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Influence of the bulk electrode on the characteristics and the channel noise of SOS-MOS transistors (*)

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Résumé. — L'évolution de la densité spectrale du courant de bruit du canal des transistors SOS-MOS (canal à inversion de type n) en fonction de la tension drain source met en évidence l'apparition d'une bosse, que le substrat du dispositif soit à un potentiel flottant ou mis à la masse. Dans ce dernier cas, cette bosse apparaissant à des tensions de drain plus élevées, suggère l'existence d'un effet kink masqué sur la caractéristique courant drain-tension drain par la multiplication importante des porteurs. Cette étude est développée à partir de l'analyse de schémas équivalents électriques et de bruit de fond des dispositifs où il est tenu compte de l'électrode d'accès au substrat et du générateur de courant de multiplication associé à la charge d'espace dans la région drain.

Abstract. — The channel noise current spectral density of n-type enhancement SOS-MOS transistors *versus* the drain-source voltage V_{DS} exhibits a peak not only for a floating bulk electrode but also when it is grounded. In the latter case, this peak appears at higher values of V_{DS} . This suggests the kink effect which is now masked on the D.C. characteristics I_D-V_{DS} by a stronger multiplication. Theoretically we characterize this effect by means of an equivalent circuitry (electrical and noise) where the bulk electrode and the multiplication current generator associated with the drain space charge region are taken into account.

1. Introduction. — Anomalous I_D-V_{DS} characteristics on n-channel SOS-MOS transistors (*Kink effect*) have been already reported by several authors. They were explained by the assumption of traps [1], then by the influence of the bulk floating potential on the threshold voltage [2], [3]. The device under test is an n-channel enhancement SOS-MOS transistor with an electric contact on the bulk. In this paper, we point out the influence of the bulk potential on D.C. and noise characteristics.

2. Effects of the substrate potential on I_D-V_{DS} curves. — The tested device is an n-channel enhancement SOS-MOS transistor with a bulk electrode ⁽¹⁾ (see Fig. 1). The transistor parameters are : bulk doping density $N_A = 6 \times 10^{16} \text{ cm}^{-3}$, channel length $L = 10 \text{ }\mu\text{m}$, silicon-film thickness $t_{si} \approx 0.65 \text{ }\mu\text{m}$, aspect ratio $Z/L = 44/10$ and oxide thickness $t_{ox} = 550 \pm 50 \text{ \AA}$.

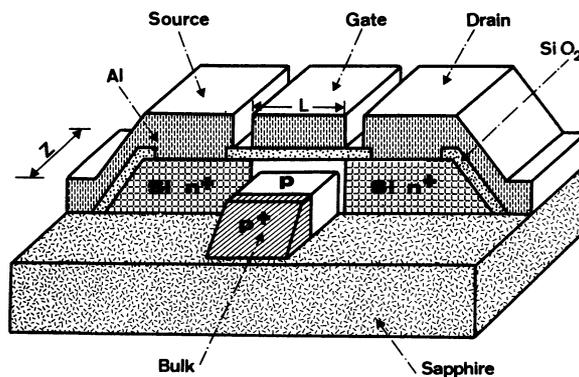


Fig. 1. — Structure of the device under test.

When the bulk is at floating potential, the *kink* in the drain current is obvious in D.C. characteristics I_D vs. V_{DS} (Fig. 2).

The dimensions of the device ($L = 10 \text{ }\mu\text{m}$) and the doping value of the bulk are such that the second kink due to a bipolar parasitic transistor was not observed [3].

When the bulk is grounded, the kink disappears and we can notice an increase of I_D for $V_{DS} > 9 \text{ V}$.

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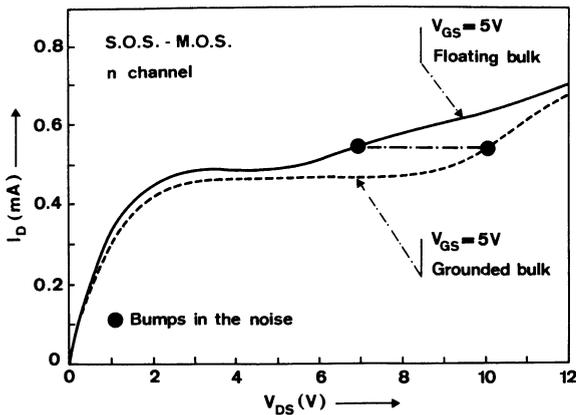


Fig. 2. — I_D - V_{DS} characteristics showing the *kink* effect with a floating bulk.

In figure 3 is represented the autopolarization voltage V_{BS} of the bulk *versus* V_{DS} for $V_{GS} = 5$ V and $V_{GS} = 10$ V.

For a null gate bias, the channel is not created; then the increase of V_{BS} is due to the reverse current of the bulk-drain diode flowing through the neutral bulk and the forward biased bulk-source diode [2]. When the gate is biased in order to create the inversion channel, for lower values of V_{BS} , we find again a *plateau* due to the reverse current of the bulk-drain diode. The strong increase of V_{BS} is then significant of the hole flow coming from the multiplication zone near the drain contact [4].

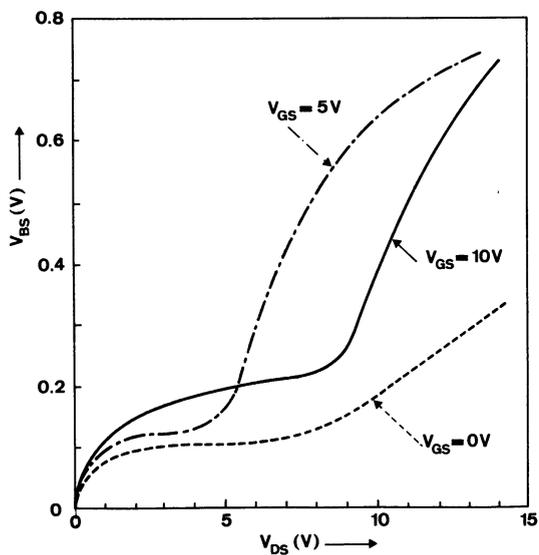


Fig. 3. — Autopolarization voltage of the bulk V_{BS} *versus* V_{DS} for different gate voltages.

The cross section of the transistor is drawn in figure 4 including the different currents, the location of the two diodes D_1 and D_2 and the impedances of the bulk electrode.

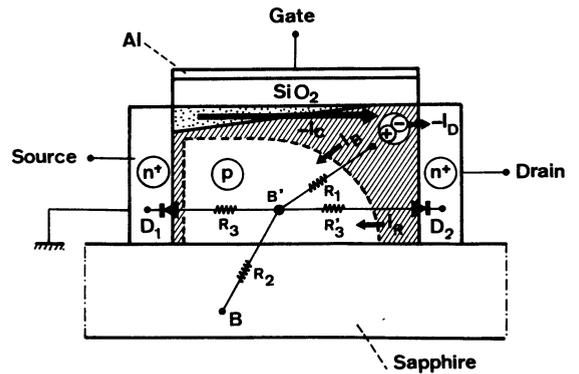


Fig. 4. — Cross section of the device in saturation.

In the saturation range, an electron current I_c is injected from the channel into the drain space charge region where a multiplication effect occurs. The electrons are collected on the drain contact (I_D) whereas the holes (I_B) reach the source contact through the neutral bulk and the forward biased bulk-source diode D_1 when the bulk is floating. If M is the current multiplication factor, we can write :

$$I_D = MI_c \quad \text{and} \quad I_B = (M - 1) I_c$$

I_R is the reverse current of the bulk-drain diode D_2 .

The equivalent circuit of the bulk electrode is given by a set of resistors where R_2 takes into account the bulk access electrode.

In figure 5 we show the forward D.C. characteristics of the bulk-source diode D_1 and the effect of the series resistor.

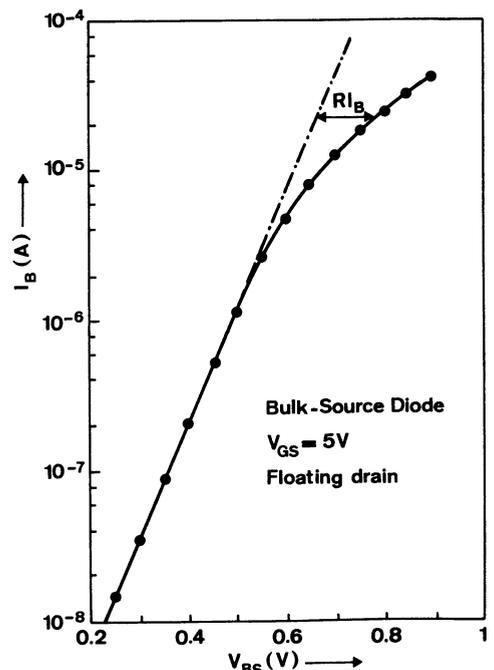


Fig. 5. — Forward characteristics of the bulk-source diode D_1 .

The effect of this parasitic resistor has been pointed out. Its value is about 5 kΩ. It is mainly due to the bulk electrode R_2 (the geometry of the device is such that $R_3 \ll R_2$).

From the figures 3 and 5 we have deduced the variation of the bulk current *versus* V_{DS} and the current multiplication factor (Fig. 6), taking into account the effect of the bulk resistor R_2 . The M values are in good agreement with similar data given in [5].

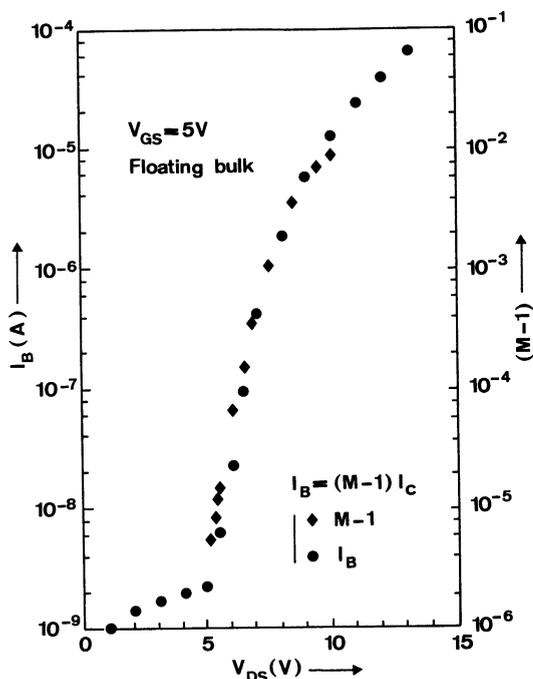


Fig. 6. — Hole current I_B through the bulk and multiplication factor *versus* V_{DS} .

3. Channel noise current in the saturation range. —

The noise of the device has been measured between the drain and the source, the gate being connected to the source for the alternative components.

Spectra of the channel noise current are given in figure 7, for different values of the drain bias and a floating bulk. Most of the experimental data follow a $1/f$ law. The values of the drain bias have been chosen around the kink region (see Fig. 2).

All the curves shown in figure 8 are measured at $f = 100$ kHz and at room temperature.

When the bulk is floating, for a given V_{GS} , we observe a peak in the noise curve. When the bulk is grounded a similar peak occurs for a higher drain bias.

In order to explain this noise behaviour an equivalent circuit has been designed (Fig. 9). We have represented the diodes D_1 and D_2 , the different resistors shown previously in figure 4 and the current generator $(M - 1) I_c$ taking into account the impact ionization near the drain contact.

The device can be considered as a double gate FET : one being a pure MOS-FET and the other one

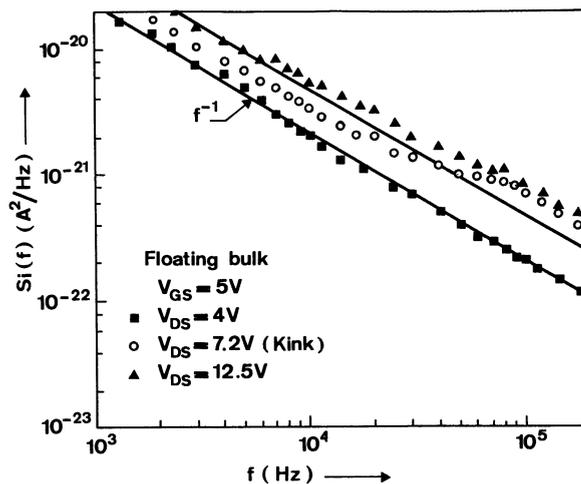


Fig. 7. — Channel noise current spectra for different drain bias V_{DS} .

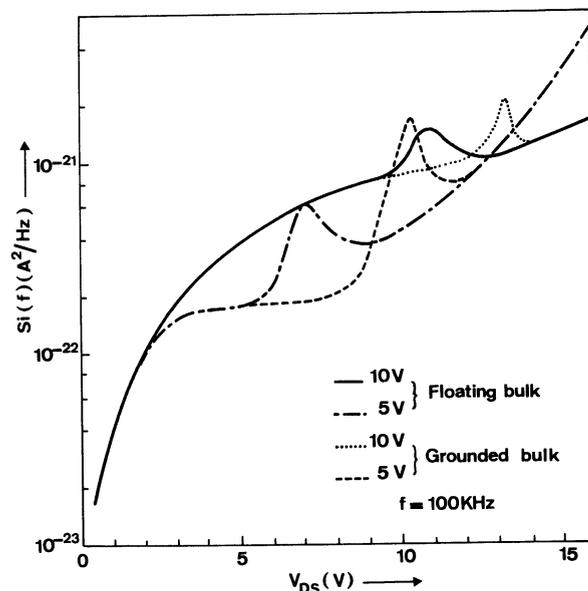


Fig. 8. — Channel noise current *versus* V_{DS} showing bumps even for a grounded bulk.

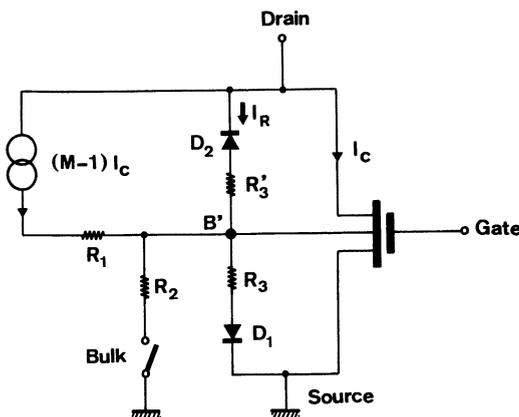


Fig. 9. — Equivalent circuit including the bulk access.

a kind of JG-FET acting not on the geometry of the channel but on its free carrier density. Such a device has been named B-MOS [6] but whereas this B-MOS works in the subthreshold region, the described SOS-MOS acts strongly inverted and in the saturation range.

The voltage of the gate B' of this second transistor is related to the drain voltage through the set of resistors; according as the bulk is grounded or not, the biasing circuit will change: to obtain the same value of $V_{B'S}$, the drain voltage will be different.

Figure 10 gives the noise equivalent circuit: $i_c(t)$ is the intrinsic noise current generator of the channel, $i_B(t)$ is the input noise current generator of the parasitic JG-FET taking into account the noise induced by the current generator $(M - 1) I_c$ and the noise of the gate load.

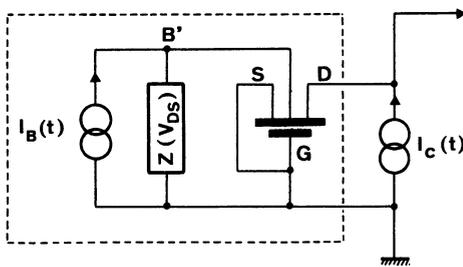


Fig. 10. — Equivalent noise circuit with AC short circuited gate.

The noise measured at the output is the sum of $i_c(t)$ and the noise induced by $i_B(t)$ in the parasitic JG-FET.

The value of the gate load of this transistor is a decreasing function of V_{DS} , whereas $i_B(t)$ is an increas-

ing function. Thus, the peak in the noise can be explained by the product of these two variations.

For higher values of V_{DS} , the contribution of $i_B(t)$ is negligible because of the low value of $Z(V_{DS})$ which is mainly the differential resistance of the forward-biased diode D_1 [7].

The channel noise increases after the kink bump because of multiplication effects generating an additional noise source.

When the bulk is grounded, the shunting effect of R_2 is such that to obtain the same value of $V_{B'S}$, giving the noise bump, we need higher values of the multiplication current ($I_B = 10 \mu\text{A}$ in spite of $0.1 \mu\text{A}$) i.e. higher values of V_{DS} [8]. Then the parasitic transistor is in the same gate bias conditions as in the floating bulk case.

We notice that the maxima of the peaks for $V_{GS} = 5 \text{ V}$ (see Fig. 8) appear for the same value of the drain current ($550 \mu\text{A}$) for both cases of floating and grounded bulk (see Fig. 2).

4. Conclusion. — To describe the *kink effect* in SOS-MOS transistors, we have given an equivalent circuit of these devices showing a parasitic JG-FET with a gate load which is a function of the drain voltage even if the bulk is grounded. The noise curves exhibit a peak which is still present even for a grounded bulk. Then the *kink effect* in the D.C. characteristics is masked by a stronger electron multiplication effect. Grounding the bulk is not sufficient to eliminate the peak in the noise: it is only shifted towards a higher drain voltage because of the shunting effect of the access bulk resistance (R_2). Finally the maxima of the bump in noise curves appear for the same value of the drain current.

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