Vertical Silicon-on-Nothing FET: Threshold Voltage Calculation Using Compact Capacitance Model

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The silicon-on-nothing (SON) technology promises improved short-channel performance for ultra-scaled CMOS, without the added cost of the UTB SOI wafers [1]. The vertical fully-depleted SON concept (VFD SONFET) demonstrates the vertical SON structure, using the active transistor region grown on the sidewall of the Si/SiGe/Si stack with subsequent highly-selective SiGe removal [2]. As well as the improved SCE, the standard bulk region is eliminated in the VFD SONFET, making it a three-terminal device [Fig. 1 (a)] with well-controlled dimensions by the thickness of the grown layers [Fig. 1 (b)]. The absence of the transistor bulk is a unique property of the VFD SONFET, not present in either bulk or SOI CMOS, and the compact capacitance model is developed to describe the two-dimensional nature of this fully-depleted MOS structure. The calculation of the threshold voltage (V_{th}) using the compact model is presented in this paper.

The capacitance components of the VFD SONFET in the subthreshold region are shown in Fig. 2 [3]. Intrinsic capacities include the capacitance of the depleted silicon body $C_{Si,d}$, gate oxide capacitance $C_{GOX}=k_{GOX}L_{eff}/t_{GOX}$, and buried oxide capacitance $C_{BOX}=2k_{BOX}\ln(1+L_{eff}/2d_{BOX})/\pi$. The buried oxide capacitance C_{BOX} of the VFD SONFET has specific, two-dimensional properties and its analytical relation is given with an approximation by perpendicular planes. For the effective channel lengths that are $t_{BOX} < L_{eff}/2$ analytical relation is $C_{BOX}=2k_{BOX}\ln(1+t_{BOX}/d_{BOX})/\pi$. Overlap, fringe and source/drain depletion capacitances are also included in Fig. 2, but do not have significant influence on the V_{th}. Equivalent capacitive circuit of the VFD SONFET in the subthreshold region is shown in Fig. 3, where V_{FB1} and Ψ_{s1} are the top-gate flat-band voltage and potential, and V_{FB2} and Ψ_{s2} are the back-gate flat-band voltage and potential.

The voltage-doping transformation (VDT) is used for the short-channel effects modeling [4]. According to the VDT, the effective channel doping is $N_A^*=N_A-k_{Si}2V_{DS}^*/(qL_{eff}^2)$, where $V_{DS}^*=V_{DS}+2(V_{bi}+\Psi_{s2}-\Psi_{s1})\pm2\sqrt{[(V_{bi}+\Psi_{s2}-\Psi_{s1})(V_{DS}+V_{bi}+\Psi_{s2}-\Psi_{s1})]}$. The silicon body capacitance with short channel effects (VDT) taken into account is $C_{Si,d}^*=qN_A^*t_{Si}L_{eff}/(\Psi_{s1}-\Psi_{s2})$, where $\Psi_{s2}=qN_At_{Si}L_{eff}/C_{BOX}$. The threshold voltage is determined from the strong inversion criterion $\Psi_{s1}=2\Psi_b$, where $\Psi_b=V_T\ln(N_A/n_i)$. From the equivalent capacitive circuit, V_{th} can be extracted as:

$$V_{th}=V_G\big|_{\Psi_{s1}=2\Psi_b}=V_{FB1}+2\Psi_b\left(1+\frac{2C_{Si,d}^*C_{BOX}}{C_{GOX}\left(C_{Si,d}^*+2C_{BOX}\right)}\right)-V_{DS}\frac{C_{Si,d}^*C_{BOX}}{C_{GOX}\left(C_{Si,d}^*+2C_{BOX}\right)}+2V_{FB2}\frac{C_{Si,d}^*C_{BOX}}{C_{GOX}\left(C_{Si,d}^*+2C_{BOX}\right)}$$

where $V_{FB1}=V_T\ln(N_GN_A/n_i^2)$ and $V_{FB2}=V_T\ln(N_{S\text{-}D}N_A/n_i^2)$.

The calculated V_{th} values are compared to the results of the two-dimensional, drift-diffusion model simulations in MEDICI [5]. In Fig. 4, calculated and simulated threshold voltage values are plotted against L_{eff} for different t_{GOX} (a), channel concentrations (b), BOX dielectrics (c), and BOX thicknesses (d). Good agreement between our model and MEDICI data is achieved for L_{eff} down to 50 nm, with differences less than 5 mV (2 %). For L_{eff} below 50 nm, compact model loses accuracy due to rough approximation of the effective doping in the channel area N_A^*, which affects the calculated silicon body capacitance $C_{Si,d}^*$.

References

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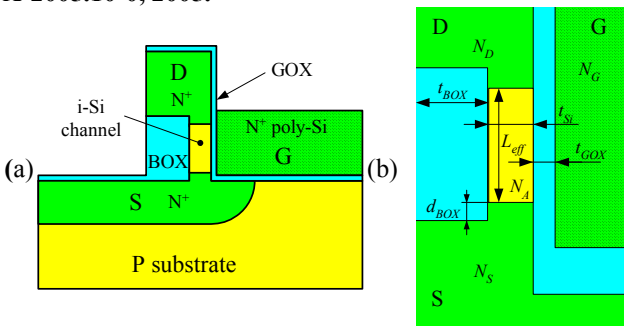

Fig. 1. (a) VFD SONFET structure cross-section, (b) VFD SONFET structure close-up.

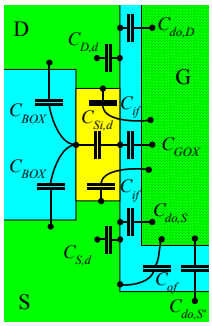

Fig. 2. Capacitive model of the VFD SONFET in subthreshold region.

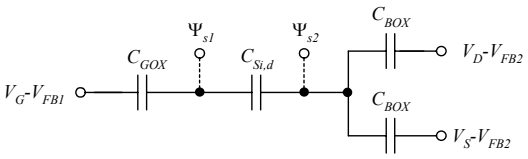

Fig. 3. Equivalent capacitive circuit of the VFD SONFET in subthreshold region.

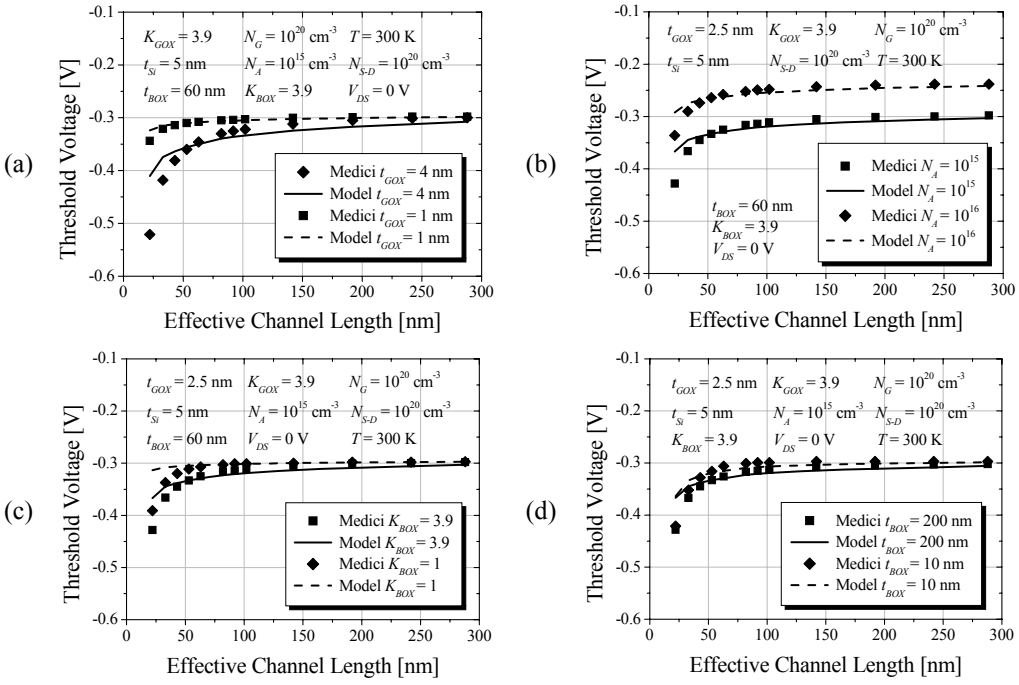

Fig. 4. Dependence of threshold voltage on: (a) t_{GOX}, (b) N_A, (c) K_{BOX}, (d) t_{BOX}.