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A New Analytical Model for Improving Sub-threshold Conduction of MOSFETs

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The sub-threshold current conduction in MOSFETs has already been discussed in a great detail in literature. Improvement of sub-threshold current slope of MOS devices still remains a concern due to static power dissipation in dynamic circuits and standby CMOS power consumption. Here, we propose a long channel MOSFET structure with larger effective channel thickness and a mathematical model to represent it, which reduces the magnitude of sub-threshold current to pico ampere level. However, inclusion of oxide charges, mobile ions and interfacial traps increase it to nano ampere range.

The diffusion current through the channel in sub-threshold region of operation can be derived into the following equation [1],

$$I_D = \frac{W}{L} x_d \mu_n kT n_{po} e^{\beta\psi_s}(1-e^{-\beta v_D}) \qquad (1)$$

Where, β is equal to $\frac{kT}{q}$, v_D is the drain voltage, ψ_s is the surface potential, x_d is the effective channel thickness and all other parameters bear the usual meaning found in the literature.

To find out the relation between potential and depletion depth, at first 1-D Poisson equation is solved at the surface charge region. The solution gives potential as a function of the distance along the depth of the depletion region (fig.1). A tangent is drawn in fig. 1 at $x=0, \psi=\psi_s$. It is assumed that the intersection of the tangent with x axis is the effective channel thickness which is larger than the previous assumption in [1]. Substituting the new effective channel thickness in (1), current is found to be,

$$I_D = \frac{W}{L}\mu_n kT n_{po} e^{\beta\psi_s}(1-e^{-\beta v_D})\psi_s\varepsilon_s \cdot \frac{\left[2\left(\frac{\psi_s}{\beta}+e^{\beta\psi_s}+j\right)\left(1+e^{\beta\psi_s}\right)\beta e^{\beta\psi_s}-\left(1+e^{\beta\psi_s}\right)^2\left(\frac{1}{\beta}+\beta e^{\beta\psi_s}\right)\right]}{b(1+e^{\beta\psi_s})^4\beta q} \qquad (2)$$

Where, $\frac{p_{po}e^{-\beta\psi_s}-n_{po}e^{\beta\psi_s}}{\left(n_{po}-p_{po}\right)}-\beta\psi_s = j$

and $\sqrt{\frac{\varepsilon_s}{2q}}\frac{2}{\sqrt{\beta}}\frac{1}{\left(1+e^{\beta\psi_s}\right)}\sqrt{\frac{\psi_s}{\beta}+e^{\beta\psi_s}+j} = b.$

The resultant sub-threshold current is shown in fig. 2. Effects of fixed oxide charge, mobile ion [2] and interfacial traps [3] are included in (2) because $V_{GB}=\psi_s+\psi_{ox}+\phi_{MS}$. V_{GB} is replaced by $V'=V_{GB}+\Delta V_{GB}$, where ΔV_{GB} accounts for changes in gate voltage due to non-ideal effects [2]. Fig. 3 shows the comparison between sub-threshold conduction in ideal and non–ideal MOSFET. Changes in V_{GB} due to oxide charges, mobile ions and interfacial traps are calculated from corresponding formulas[2-3].

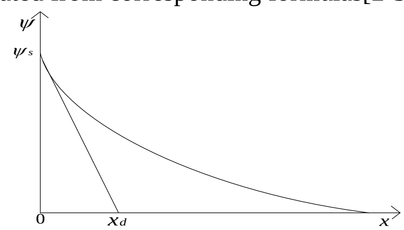

Fig.1. Potential vs. depletion width curve

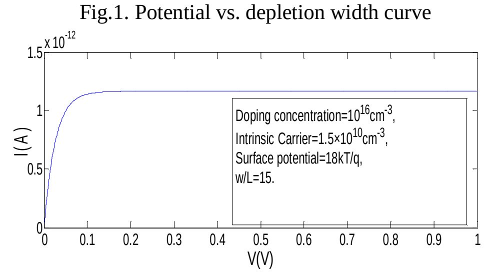

Fig.2. Sub-threshold Current Vs. drain voltage

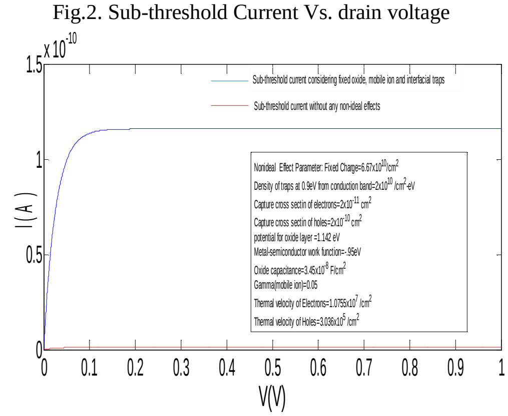

Fig. 3.Sub-threshold conduction at ideal and non-ideal condition vs. drain voltage

References

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[2] R. Pierret, Semiconductor Device Fundamentals, pp. 650-662, Pearson Education.
[3] *Atlas User's Manual*, 1st ed, Silvaco International, Santa Clara, CA.