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Channel Width Effect on MOSFET Breakdown

Y. Fong, G. C. Liang, T. Van Duzer, and C. Hu

***Abstract*—Wide-channel MOSFET's have typically 10 to 30% lower breakdown voltages than narrow-width ($W \approx L$) transistors and are less likely to exhibit clear snapback characteristics. These observations can be explained using a simplified model to determine the width dependence of the MOSFET substrate resistance. The normalized substrate current I_{SUB}/W required for source turn-on predicted by this model is found to decrease by an order of magnitude for wide-channel-width transistors in agreement with measured data. This results in the observed decrease in breakdown voltage for wide-channel MOSFET's.**

I. Introduction

The breakdown phenomenon in MOSFET's is important in many respects. For MOS integrated circuits, it determines the maximum sustainable voltage before destruction due to thermal runaway and thus is one of the limiting factors in device scaling [1]. MOSFET breakdown also plays a role in nonvolatile memory applications. Transistors with high breakdown voltages are needed to sustain the high program/erase voltages required for EPROM's and EEPROM's. Also, for wide-channel EPROM's which are attractive for high-speed programmable logic circuits, lower breakdown voltages will result in a smaller window between the programming and breakdown voltages.

MOSFET breakdown is due to the positive feedback which occurs as the parasitic lateral bipolar transistor is turned on [2]. For this positive feedback to take place, two conditions have to be met. One condition is that the substrate–source junction be turned on (source turn-on) and the other is that the multiplication factor be sufficiently large to cause significant positive feedback. Source turn-on is due to the ohmic drop in the substrate caused by holes flowing from the drain to the substrate contact. The condition for source turn-on is $I_{SUB}R_{SUB} \gtrsim 0.6$ V, where I_{SUB} is the substrate current and R_{SUB} is the substrate resistance. In this brief, the lower breakdown voltages observed for wide-channel devices are determined to be due to the width (W) dependence of the normalized substrate resistance WR_{SUB}.

II. Width Effect on MOSFET Breakdown

Fig. 1 shows the effect of channel width on the breakdown characteristics for 230-Å n-channel transistors with widths of 20 and 2 μm and a channel length of 2 μm. To observe the breakdown region, the transistor I–V curves were obtained by ramping I_D through a series resistor. Depending on the gate voltage V_G, wide-W devices can have 10–30% lower breakdown voltages than narrow-W devices. Fig. 1 also shows that the narrow-W device exhibited clear "snapback" behavior as V_D decreased to a lower voltage (BV_{CEO} of the parasitic lateral bipolar transistor [2]). As will be shown in the next section, wide-W devices often experience source turn-on at a lower V_D than BV_{CEO} so that no clear snapback behavior is seen over a wide V_G range. The $W = 20$ μm device is such an example.

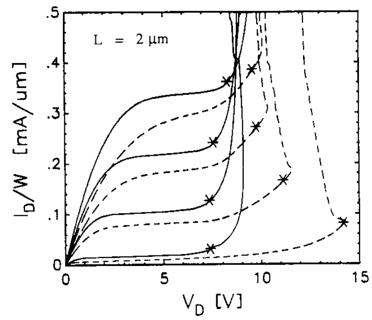

Fig. 1. I–V characteristics for transistors with a channel length of 2 μm and channel widths of 20 μm (solid line) and 2 μm (dashed line). $V_G - V_T$ ranged from 1 to 7 V in 2-V steps. The "*" marks the point of source turn-on.

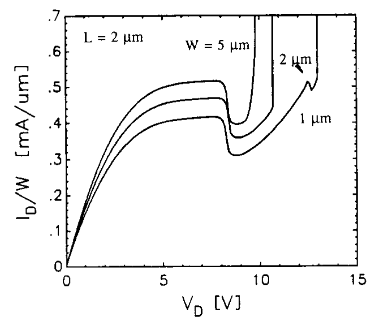

Fig. 2. Programming characteristics for EPROM devices with different channel widths.

The lower breakdown voltage of wide-W transistors is also observed in floating-gate EPROM's (Fig. 2). This means that wide-W EPROM's, which conduct the higher currents required for high-speed programmable logic circuit applications, will have a smaller window between the programming and breakdown voltages. Since the amount of programming (percentage decrease in I_D due to electrons accumulating on the floating gate) is approximately the same for the wide-W EPROM when compared to the narrow-W EPROM, the difference in breakdown voltages is not due to a difference in channel electric field from edge effects.

III. Substrate Resistance Model

To explain the observed channel width dependence of MOSFET breakdown, a simplified three-dimensional substrate resistance model (Fig. 3) is used. The narrow region at the edge of the drain junction where holes are generated is modeled as a W (channel

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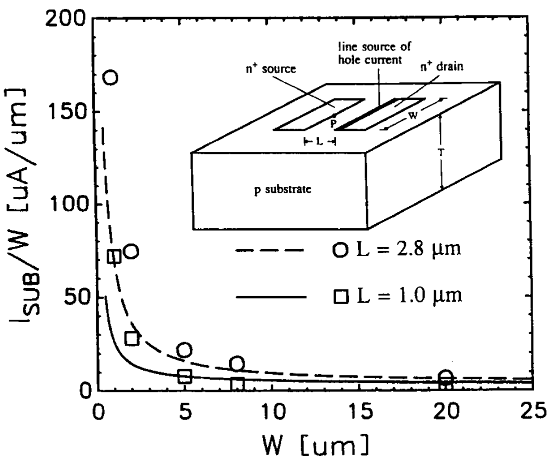

Fig. 3. Measured (symbols) and predicted (lines) substrate currents at breakdown for different channel lengths and widths. The substrate resistivity and thickness were 15 Ω · cm and 500 μm, respectively. The simplified model used to solve for the substrate resistance is also shown.

width) long line conductor located on the surface of a substrate of resistivity ρ and thickness T. The substrate current I_{SUB} is the current flowing out of this line. The largest substrate–source junction bias at a distance L (channel length) away from the line source occurs in the middle of the transistor in the width direction (point P).

An analytical expression for the potential at P can be derived by taking the line source as the limiting case of an ellipsoid and approximating the substrate back contact with a confocal ellipsoid surface [3]. The normalized substrate resistance is then

$$WR_{SUB} = \frac{\rho}{2\pi} \ln \left[\frac{(\sqrt{W^2 + 4L^2} + W)(\sqrt{W^2 + 4T^2} - W)}{(\sqrt{W^2 + 4L^2} - W)(\sqrt{W^2 + 4T^2} + W)} \right] \approx \frac{\rho}{2\pi} \ln \left[\frac{\sqrt{W^2 + 4L^2} + W}{\sqrt{W^2 + 4L^2} - W} \right]. \quad (1)$$

Fig. 3 shows the measured substrate current at breakdown for different channel lengths and widths with the transistor biased in the off-state. In this case, breakdown is triggered by the condition

$$I_{SUB} R_{SUB} = \left(\frac{I_{SUB}}{W} \right) (WR_{SUB}) \gtrsim 0.6 \text{ V}. \quad (2)$$

Fig. 3 also shows the predicted substrate currents using (1) and (2). Resonable agreement is seen. This strong I_{SUB}/W dependence on W for $W \approx L$ is not predicted by the substrate resistance model in [2]. The disagreement for very narrow channel widths is due to the fact that the model did not include the effect of the field implant which would decrease WR_{SUB} and increase I_{SUB}/W at breakdown. The lower breakdown voltages for wide-W transistors (Fig. 1) can be attributed to the width dependence of WR_{SUB}. In the wide-W device, source turn-on occurred at a lower I_{SUB}/W, hence a lower V_D. The "*" symbol in Fig. 1 indicates when the product of measured I_{SUB}/W and WR_{SUB} is equal to 0.6 V.

This channel width effect on MOSFET breakdown is dependent on the transistor channel length. From (1), (2), and Fig. 3, transistors with shorter channel lengths require less I_{SUB}/W for source turn-on. This difference in I_{SUB}/W will result in a difference in the amount of decrease in the breakdown voltage for wide-W transistors. Fig. 4 is a plot of normalized substrate current as a function of drain voltage for transistors with channel lengths of 1 and 2 μm.

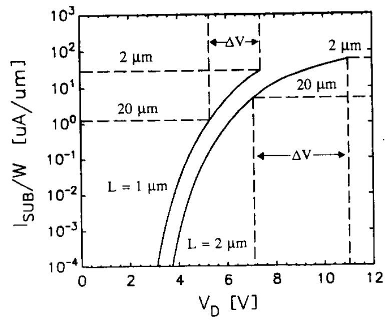

Fig. 4. Normalized substrate current versus drain voltage characteristics measured on transistors with $L = 1$ and 2 μm. The $L = 1$ μm transistor will have a smaller difference in breakdown voltage ΔV between wide- and narrow-W transistors because it required less I_{SUB}/W for source turn-on.

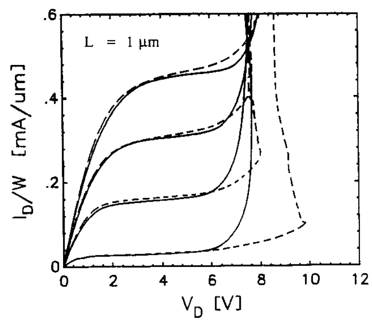

Fig. 5. I-V characteristics for transistors with a channel length of 1 μm and channel widths of 20 μm (solid line) and 2 μm (dashed line). $V_G - V_T$ ranged from 1 to 7 V in 2-V steps.

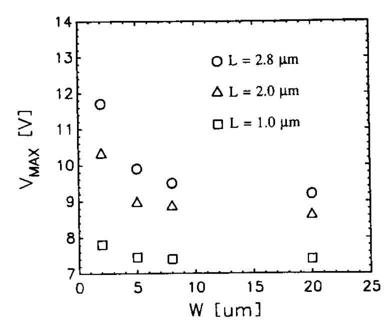

Fig. 6. The maximum sustainable voltage V_{MAX} measured for transistors with different channel lengths and widths. V_{MAX} is defined to be the minimum V_D for any $V_G < V_D$ which will result in MOSFET breakdown.

Because the log $(I_{SUB}/W) - V_D$ slope increases as I_{SUB}/W decreases [4], transistors with shorter channel lengths will exhibit a smaller difference in the breakdown voltage between wide- and narrow-W transistors. This is evident when comparing Fig. 5, transistors with $L = 1$ μm, and Fig. 1, transistors with $L = 2$ μm.

Fig. 6 shows the maximum sustainable voltage V_{MAX} measured for transistors with different channel lengths and widths. V_{MAX} is defined to be the minimum V_D (for any $V_G < V_D$) which will result in MOSFET breakdown and thus limit the maximum supply voltage. Transistors with wider channel widths have a lower V_{MAX} as expected. Again this difference is reduced for shorter channel lengths.

IV. Summary

In this brief, the effect of channel width on MOSFET breakdown was studied. Wide-channel MOSFET's have 10 to 30% lower breakdown voltages than narrow-width transistors and are less likely to exhibit clear snapback characteristics due to the width dependence of the normalized substrate resistance WR_{SUB}. An analytical expression for WR_{SUB} was derived for different channel lengths and widths. The I_{SUB}/W required for source turn-on predicted by this WR_{SUB} equation agrees with measured data and is found to decrease by an order of magnitude for wide-channel-width transistors resulting in the observed decrease in breakdown voltage. The difference in breakdown voltage for wide- and narrow-width transistors decreases for transistors with shorter channel lengths because they require less I_{SUB}/W for source turn-on. These effects also apply to the transistor's maximum sustainable voltage.

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