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The Effects of P Co-Implants Upon the RF Performance of Ion-Implanted GaAs Power FETs

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Abstract

The use of P-type co-implants to improve GaAs MESFET performance has been examined by use of a physically based, analytic large-signal device model. The P dopants are shown to affect RF performance by altering both the shape and conduction characteristics of the channel. The P dopants improve channel charge confinement, but reduce the electron transport characteristics. RF performance degradation due to the reduced mobility and saturation velocity can be compensated by increasing the drain bias, since BV_{gd} is increased. The net result is that improved RF performance is obtained compared to similar devices fabricated without the P co-implants. The model is verified by comparison with measured RF data of an X-band ITT-GTC MSAG MESFET.

I. Introduction

The use of P-type dopants such as Be or Mg in the fabrication of ion-implanted GaAs MESFETs is of interest. The general conclusion concerning this technology is that improved RF performance is often obtained. The exact manner in which the P co-implants affect RF performance, however, is not well understood. This paper examines the use of P co-implants and offers some insight into how the P dopants affect RF performance. Devices with P co-implants are simulated using the NCSU large signal GaAs MESFET simulator (TEFLON) [1]. The simulated device results reveal the physical operation of these FETs. Experimental results obtained from Mg co-implanted devices fabricated by ITT-GTC are used to confirm the theoretical calculations. It is demonstrated that a primary factor in obtaining improved RF performance from P co-implanted devices is an increase in gate-drain breakdown voltage, thereby permitting the device to be biased at greater drain voltages with a corresponding increase in RF output power.

II. Discussion

The NCSU large signal device simulator is a quasi two dimensional, analytic, physical model. The model allows for arbitrary doping profiles and for the variation of charge carrier transport characteristics (i.e., mobility and saturation velocity) with channel depth. The model includes physical phenomena known to be of importance to device operation such as the velocity vector rotation effect as carriers approach the drain, and deviations from space charge neutrality (charge domain dipole). By specifying the variations in implant dose and energy for both the P (Mg) and N (Si) dopants, effective channel doping profiles can be obtained by observing that the deep level P atoms serve as trapping centers for free electrons. The effective channel charge profile can, therefore, be designed by controlling the position and magnitude of the P profile. Typical channel profiles are shown in Fig. 1.

The P dopants affect the large signal RF performance of the devices through three mechanisms: (1) The modified channel charge profiles have a more abrupt interface to the substrate. This improves the gate length to channel depth ratio and produces better gate control. The

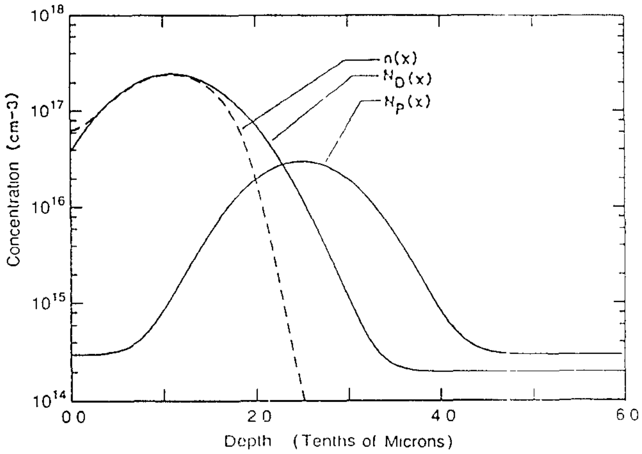

Fig. 1 Channel Charge Profiles

reduced charge under the gate, however, produces a reduced channel current. The net result is that device power and efficiency are reduced. (2) The P dopants serve as scattering sites, thereby reducing the channel charge mobility and velocity. This effect is demonstrated in the mobility versus P implant depth profile shown in Fig. 2. This also serves to decrease the RF performance of the device. (3) The P dopants (especially those at the channel/substrate interface) apparently act to increase the gate to drain breakdown voltage of the device. The exact cause of this phenomenon is, as of yet, not clearly identified. However, results of Mg co-implants on the ITT MSAG devices indicate that the increase in breakdown voltage can be significant (e.g., 10 v to 18 v and typically about a factor of two). The use of AlGaAs buffer layers provide even greater breakdown voltages (e.g., about 30 v) [2]. Improvements in BVgd on the order of a factor of two have also been reported using buffer layers of low temperature MBE grown GaAs [3]. The increased breakdown voltage permits the device to be biased at larger drain voltages. This in turn allows larger RF voltage swings and greater RF output power and power-added efficiency. This latter effect, when taken advantage of, appears to be, in fact, dominant and the reason that P co-implants can result in improved RF performance.

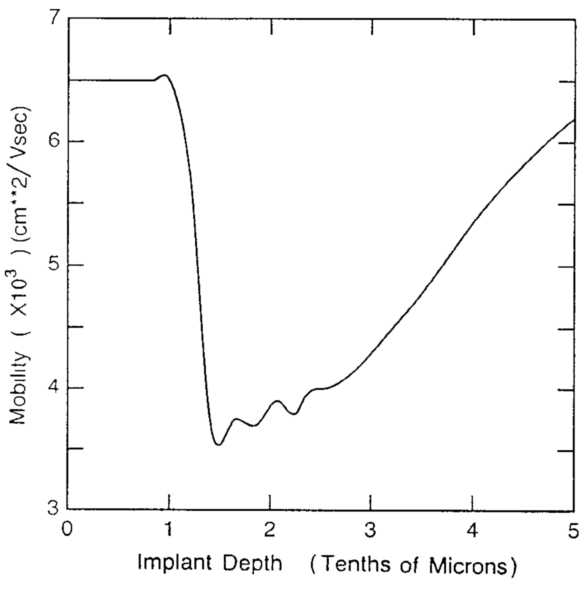

Fig. 2 Electron Mobility in the MESFET Conducting Channel at the Maximum Current Location for Various Depths of the P Co-Implant

III. Results

RF output power is sensitive to the P co-implant depth. At fixed drain-source voltage, the transport degradation due to increased scattering reduces RF output power and this effect is dominant over any increase resulting from an improved gate length to channel depth ratio. This effect can be seen in Fig. 3. In this figure the RF output power at 10 GHz for a 0.5 micron gate length and 1 mm gate width device biased at Vds=10 v and Ids=Idss/2 is shown for various depths of the P co-implant. The RF output power reaches its maximum value when the peak of the P co-implant is either very deep (0.5 micron) or very shallow (0.083 micron) in the channel. Maximum degradation occurs when the donor and acceptor concentrations are of the same order of magnitude [4]. That is, when the peak of the P co-implant is located at the tail of the donor profile. As the P implant depth increases its affect on the free electron profile becomes less but the effective channel mobility and velocity increase, which increases the RF performance.

The effects of increased breakdown voltage are shown in Fig. 4. In this figure the RF output power as a function of input power is calculated for an ITT MSAG device biased at Vds=8 v, Ids=40% of Idss, and F=5.5GHz, but with gate-drain breakdown voltages ranging from the maximum value to a 50% reduction, which demonstrates that the increase in breakdown voltage for the P implanted device increases the output power saturation point significantly. As shown, a low breakdown voltage significantly reduces the RF power capability of the device. The increased breakdown voltage permits larger RF voltage swings before waveform clipping and RF power degradation occurs. Typically, a GaAs MESFET can be biased to about one half the gate-drain breakdown voltage. Increased breakdown voltages allow larger drain bias voltages to be applied with corresponding increases in RF power and power-added efficiency.

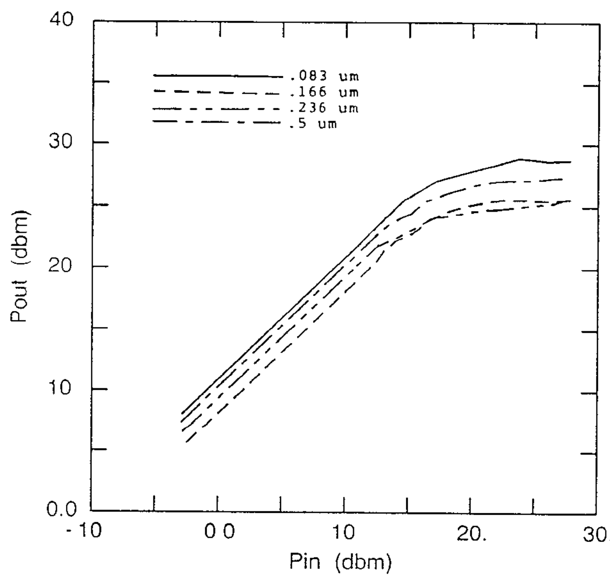

Fig. 3 RF Output Power versus Input Power for Various Depths of the P Co-Implant (Vds=10 v, Ids=Idss/2, F=10 GHz)

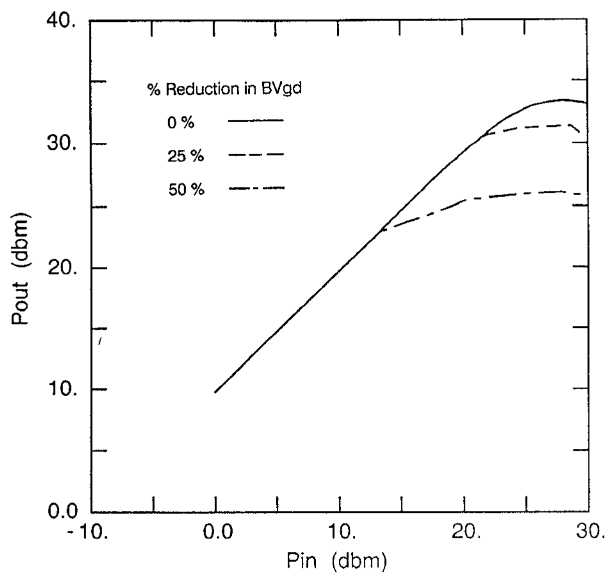

Fig. 4 RF Output Power versus Input Power Showing Effects of Reduced Gate-Drain Breakdown Voltage

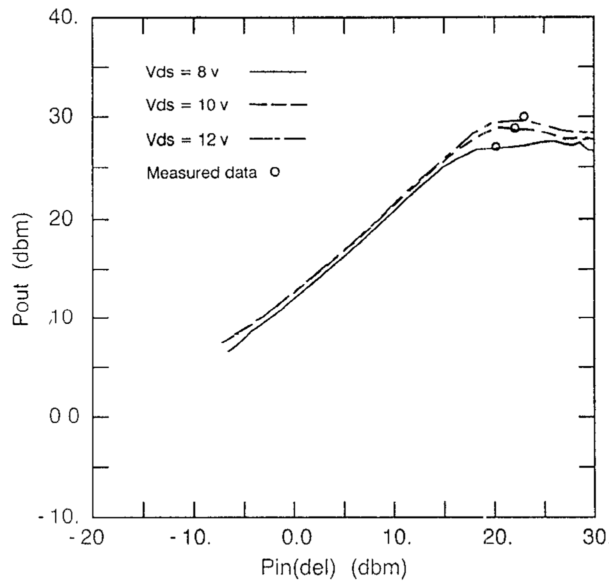

Fig. 5 Comparison Between Measured and Calculated RF Output Power for a P Co-Implanted MESFET in a Class B Hybrid Amplifier (Lg=0.5 um, W=1.25 mm, Ids=5% Idss, F=10 GHz)

Results obtained with MSAG devices produced by ITT are in agreement with the model results. As compared to a standard device the Mg co-implant decreased the Idss for the device, but increased the gate-drain breakdown voltage from 10 to 18 v. A 1.25 mm gate width device operated at 5% of Idss in a Class B Hybrid Amplifier configuration at 10 GHz produced 0.51 W with 53% PAE and 6.9 db gain at Vds=8 v, 0.77 W with 51% PAE and 6.8 db gain at Vds=10 v, and 1.0 W with 50% PAE and 7.0 db gain at Vds=12 v. These values correspond with the model predictions and demonstrate that by increasing the drain-source voltage the RF power output can be increased. This can be seen in Fig. 5. In this figure the RF output power is shown versus the input power for the previously stated bias conditions and the results predicted are in good agreement with the measured data. The high efficiency and gain at the same bias conditions are shown in Fig. 6 and Fig. 7. The measured data points were found by tuning the amplifier for maximum efficiency at each bias level.

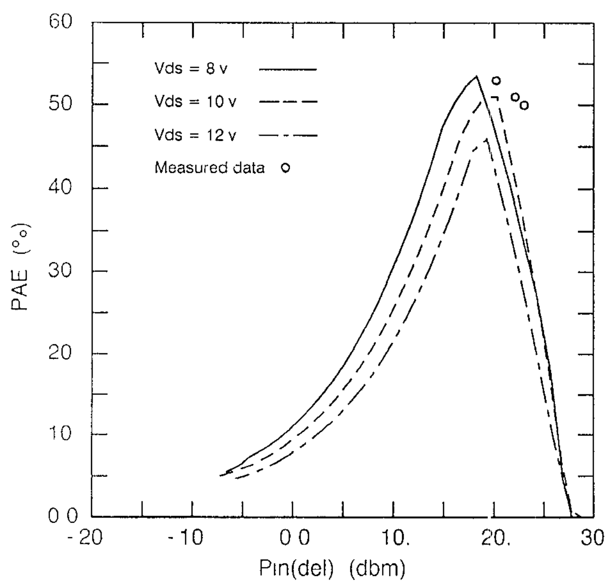

Fig. 6 Comparison Between Measured and Calculated Power-Added Efficiency for a P Co-Implanted MESFET in a Class B Hybrid Amplifier (same conditions as indicated in Fig. 5)

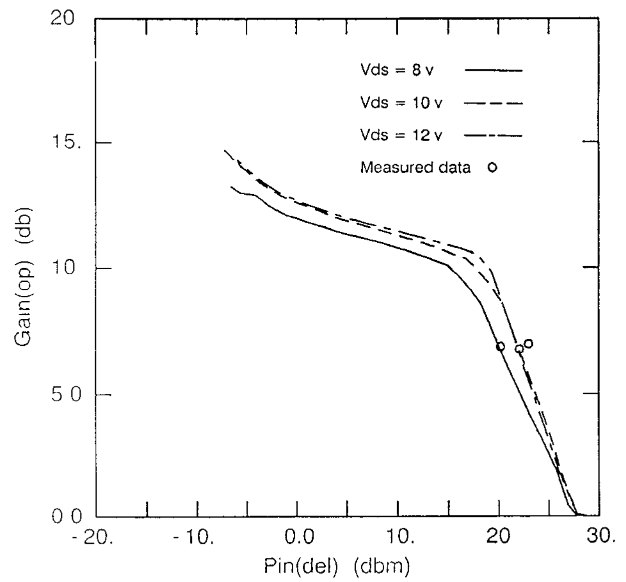

Fig. 7 Comparison Between Measured and Calculated Gain for a P Co-Implanted MESFET in a Class B Hybrid Amplifier (same conditions as indicated in Fig. 5)

IV. Conclusions

The use of P co-implants in the fabrication of GaAs power FETs reduces channel conductivity by degrading charge carrier transport characteristics through an increase in scattering sites, and also by trapping free electrons, thereby reducing the net free charge in the channel. The degradation of transport characteristics and reduced channel current dominate the improved gate length to channel depth ratio and the large-signal RF performance of the device is degraded. The P dopants, however, also appear to increase gate-drain breakdown voltage. This latter effect allows the device to be biased at greater drain voltages with the result that improved RF power and power-added efficiency are obtained.

References

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