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Modeling & Analysis of Surface Potential and Threshold Voltage for Narrow channel 3D FDSOI MOSFET

Prashant Mani* Manoj Kumar Pandey**

Abstract : This paper represents the analysis of surface potential and Threshold voltage for Narrow width channel effect in fully depleted SOI MOSFET. The effect of ultrathin narrow width of channel on device parameters like gate to source voltage and varying doping profile considered while the other device parameters were same .The device shows better in case of higher density IC's requirement .

Keywords : Narrow channel, Fully depleted, SOI, channel width, threshold voltage.

1. INTRODUCTION

The scaling of the device today reaches beyond the limit of regime where the parasitic effect raises badly in MOSFETs. To prevent the degradation of the device the SOI technology plays a key role and results of SOI technology are as per expectation. The Fully Depleted SOI MOSFET is a most widely used in Modern electronics system .The SOI MOSFET's are advantageous over their bulk-silicon counterparts in terms of short channel-induced threshold voltage reduction [1]. Short Channel Effect and Drain induced Barrier Lowering, Hot electron Effect, Threshold roll off are some problems that to be addressed. The solution came in the form of various modeling developed in a process of Device Development. The analytical model for the channel potential and the threshold voltage of a silicon-on-insulator MOSFET with shallow source/drain (S/D) junctions due to electrically induced was discussed to investigate the short-channel effects (SCEs) [2]. The model was developed by using a two-dimensional (2-D) Poisson's equation, and considering the source/drain resistance and the self-heating effect [3]. Further a new complete short channel SOI MOSFET I-V model for circuit simulation developed. This unified model is applicable for Fully Depleted, Partially Depleted, and mixed-mode SOI MOSFET's [4]. The various methods to solve 1D, 2D analysis of SOI MOSFET were very interesting areas for work [5]-[11]. In present model, Ultra thin 3D SOI MOSFET's the reduction in threshold voltage due to the suppression of Short-Channel Effect (SCE) by decreasing silicon film thickness (t_{si}). The analytical models for short-channel SOI MOSFETs discussed taking into account the scaling of the channel length and SOI film thickness but unable to take into account the narrow width effects, which become effect less as the width of the transistor is reduced. [12]

2. MODEL FORMATION

The fig. 1 represents the channel width of MOSFET is W, the side wall thickness is represented by *toxw* .The side wall interface junction located at $z = 0$ and $z = W$. We are considering effect of narrow channel width effect in the fully Depleted SOI MOSFET. The channel width of MOSFET is W, the side wall thickness is represented by *toxw* .The side wall interface junction located at $z = 0$ and $z = W$. Analysis of the MOSFET. We are considering the Narrow channel fully Depleted SOI MOSFET.The 3D poisson's equation for FDSOI MOSFET is given by equation.

* Department of Electronics and Communication Engineering SRM University, Ghaziabad,U.P.India Email- prashantmani29@gmail.com
** Department of Electronics and Communication Engineering SRM University, Ghaziabad,U.P.India Email- director@ncr.srmuniv.ac.in

$$\frac{\partial^2\Phi(x,y,z)}{\partial x^2}+\frac{\partial^2\Phi(x,y,z)}{\partial y^2}+\frac{\partial^2\Phi(x,y,z)}{\partial z^2} = \frac{qN_A}{\varepsilon_{si}} \tag{1}$$

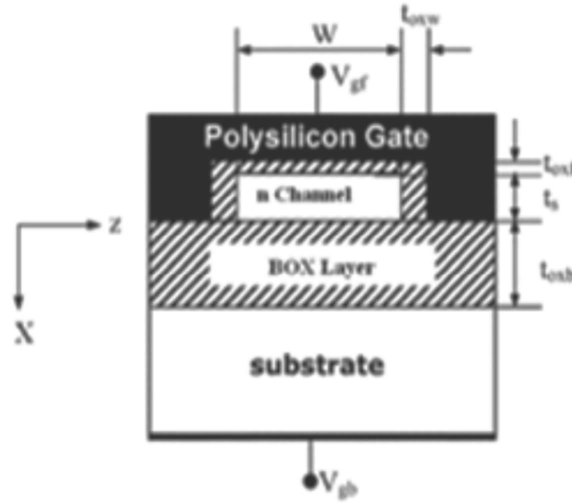

Fig. 1. The cross section of (x-z) Narrow channel FDSOI MOSFET

The solution of 3D poisson's equation is calculated by solving it by the method of separation of variable. The separation of variable method the 3D Poisson's explained in three steps.

1. Convert 3D poisson's equation in to 1D Poisson's equation.
2. Three 3D Laplace transform
3. 2D Laplace transform

Solution of above all added and the outcome of addition of solutions represents the solution of 3D poisson's equation.

As in our previous research work the calculation of surface potential equation [1] for channel length done. We extend our work in calculation of surface potential with normalized channel width in case of narrow channel FD SOI MOSFET.

3. MODELLING OF SURFACE POTENTIAL AND THRESHOLD VOLTAGE FOR NARROW CHANNEL FD SOI MOSFET

Solution of 3D possion's equation calculated as described above. The solution of 1D poisson's for appropriate boundary condition's given as

$$\varphi l(x)-\frac{t_{oxf}}{\varepsilon_{ox}}\left[\varepsilon_{si}\frac{d\varphi l(x)}{dx}\Big|_{x=0}-Q_{it}^{t}\right] = V_{gf}-V_{fb}^{f}$$

$$\varphi l(t_{si})+\frac{t_{oxf}}{\varepsilon_{ox}}\left[\varepsilon_{si}\frac{d\varphi l(x)}{dx}\Big|_{x=tsi}-Q_{it}^{b}\right] = V_{gf}-V_{fb}^{f}$$

$$\varphi l(x) = \varphi_{sb}+E_{sb}(t_{si}-x)+\frac{qN_A}{2s_{si}}(ts-x) \tag{2}$$

The solution of 2D laplace equation with appropriate boundary condition given as

$$\varphi'(xy)-\frac{t_{oxf}}{\varepsilon_{ox}}\left[\varepsilon_{si}\frac{d\varphi'(x,y)}{dx}\Big|_{x=0}\right] = 0$$

$$\varphi'(x,y)+\frac{t_{oxb}}{\varepsilon_{ox}}\left[\varepsilon_{si}\frac{d\varphi'(x,y)}{dx}\Big|_{x=ts}\right] = 0$$

$$\varphi'(x, 0) = V_{bi} - \varphi l(x)$$
$$\varphi'(X, L_{Eff}) = V_{bi} - \varphi l(x) + Vds = \varphi'(x, y) = \varphi'(x, y)$$
$$= \frac{1}{\sinh \gamma L_{Eff}} \times [V' \sinh \gamma y + V \sinh (\gamma(L_{Eff} - y))] \times \left[\sin(\gamma x) + \frac{\varepsilon_{si}}{\varepsilon_{ox}} t_{oxf} \gamma \cos(\gamma x)\right] \quad (3)$$

The solution of 3D laplace equation with appropriate boundary condition's given as:

$$\varphi''(x, y\, z) - \frac{t_{oxf}}{\varepsilon_{ox}}\left[\varepsilon_{si} \frac{\partial \varphi''(x, y, z)}{\partial x}\Big|_{x=0}\right] = 0$$
$$\varphi''(x, y\, z) + \frac{t_{oxb}}{\varepsilon_{ox}}\left[\varepsilon_{si} \frac{\partial \varphi''(x, y, z)}{\partial x}\Big|_{x=0}\right] = 0$$
$$\varphi''^{(x,\, o,\, z)} = 0$$
$$\varphi''^{(x,\, L_{Eff},\, z)} = 0$$
$$\varphi''(x, y\, w) + \frac{t_{oxw}}{\varepsilon_{ox}}\left[\varepsilon_{si} \frac{\partial \varphi''(x, y, z)}{\partial x}\Big|_{z=W} + Q_{it}^{t}\right] = V_{gf} - V_{fb}^{f} - \varphi l(x) - \varphi'(x, y)$$
$$\varphi''(x, y, z) = M_{sr}[\sinh\{X_{sr} w - z)\} + \sinh(X_{sr} z)] \times \frac{\sin(\alpha_s y - L_{Eff}))}{\cos(\alpha_s L_{Eff})}\left[\sin(x\beta_r) + \frac{t_{oxf}}{\varepsilon_{ox}} \varepsilon_{si} \cos \beta_r x\right] \quad (4)$$

The combination of all solution gives the overall solution of 3D poison's equation.

$$\varphi(x, y, z) = \varphi l(x) + \varphi'(x, y) + \varphi''(x, y, z) \quad (5)$$

The threshold voltage of Narrow channel FD SOI MOSFET is calculated as given below :

In this section modeling of threshold voltage is represented for narrow width FD SOI MOSFET .The front gate Threshold voltage (V_{TF1}) of narrow width SOI MOSFET is defined as

$V_{TF1} = V_{gf}$ when $\varphi(0, y_{\min}^{f}, W) = 2\phi_b$ here $y_{\min}^{f}$ is the position of surface potential in lateral direction. By differentiating the equation (5) with respect to y at $x = 0$ and $z = W/2$. Solving the equation, the solution came in form.

$$V_{TFO} = y_{FB}^{f} + 2\Phi b + \frac{Q_{it}^{t}}{C_{oxf}} + \frac{\varepsilon_{si}}{C_{oxf}} \frac{d\varphi l(c)}{dx}\Big|_{x=0}$$
$$= y_{FB}^{f} + \left(1 + \left(\frac{C_s + C_{it}^{r}}{coxf}\right) 2\Phi b\right) - \frac{C_S}{C_{oxf}} \varphi_{sb} + \frac{qN_A t_s}{2\, C_{oxf}}$$

4. RESULTS & DISCUSSION

Fig. 2 represents the surface potential changes with channel length. At source side the surface potential starts increase at drain to source voltage 1.0(V) and increase just double at the drain side due to reduced DIBLof the device. Between the source and drain i.e. the mid of channel the constant value of surface potential increasing towards drain side. Our results better match with simulated data Fig. 3 shows the surface potential variation with mid position along the channel length. In the mid of the channel the surface potential at the source side increases slightly and in the drain side abruptly. The drain to source voltage kept same in previous case.

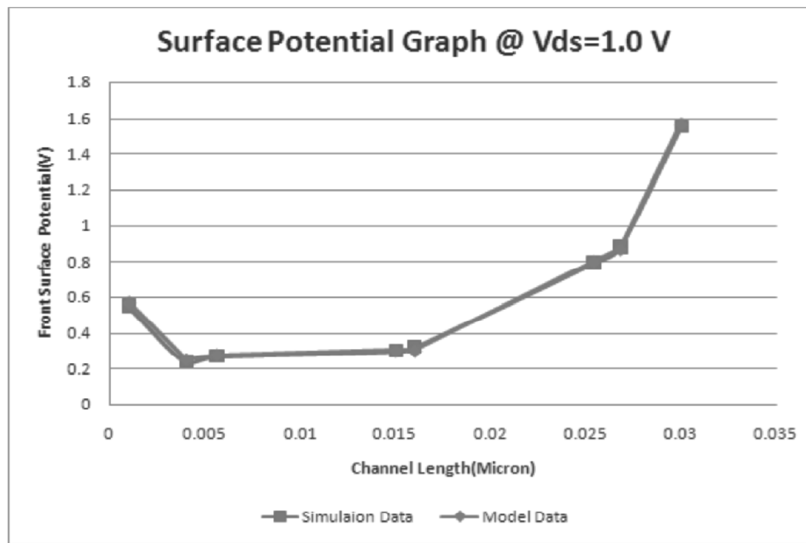

Fig. 2. Channel potential variation with various positions along the channel length.

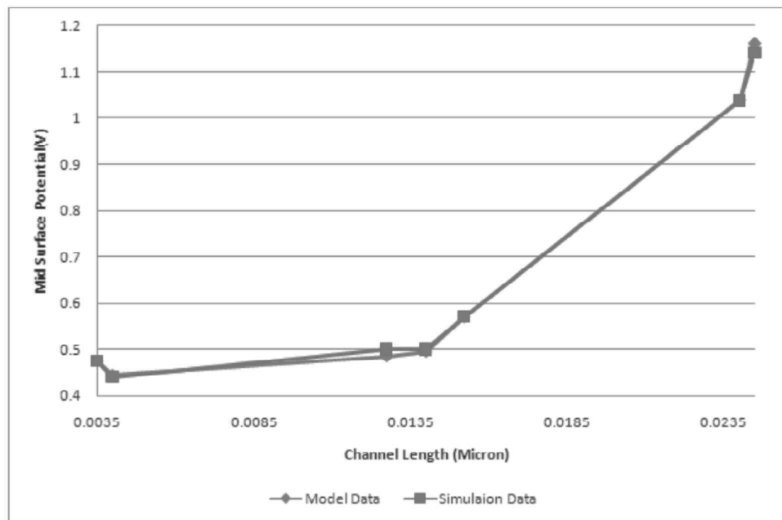

Fig. 3. Change in mid of Channel potential with mid position along the Channel Length.

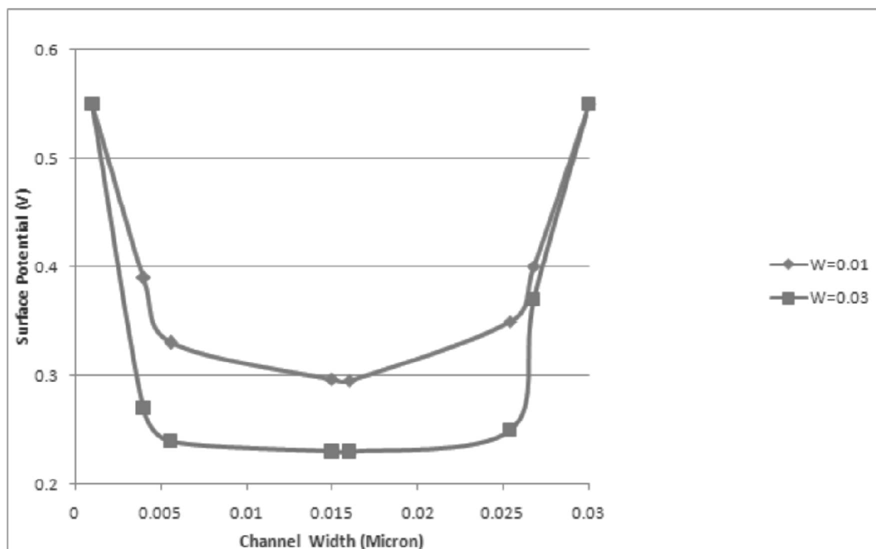

Fig. 4. Channel potential changes with various position along the channel width.

Fig. 4 shows the surface potential changes with various positions along the channel width. At $w = 0.01$ and $w = 0.05$ the surface potential calculated. Surface potential at $z = 0$ and $z = 0.01$ and $z = 0.05$ same we got. But decreased and increased near the device end. The surface potential at the mid of channel in z direction found constant and minimum.

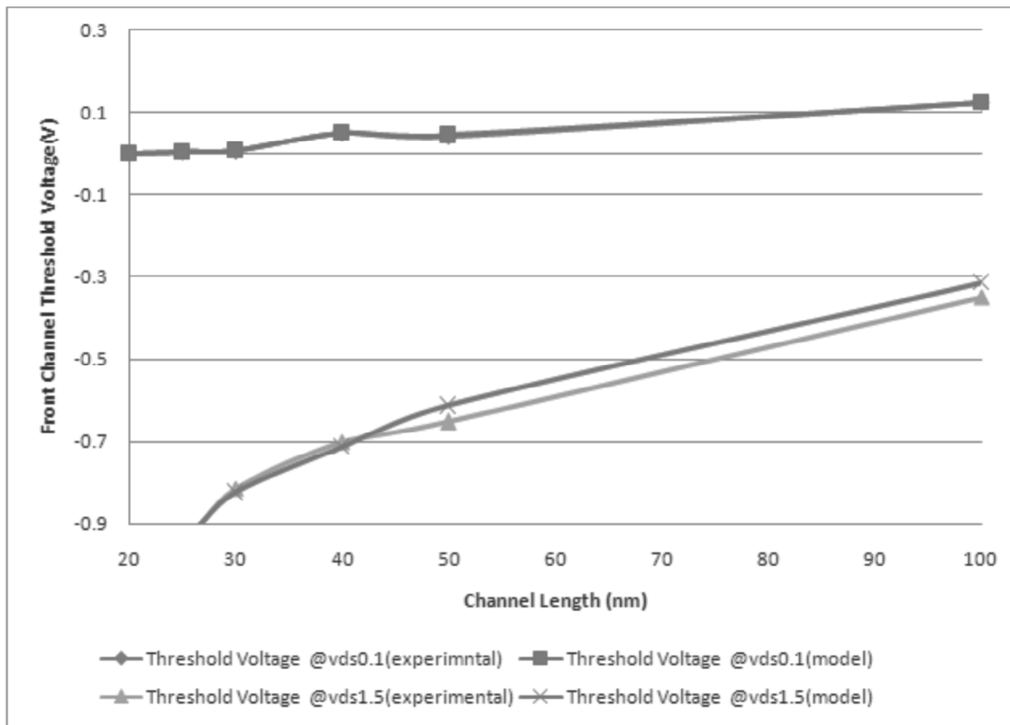

Fig. 5. Comparison of Front channel Threshold Voltage with V_{ds} = 0.1V and V_{ds} = 1.5 V.

Fig.5 Shows the front channel threshold voltage along the channel length at varying drain to source voltage.

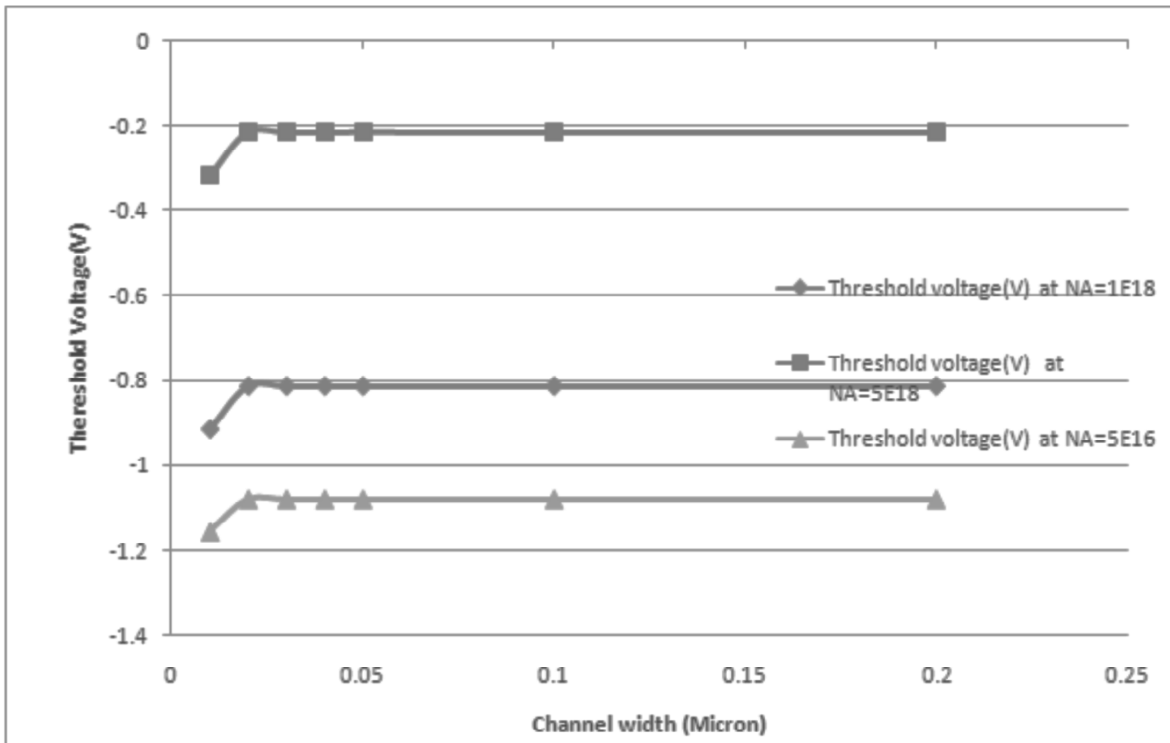

Fig. 6. Threshold voltage Variation along the channel width with L_{Eff} = 0.03 μm, V_{ds}=1.5 V for varying doping profile.

Fig.6 shows the threshold voltage variation along the channel width.As the doping profile reduced the threshold voltage increase and in case of narrow channel at N_A=1E18, 5E18, 5E16. So in case of narrow channel the negative threshold voltage we found in case of doping profile.

5. CONCLUSION

The proposed model has been accurately matched by the results achieved by ATLAS 3-D device simulator. The MOSFET having gate length 30nm and narrow channel width 25 nm and 50 nm have been simulated, while considering all other device parameters remain unchanged. The other various device parameters are as follows: $t_s = 15$ nm, $t_{ox} = 3nm$, $N_A = 1 \times 18$ cm^3. The out come of surface potential shows the changes of channel potential with the various channel position for channel length 30 nm and $V_{ds} = 0.5\ v$. The Short Channel Effects suppressed and due to this the channel barrier is decreased. The effect of varying channel width in suppression of SCE in device. The threshold voltage of the narrow channel device reduced as the channel length of the device reduced at Nano scale *i.e.* $L_{Eff} = 30$ nm. The thickness of the width also plays a key role in reduction of threshold voltage.

6. ACKNOWLEDGEMENT

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