

# EFFECTS OF PROCESSING FLUCTUATIONS ON A 0.1 $\mu\text{m}$ MOSFET

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**Abstract** - Fluctuations in the processing parameters can lead to a separation between the gate and the source/drain extensions in MOSFETs. A 0.1 $\mu\text{m}$  MOSFET was simulated with 5%, and 10% separation and it was found that the transconductance was reduced, the threshold voltage was not significantly changed, and that there was no effect on the breakdown because the device has suffered punchthrough rather than avalanche breakdown.

## I. INTRODUCTION

It is the aim of semiconductor designers to continually reduce the size of MOSFETs so that the speed and density of the circuits can be increased. The current technology being explored is the deep submicron or 0.1 $\mu\text{m}$  channel length technology. To scale down the channel length to this size requires great accuracy because fluctuations in the processing parameters can affect the device operation. One such effect is where there is a physical separation between the edge of the gate and the edge of the source or drain extensions as shown in figure 1. The separation can occur due to the variations in the annealing process, diffusion process, implantation process, and plasma etching process. Any undercutting in the plasma etching can lead to a separation. The uncertainty inherent in the diffusion and annealing processes used to create the source and drain extensions can inadvertently lead to separation. Since implantation is performed at a 7° angle to reduce channelling [3] the gate stack can shield part of the wafer from the ions thereby shifting the edge of the extensions which can lead to separation.

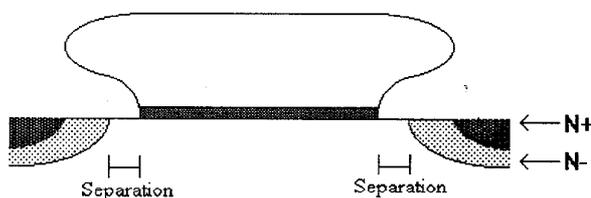


Fig. 1 Cross-section of a MOSFET to illustrate a possible scenario for separation due to process fluctuations.

The Authors have previously studied the effects of process induced separation on a 1 $\mu\text{m}$  MOSFET [1][2]. Measurements of the transfer characteristics showed that separation reduced the transconductance but did not increase the threshold voltage significantly. Measurements of the output characteristics showed that separation reduced the drain current but also increased the breakdown voltage since the breakdown is avalanche breakdown and the lateral electric field in the separation region is reduced. The lateral electric field is reduced because the gate field opposes the drain field in the separation region. A consequence of the reduced electric field is a reduction in the hot carriers produced. This was indicated by measurements showing that separation reduced the peak magnitude of the substrate current. Since the hot carriers reduce the device lifetime, the lifetime was measured. It was found that separation increases the device lifetime dramatically due to the reduction of the hot carriers.

The aim of this paper is to use simulation to determine the effect of separation on a 0.1 $\mu\text{m}$  MOSFET. These effects can then be compared to the known effects of separation on a 1 $\mu\text{m}$  MOSFET.

## II. SIMULATION

In order to determine the effects of separation on a 0.1  $\mu\text{m}$  transistor the simulator must first be calibrated to a known 0.1 $\mu\text{m}$  transistor. In 1987, a 0.1 $\mu\text{m}$  NMOS transistor was developed at the IBM laboratories and the characteristics were reported in the literature [4]. The transistor is a NMOS transistor with a channel length of 0.1 $\mu\text{m}$ . The drain and source diffusions have a junction depth of 100nm with 50nm for the shallower extensions. The extensions extend under the gate by 20nm, still leaving the 0.1 $\mu\text{m}$  channel. The device also includes a threshold voltage implant.

The simulator used is the MEDICI simulator from Technology Modeling Associates[5]. The simulator has been calibrated for this 0.1 $\mu\text{m}$  MOSFET in previous work [6]. The results of the calibration are shown in figure 2.

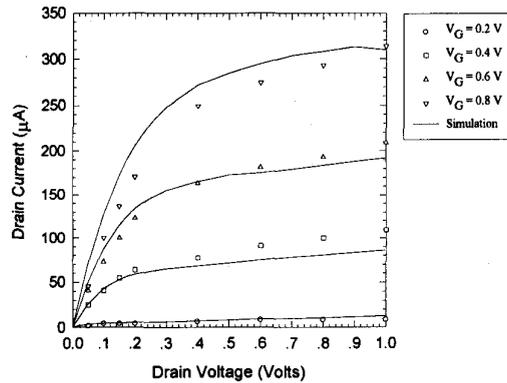


Fig. 2 Results of the simulator calibration

After the MOSFET was calibrated, separation was added. The separation was added to both ends of the channel symmetrically as shown in figure 1. It is estimated that the separation would normally be less than 10% of the channel length. Therefore to see the effects of the separation, separations of 5% and 10% of the channel length were used.

### III. RESULTS

The transfer characteristics for the 0.1μm transistor were simulated and are shown in figure 3. It can be seen that separation has not significantly increased the threshold voltage from the unseparated device. However, separation has a dramatic effect on the transconductance of the device. The 5% and 10% separation have a much reduced transconductance compared to the unseparated device. It is thought that the transconductance reduction is due to some of the gate voltage needing to be used to deplete the gate-to-source and gate-to-drain separation regions [1].

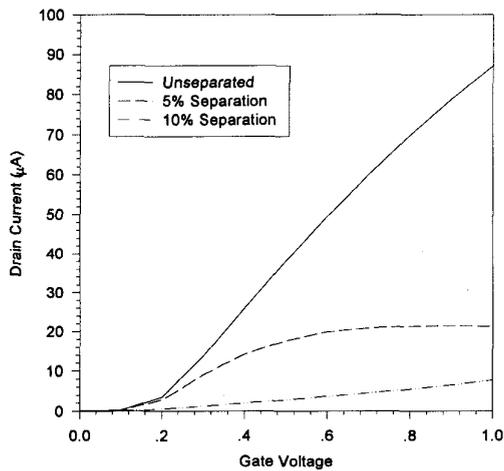


Fig. 3. Transfer Characteristics for the 0.1mm MOSFET in the linear region. The Drain Voltage is 50mV

The output characteristics showing the breakdown region were simulated and are given in figure 4. As can be seen there is a reduction in the drain current. This reduction is a manifestation of the transconductance reduction. The breakdown region is interesting because it shows that separation has no real effect on the breakdown voltage. This is because the breakdown is a punchthrough rather than avalanche breakdown which is highly dependant upon the electric field.

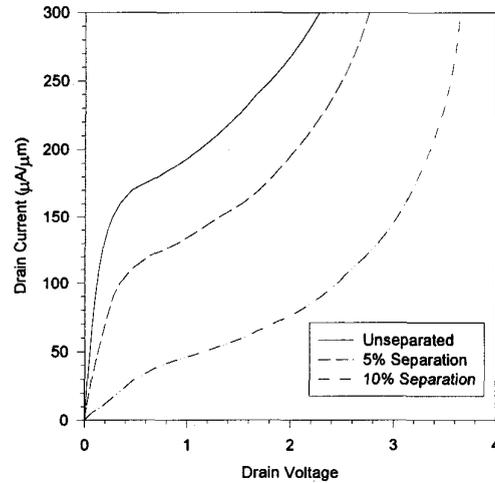


Fig. 4. Output characteristics showing punchthrough. The Gate Voltage is 0.6V

Figure 5 shows the substrate current dependence on the Gate voltage for the Drain voltage close to the start of the breakdown. The substrate current for the unseparated MOSFET is as expected. However, the substrate current for the separation behaves in an unexpected manner. The substrate current continues to rise dramatically. This is an unexpected occurrence and warrants further examination.

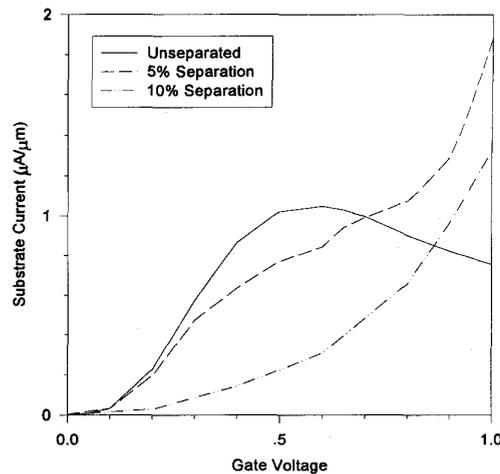


Fig. 5. Substrate current dependence on gate voltage. The Drain Voltage is 1V.

### III. DISCUSSION AND CONCLUSION

Separation is more likely to occur as device dimensions decrease due to fluctuations in the processing parameters. Since the channel of a  $0.1\mu\text{m}$  MOSFET is so small, any fluctuations in the extensions is going to take a more significant percentage of the channel, thus affecting the device operation. The  $0.1\mu\text{m}$  MOSFET was simulated with separation. It was found that the separation caused a reduction in the transconductance, but had little effect on the threshold voltage for the separations chosen. However, if the separation becomes too large then the threshold voltage will shift significantly because more of the gate voltage has to be used to penetrate to the source. Simulation of the output characteristics show a reduced drain current, due to the reduced transconductance. The output characteristics show that the breakdown is punchthrough breakdown. Separation appears to have no effect on the breakdown. Simulation of the substrate current shows that the current undergoes a dramatic rise. This effect requires further investigation.

Previous work on a  $1\mu\text{m}$  channel has shown the transconductance reduction, and the insignificant change of the threshold voltage with separation. The same effects were also exhibited by the  $0.1\mu\text{m}$  MOSFET. The reasons for these effects are the same in both devices as the gate voltage has to be spent to overcome the separation regions. The real difference is the effect of the separation on the breakdown, and substrate currents of the two devices. The effect of separation on the breakdown of the  $1\mu\text{m}$  device was to increase the breakdown voltage, whereas it had no effect on the breakdown voltage of the  $0.1\mu\text{m}$  device. This is due to the breakdown in the  $1\mu\text{m}$  device being avalanche breakdown while the  $0.1\mu\text{m}$  device suffered breakdown due to punchthrough. The substrate current was reduced in the  $1\mu\text{m}$  device indicating a reduction in the hot carriers generated whereas the  $0.1\mu\text{m}$  device showed an unexpected rise.

Overall it has been shown that separation has detrimental effects on the  $0.1\mu\text{m}$  device behaviour due to the device being extremely prone to punchthrough.

### IV. ACKNOWLEDGMENTS

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### V. REFERENCES

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