Novel Y-function methodology parameter estimation from weak to strong inversion operation

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Considering the expressions of the drain current and of the transconductance in ohmic operation regime [1], and of the general assumed extrinsic effective mobility [2,3]:

$$I_D = \frac{W}{L}\mu_{eff} Q_i V_{DS} \;\; (1)\,; \quad g_m = \frac{W V_{DS}}{L}\frac{C_{ox}C_i}{C_{ox}+C_d+C_{it}+C_i}\frac{\partial(\mu_{eff}Q_i)}{\partial Q_i} \;\; (2); \quad \mu_{eff} = \frac{\mu_0}{1+\theta_1(Q_i/C_{ox})+\theta_2(Q_i/C_{ox})^2} \;\; (3)$$

the expression of the Y-function may be derived as:

$$Y = \frac{I_D}{\sqrt{g_m}} = \frac{\sqrt{G_M V_{DS}}}{\sqrt{1-\theta_2(Q_i/C_{ox})^2}}\sqrt{\left(\frac{SS}{\ln 10}+\frac{Q_i}{C_{ox}}\right)\frac{Q_i}{C_{ox}}} \qquad (4)$$

where $G_M = W\mu_0 C_{ox}/L$ [2]; W and L the effective width and length of the channel; μ_{eff} the extrinsic effective mobility; μ_0 the low field mobility; θ_1 and θ_2 the first and second mobility attenuation factors; Q_i the inversion charge density; V_{DS} the drain to source voltage; C_{ox}, C_d, C_{it} and C_i are the gate, depletion, interface state and inversion charge capacitances per unit or area and SS the subthreshold swing. Assuming that $C_i \ll C_{ox} + C_d + C_{it}$ in weak inversion and $C_i \gg C_{ox} + C_d + C_{it}$ in strong inversion with $C_i = q\,Q_i/(k_B T)$ ($k_B T/q$ being the thermal voltage) [1] the Q_i/C_{ox} may be evaluated: in weak inversion as: $Q_i/C_{ox} = Y^2/G_M V_{DS}\,SS/\ln 10$ (5) and in strong inversion as $Q_i/C_{ox} = Y/\sqrt{G_M V_{DS} + \theta_2 Y^2}$ (6). Without any approximation, from weak to strong inversion the ratio Q_i/C_{ox} may be expressed as: $(G_M V_{DS} + \theta_2 Y^2)\left(\frac{Q_i}{C_{ox}}\right)^2 + G_M V_{DS}\frac{SS}{\ln 10}\frac{Q_i}{C_{ox}} - Y^2 = 0$ (7).

The G_M and θ_2 parameters were extracted using criteria of [3] and the subthreshold swing SS may by determined from I-V curves in the subthreshold zone. Consequently, the Q_i/C_{ox} ratio may be easily evaluated from weak to strong inversion operation by solving the second-degree equation of (7) (Figure 1). Further, the drain current may be evaluated using (1), having θ_1 estimated using [3] and the transconductance using (2) or $g_m = {I_D}^2/Y^2$, where Y is modeled using (3). Very good agreement between the experimental I_D and the g_m models of (1), respectively (2) may be observed for devices for different technologies (Figure 2 and 3), even at 80 K operation (Figure 3).

The advantage of this new methodology is that no capacitance measurements or mathematical formulation as Lambert W function or Kubo-Greenwood modeling approach are necessary [4,5]. Moreover, only four parameters are needed to be estimated: three extracted in strong inversion (G_M, θ_2 and θ_1) and one estimated in the subthreshold zone (SS). The inversion charge over the gate capacitance ratio is estimated using its dependency on the Y-function described in (7). Finally, a compact Y-function methodology may be proposed, providing accurate and physical electrical parameters extraction and allowing to model the transfer characteristics behaviour from weak to strong inversion operation regime if the drain current may be expressed as in (1) and the extrinsic effective mobility as in (3).

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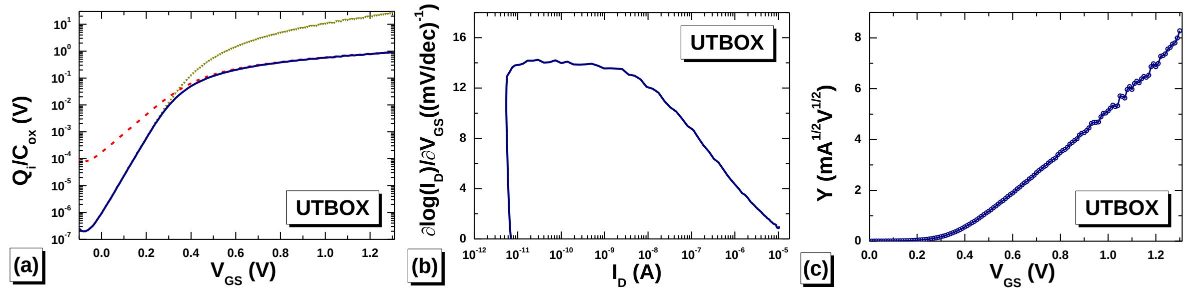

Figure 1: (a) Q_i/C_{ox} versus the applied gate voltage estimated from (5) (short-dot line), from (6) (short dash line) and from (7) (full line). (b) $\partial\log(I_D)/\partial V_{GS}$ permitting the estimation of the SS parameter. (c) very good agreement between the experimental Y-function and model of (4). UTBOX n-channel device: L / W = 120 nm / 1 µm, EOT of 2.6 nm, after processing a BOX thickness T_{BOX} of 15 nm and a silicon film thickness T_{Si} of 16 nm.

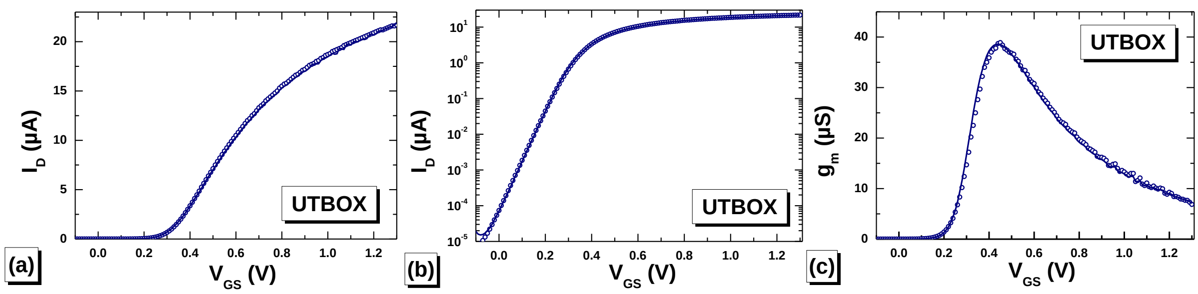

Figure 2: I_D *vs.* V_{GS} in linear scale (a) and log-lin scale (b); (c) g_m *vs.* V_{GS}; Good agreement between the experimental (symbols) and the model (full line) is observed.

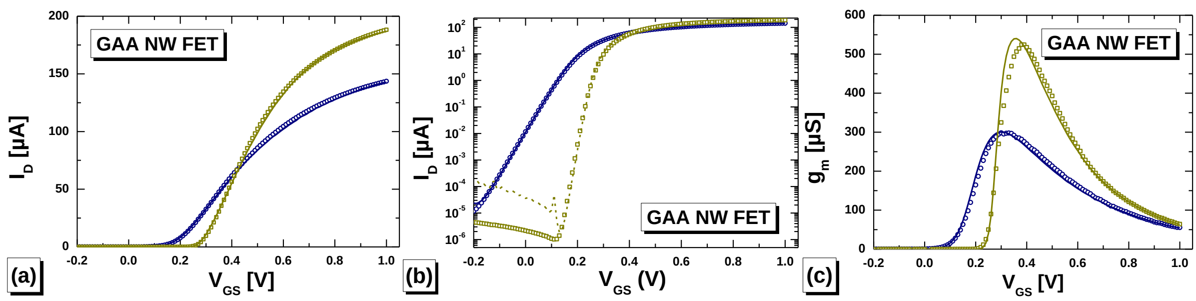

Figure 3: I_D *vs.* V_{GS} in linear scale (a) and log-lin scale (b); (c) g_m *vs.* V_{GS}, Good agreement between the experimental (symbols) and the model (full line) can be observed. circle points represent 300 K, square points represent 80 K temperature operation. GAA NS FET device: L / W = 100 nm / 2288 nm, EOT of 0.9 nm; vertical distance between the stacked nanosheets 7.5 nm.