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MOSFET threshold extraction from voltage-only measurements

C. Galup-Montoro, M.C. Schneider, A.L. Koerich and R.L.O. Pinto

Indexing terms: MOSFET, Semiconductor device characterisation

The authors describe a method for determining the MOS transistor parameters from voltage measurements by considering two transistors in series. The voltage characteristics at the intermediate node of the two connected transistors allow easy and direct determination of the threshold voltage, the pinch-off voltage and the slope factor.

Introduction: The accurate determination of MOSFET parameters is important for IC process development, manufacturing and design. In recent years, methods based on the analysis of the drain current for the extraction of MOSFET parameters have been proposed [1,2]. The main drawback of these methods is that a single measured variable, the drain current, is employed to determine two independent physical variables, the threshold voltage, related to the carrier charge density, and the mobility. In the classical determination of the charge density and the mobility using the Hall effect both the current and the Hall voltage have to be measured [3].

This Letter presents a new method for the extraction of MOSFET parameters based on the properties of the series connection of MOS transistors [4]. The voltage at the intermediate node of the connected transistors provides the information needed to determine the parameters related to the chanel charge, namely, the zero bias threshold voltage (V_{T0}), the pinch-off voltage (V_P) and the slope factor (n).

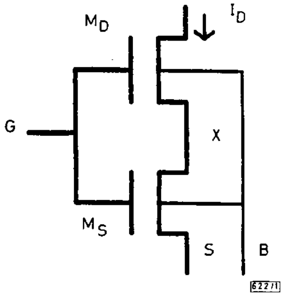

Fig. 1 *Series association of transistors*

Principle of method: We consider here the series connection of transistors, as shown in Fig. 1, i.e. the gate and bulk terminals are common to both transistors. The series connection can be viewed as a single transistor [4], where the potential at an internal point of the channel is accessible. To determine the theoretical potential at the intermediate node, we consider a first order transistor model as follows. In the triode region and in strong inversion, the drain current of an MOS transistor can be written [5–7] as

$$I_D = \frac{W}{L}\mu_{eff}C'_{ox}\frac{n}{2}\left[(V_P - V_S)^2 - (V_P - V_D)^2\right] \qquad (1)$$

where all voltages are referred to the substrate. μ_{eff} is the effective mobility, which in the usual approximations for long-channel devices depends only on the gate voltage [1,6]. The pinch-off voltage [5–7] is given by

$$V_P \simeq \frac{V_G - V_{T0}}{n} \qquad (2)$$

The undefined symbols in eqns. 1 and 2 have their usual meanings [5,6]. For the series connection of transistors (Fig. 1), assuming that the drain currents of M_S and M_D are equal and that the two transistors have the same width and length, we obtain

$$(V_P - V_X)^2 = \frac{1}{2}(V_P - V_D)^2 + \frac{1}{2}(V_P - V_S)^2 \qquad (3)$$

from the application of eqn. 1 for both transistors. On the verge of saturation of the transistor M_D, $V_D = V_P$; therefore, eqn. 3 reduces to

$$V_X \simeq \frac{V_G - V_{T0}}{n}\left(1 - \frac{1}{\sqrt{2}}\right) + \frac{V_S}{\sqrt{2}} \qquad (4)$$

In this work we have used eqn. 4 to determine V_{T0}, V_P and n.

Results and discussion: To test the above method of parameter extraction, measurements for the series connection (Fig. 1) of two identical (W = 6μm, L = 5μm) N-channel transistors from a 2μm CMOS technology have been performed.

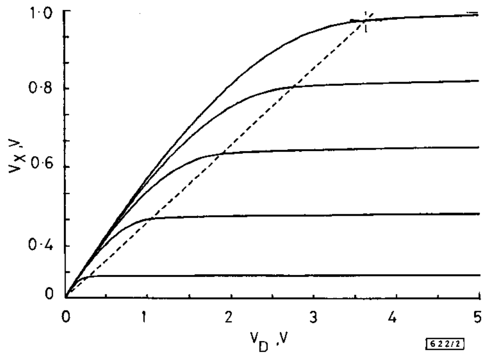

Fig. 2 *Experimental intermediate node voltage $V_X(V_D)$ characteristics for V_G = 1, 2, 3, 4 and 5 V and V_S = 0*

Fig. 2 plots the measured voltage V_X at the intermediate node in the series connection of transistors as a function of V_D. The dashed line $V_X = (1 - 1/\sqrt{2})V_D$ is the theoretical boundary between the triode and the saturation regions, according to eqn. 4.

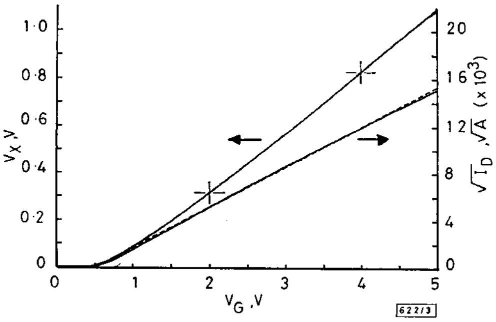

Fig. 3 *Experimental intermediate node voltage $V_X(V_G)$ and square root of drain current $\sqrt{I_D}(V_G)$ for V_D = V_G and V_S = 0*

Fig. 3 displays the measured $\sqrt{I_D}(V_G)$ and $V_X(V_G)$ characteristics for the series connection of the transistors. The zero bias threshold voltages obtained from the linear extrapolation of the $\sqrt{I_D}(V_G)$ and

$V_X(V_G)$ curves to the X-axis are 499 and 762 mV, respectively. The determination of V_{T0} from the $V_X(V_G)$ curve is direct because this plot is linear for values of V_G larger than, say, 2V. The determination of V_{T0} from the $\sqrt{I_D(V_G)}$ curve, however, is not precise because of the mobility dependence on the transversal field, which depends on V_G. It should be noted here that the extraction of the threshold voltage from the $V_X(V_G)$ curve does not depend on the value of the effective carrier mobility. The slope factor n is easily determined from the gradient of the $V_X(V_G)$ curve, which is equal to $(1 - 1/\sqrt{2})/n$, according to eqn. 4. In our case, the gradient is 0.256; hence, $n = 1.14$.

Fig. 4 shows $V_X(V_S)$ curves. The slope of the curves for low values of V_S, i.e. for strong inversion operation, is $\sim 1/\sqrt{2}$, according to eqn. 4. The value of the pinch-off voltage for any value of V_G is determined by the intersection of the tangent to the curve $V_X(V_S)$ for low V_S and the straight line $V_X = V_S$, according to eqn. 4.

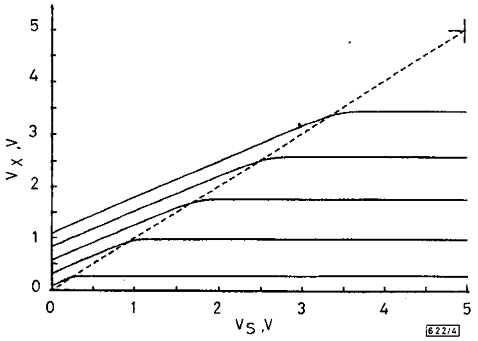

Fig. 4 *Experimental intermediate node voltage $V_X(VS)$ characteristics for V_G = 1, 2, 3, 4, and 5V with $V_D = V_G$*

Conclusion: We have proposed a direct method to determine the MOS transistor parameters that are related to the channel charge without using current measurements. We have used information provided by the voltage at the intermediate node of the series connection of transistors in order to determine the zero bias threshold voltage, the pinch-off voltage and the slope factor. The voltage measurements presented in this work together with the drain current measurement can be used to precisely determine the effective mobility dependence on the gate voltage.

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