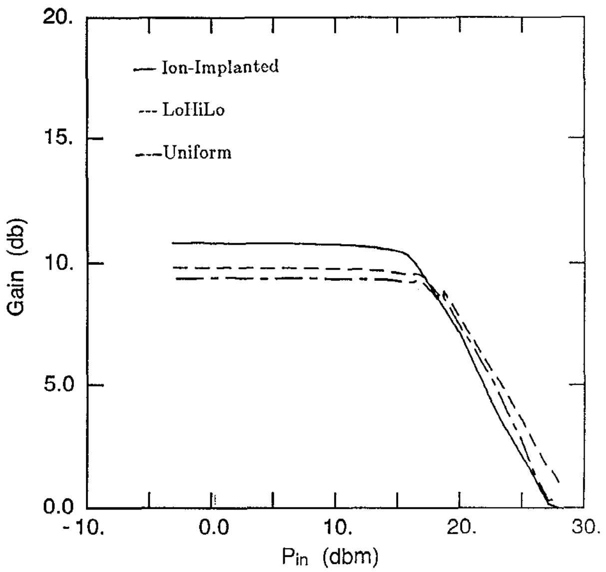

Fig. 5 Gain versus Input Power for the Three Devices

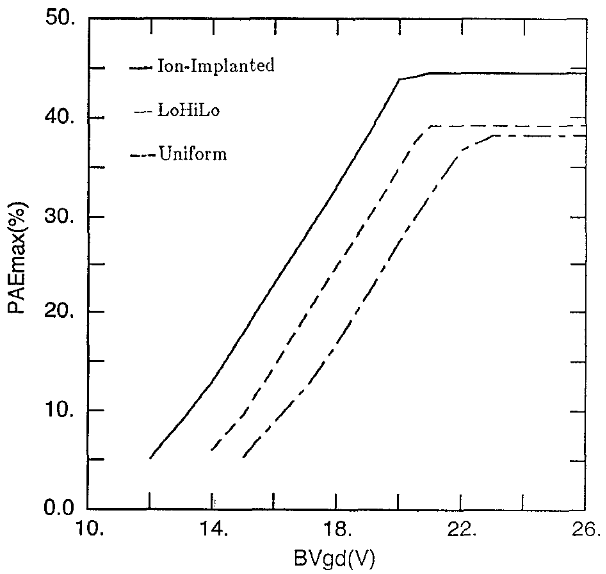

Fig. 6 Power-Added Efficiency versus Gate-Drain Breakdown Voltage for the Three Devices

Table I
Performance Sensitivities
Uniform Doped Profile Device

Variable	Nominal Value	$(PAE)_{max}$ Sensitivity	P_{1dB} Sensitivity
Gate Length (μm)	0.42	0.43	-0.04
Channel thickness (μm)	0.35	-4.18	-0.29
Saturation velocity (cm/s)	1.5×10^{17}	-0.12	-0.03
Low field mobility ($cm^2/v.s$)	4000	-1.3	0.02
Channel doping (cm^{-3})	1.1×10^{17}	-1.79	-0.15
Breakdown voltage (v)	21.0	0.0	0.0
Gate drain breakdown resistance (Ω)	2.0	0.78	0.0
Gate source leakage resistance (Ω)	2.0	-0.15	0.0
Source resistance (Ω)	0.62	-0.04	0.0
Source inductance (nH)	0.02	-0.11	0.01
Drain resistance (Ω)	1.83	-0.12	-0.04
Drain inductance (nH)	0.05	0.79	0.0
Gate resistance (Ω)	0.573	0.76	0.0
Gate inductance (nH)	0.05	0.04	0.0
Gate bias voltage (v)	-2.525	1.71	+0.10
Drain bias voltage (v)	6.94	0.56	0.37

Table II
Performance Sensitivities
Ion-Implanted Profile Device

Variable	Nominal Value	$(PAE)_{max}$ Sensitivity	P_{1dB} Sensitivity
Gate Length (μm)	0.42	-0.16	-0.02
Channel thickness (μm)	0.35	-0.17	-0.03
Saturation velocity (cm/s)	1.5×10^{7}	-0.16	0.02
Low field mobility ($cm^2/v.s$)	4000	0.02	0.01
Peak doping (cm^{-3})	2.1×10^{17}	-1.73	-0.02
Breakdown voltage (v)	18.0	2.67	0.42
Gate drain breakdown resistance (Ω)	2.0	0	0.0
Gate source leakage resistance (Ω)	2.0	0	0.0
Source resistance (Ω)	2.62	0.01	-0.01
Source inductance (nH)	0.02	0	0.01
Drain resistance (Ω)	1.83	-0.036	-0.01
Drain inductance (nH)	0.05	0.01	0.0
Gate resistance (Ω)	0.573	-0.01	0.0
Gate inductance (nH)	0.05	-0.024	0.0
Gate bias voltage (v)	-2.525	0.49	0.04
Drain bias voltage (v)	6.94	-1.51	-0.02

Table III
Performance Sensitivities
Lo-Hi-Lo Profile Device

Variable	Nominal Value	$(PAE)_{max}$ Sensitivity	P_{1dB} Sensitivity
Gate Length (μm)	0.42	-0.26	-0.01
x low (μm)	0.12	-2.01	-0.05
w high (μm)	0.065	-3.09	-0.10
Saturation velocity (cm/s)	1.5×10^{7}	-0.26	0.14
Low field mobility ($cm^2/v.s$)	4000	-0.02	-0.01
Peak doping (cm^{-3}) n low	5×10^{17}	-0.23	-0.06
Peak doping (cm^{-3}) n high	5×10^{16}	-1.94	-0.04
Breakdown voltage (v)	31.0	0.00	0.0
Gate drain breakdown resistance (Ω)	2.0	0.0	0.0
Gate source leakage resistance (Ω)	2.0	-0.36	0.0
Source resistance (Ω)	0.62	-0.04	-0.01
Source inductance (nH)	0.02	0.05	0.06
Drain resistance (Ω)	1.83	-0.16	-0.04
Drain inductance (nH)	0.05	-0.10	-0.02
Gate resistance (Ω)	0.573	0.34	0.0
Gate inductance (nH)	0.05	-0.36	0.0
Gate bias voltage (v)	-2.525	0.58	0.02
Drain bias voltage (v)	6.94	0.45	0.36