where $\lambda = \sqrt{\frac{\varepsilon_s t_{ox} d_s}{\varepsilon_{ox}}}$.

The lowest order approximations for the potential solution ψ in the regions S and D are given by $\psi = \Psi_S$, and $\psi = \Psi_D$, respectively.

The threshold voltage V_{th} is obtained from the condition that the minimum of the surface potential in B is equal to twice of the hole Fermi potential ψ_B. The expression for V_{th} is

$$V_{th} = V_{FB} + 2\psi_B + \frac{qN_A t_{ox} d_s}{\varepsilon_{ox}}$$

$$-2\sqrt{\left(\Psi_S - 2\psi_B\right)\left(\Psi_D - 2\psi_B\right)}\exp\left(-\frac{L_c}{2\lambda}\right)$$

III. COMPARISON WITH NUMERICAL SIMULATION

The present model is derived under the assumptions mentioned above. Now we examine how well it agrees with two-dimensional numerical results from a simulator. We calculated V_{th}-L_c characteristics for cases with t_{ox}, d_s =1,3,5,7,10nm and N_A=10^{16},10^{17},10^{18} cm^{-3} (that is, 5x5x3=75 cases). We don't stick to the assumptions used in the derivation, expecting agreement in wider range of parameters. Threshold voltage is defined as a gate voltage for which the drain current is equal to $10^{-11}W/Lc$ [A] , where W is the channel width. An example of V_{th}-L_c characteristics is shown in Fig.2.

We tried to fit these curves with an expression $V_{th} = V_{th0} - K_1 \exp(-L_c / K_2)$ with fitting parameters V_{th0}, K_1 and K_2. The short channel effect is determined by parameters K_1 and K_2. To extract these parameters properly, an expression

$$\log\frac{dV_{th}}{dL_c} = \log\frac{K_1}{K_2} - \frac{L_c}{K_2}$$

is used. $\log\left(dV_{th}/dL_c\right)$ vs. L_c relation is linear and therefore the regression analysis to obtain K$_2$ is efficiently carried out.

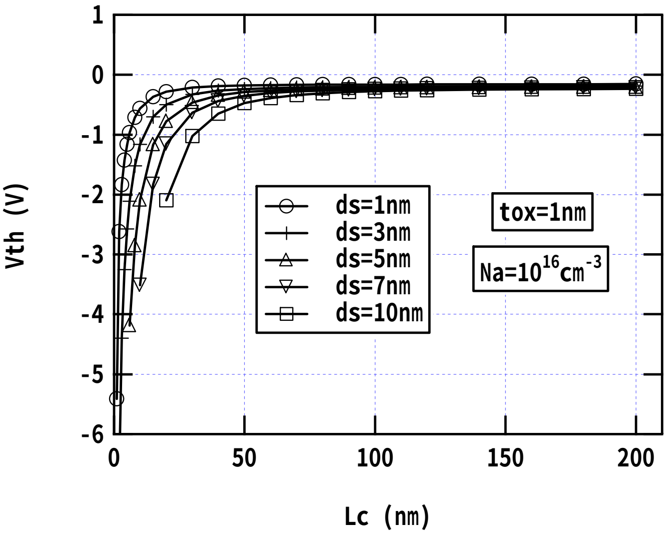

Fig.2 V_{th}-L_c curves obtained by numerical simulation.

Examples of fitting using regression analysis are shown in Fig.3. Set of parameters V_{th0}, K_1 and K_2 were obtained for all the devices. The parameter K_2 corresponds to twice of characteristic length λ [1], [2].

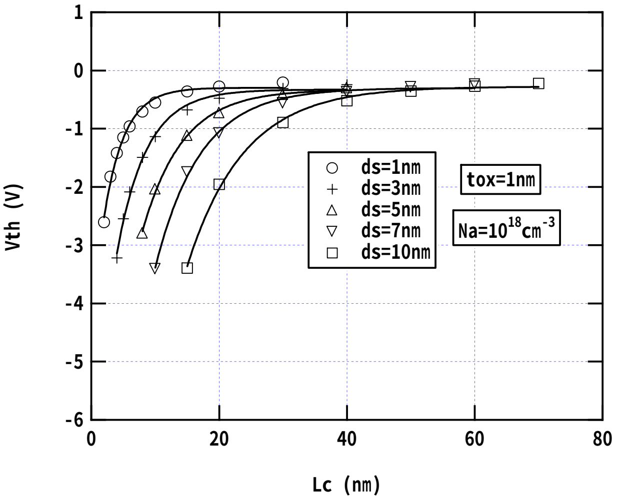

Fig.3 Regression analysis to obtain parameters V_{th0}, K_1 and K_2.

For d_s =1nm, K$_2$ agrees very well with 2 λ as a function of t_{ox} as shown in Fig.4. This is reasonable considering that d_s is assumed to be very small, of the order of μ^2, in the derivation of the model. However, the values of K_2 for t_{ox} and d_s larger than 3 nm does not agree well with 2 λ. In Fig.4 , the extracted values of K$_2$ are compared with 2 λ multiplied by a fitting parameter 2/3.

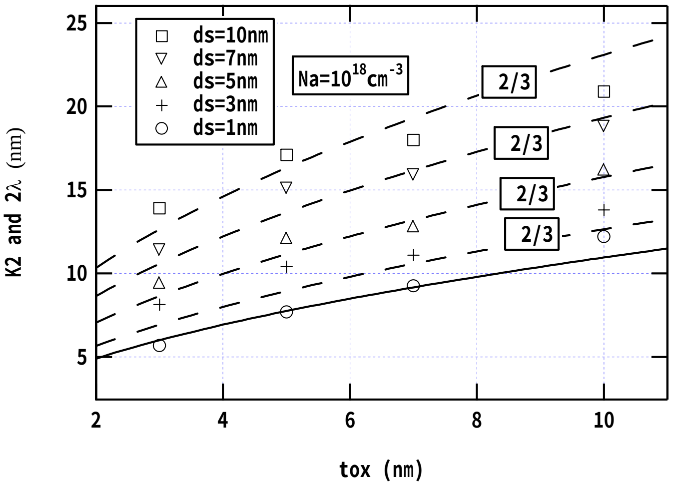

Fig.4 Comparison of K_2 with 2λ and 2 λ *2/3 (λ: characteristic length).

Thus, the threshold voltage for devices with t_{ox} and d_s larger than 3 nm is expressed by

$$V_{th} = V_{th0} - K_1 \exp(-3L_c / 4\lambda) .$$

Extracted values of V_{th0} are shown in Fig.5. They align well with the lines expressing the relation obtained above

$$V_{th0} = const. + qN_A t_{ox} d_s / \varepsilon_{ox} .$$

Threshold voltages numerically obtained and the model $V_{th} = V_{th0} - K_1 \exp(-3L_c / 4\lambda)$ are compared in Fig.6. Agreement between them is satisfactory.

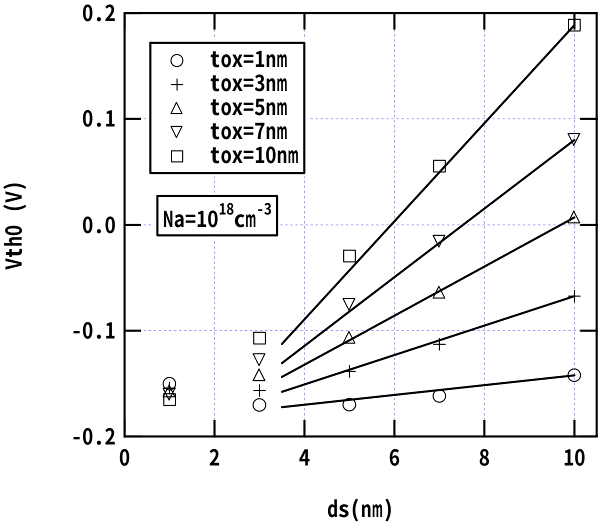

Fig.5 V_{th0} showing dependence on $qN_a t_{ox} d_s / \varepsilon_{ox}$.

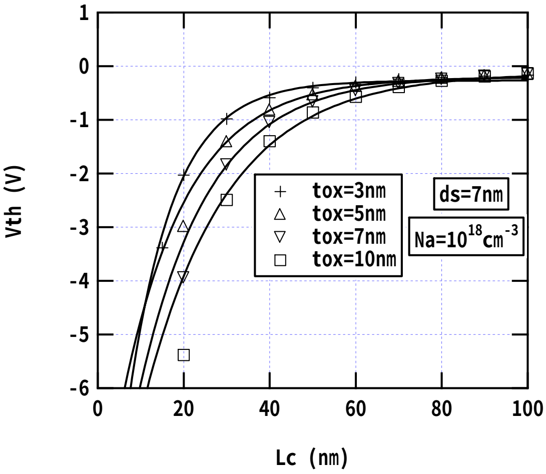

Fig.6 Comparison between the compact model and numerical results.

IV. CONCLUSIONS

The asymptotic analysis with the boundary function method is applied to the MOS device modeling. Potential distributions in SOI MOSFETs with very thin Si top layers are obtained analytically by the asymptotic method, and the compact model of threshold voltage is derived. The model is verified through the comparison with numerical results.

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