Parameter Extraction for BSIMSOI4.3 MOSFET Model

Mrs.M.Muthulakshmi, Mrs.L.Sheela

Abstract— This paper provides the extracted values of the parameters affecting the threshold voltage model of SOI MOSFET. The parameter extraction is done for BSIMSOI4.3 MOSFET model. The proposed procedure is designed to give the results based on the device characteristics data. Simulations are performed using the extracted parameters and finally it is compared for extracted parameters and generic device parameters. The effect of body bias voltage on the threshold voltage is studied by using the extracted values. Finally we summarize the work with accurate study of extracted parameters in depicting their effect on the characteristics of device.

Index Terms— Body bias effect, BSIM, BSIMSOI, DIBL, Extraction Methodology, MOSFET, Threshold voltage.

1 INTRODUCTION

SEEMICONDUCTOR devices have various models that satisfy the behaviour of the device at different operating conditions. Each model has its uniqueness that describes the physical phenomena of the device. The process of obtaining parameters by minimizing the difference between the measured parameter and the modelled parameter at different bias value is called parameter extraction. Parameter extraction is a crucial and difficult step for circuit and device simulation. The parameters may be technological or electrical or adjusting type. The models need to provide accuracy in reproducing the I-V characteristics. The most compact MOSFET model available considering all the effects due to the reduction in transistor dimensions is BSIMSOI4.3 [5].There are two ways of obtaining these parameters namely "gradient based method" and "optimization method". In the gradient based method the parameters are extracted one by one. In the optimization method all the parameters are determined at the same time [2], [8], [9].

We have considered the least mean square (LMS) method, because any physical parameter can be studied as a function of technology or operating conditions, which characterize the device. Threshold voltage is an important factor for determining the logical function of the circuit. Hence, the threshold voltage is a fundamental parameter for MOSFET modelling and characterization.

Suayb Yener [1], has designed parameter extraction algorithm from BSIM3v3 MOSFET model equations. BSIM3v3 models the bulk MOSFET characteristics. They have considered the BSIM3v3 complete threshold voltage model and the Mobility model.

- *Mrs.M.Muthulakshmi is currently pursuing masters degree program in Embedded Systems Technologies in Anna University of Technology-Tirunelveli, India. E-mail:lakshmingm.2@gmail.com*
- *Mrs.L.Sheela is currently working as an Assistant Professor in Anna University of Technology-Tirunelveli, India. E-mail:l_sheela79@yahoo.com*

In our current work, we provide an analytical parameter extraction methodology to extract all the parameters in the BSIMSOI4.3 threshold voltage model. Recently in MOSFET fabrication SOI process technology is being used to reduce parasitic bipolar effects or drain induced barrier lowering. Another advantage of SOI process technology is reduction of overlap capacitance of gate with drain, source and body regions.

Session2 provides briefly the complete BSIMSOI4.3 threshold voltage model used for parameter extraction. Session3 presents the parameter extraction strategy and procedure, process input parameters, extraction steps and the derived extraction equations. Session4 tabulates the extracted parameter values. Session5 discusses in detail, the simulation results obtained for general and extracted parameters.

2 COMPLETE BSIMSOI4.3 THRESHOLD VOLTAGE MODEL

Accurate modelling of threshold voltage is one of the most important requirements for precise description of device electrical characteristics. In addition, it serves as a useful reference point for the evaluation of device operation regimes. By using threshold voltage, the whole device operation regime can be divided into three operational regions: strong inversion region, weak inversion region and transition region. Complete threshold voltage model considers all the physical mechanisms like non-uniform doping effect, short channel and narrow channel effects and is given by (1).

In the (1) [3], the first term represents the V_{th} for V_{bs}=0V, the second and third terms consider the vertical non-uniform doping effect, the fourth term represents the lateral non-uniform doping effect, narrow width effect is considered in the fifth term, the sixth term models the small size effect in devices due to both small channel length and small width, the seventh and the eighth term are related to short channel effect and DIBL and the last term are used to model the pocket formation due to the lateral non-uniform doping effect.

$$V_{th} = V_{th0} + \left(K_{1ox} sqrtPhisExt - K_{1eff}\sqrt{\varphi_s}\right) \sqrt{1+\frac{LPEB}{L_{eff}}} - K_{2ox}V_{bseff} + K_{1ox}\left(\sqrt{1+\frac{LPE0}{L_{eff}}}-1\right)\sqrt{\varphi_s}$$
$$+(K_3+K_{3b})\frac{T_{ox}}{W_{eff}+W_0}\varphi_s -$$
$$D_{VT0W}\left(e^{-D_{VT1W}\frac{W_{eff}L_{eff}}{2l_{tw}}} + 2e^{-D_{VT1W}\frac{W_{eff}L_{eff}}{l_{tw}}}\right)(V_{bi}-\varphi_s)$$
$$-D_{VT0}\left(e^{-D_{VT1}\frac{W_{eff}L_{eff}}{2l_t}} + 2e^{-D_{VT1}\frac{W_{eff}L_{eff}}{l_t}}\right)(V_{bi}-\varphi_s)$$
$$-\left(e^{-D_{sub}\frac{L_{eff}}{2l_{t0}}} + 2e^{-D_{sub}\frac{L_{eff}}{l_{t0}}}\right)(E_{ta0}+E_{tab}V_{bseff})V_{ds}$$
$$-nv_t\frac{L_{eff}}{L_{eff}+DVTP0(1+e^{-DVTP1V_{DS}})}$$
$$-\frac{DVTP2}{L_{eff}{}^{DVTP3}}\tanh(DVTP4.V_{DS}) \qquad (1)$$

3 PARAMETER EXTRACTION ALGORITHM

Extraction methodology depends on the model and the way the model is being used [4]. Two different strategies are available for extracting parameters: single device and group device extraction strategy. Single device extraction strategy will fit only one device and will not fit devices with different geometries and does not consider the physical dependencies. BSIMSOI4.3 uses group extraction strategy since this overcomes the drawbacks of single device extraction strategy. All devices of the group are measured under same bias conditions.

Here we extract the parameters for a large size device and two small size devices. Large size devices are used to extract parameters independent of short channel and narrow channel effect. The set of devices with a fixed large channel width but different channel lengths are used to extract parameters related to the short channel effect. Similarly, the set of devices with a fixed, long channel length but different channel widths are used to extract parameters related to the narrow width effect.

3.1 Prerequisite Process Input Parameters

We consider non-uniformly doped silicon channel with gate oxide thickness T_{ox} in order of nm. We consider different channel doping concentration N_{ch}, source and drain doping concentration N_{DS}. Also, the mask level channel length and width are chosen in order of nm.Parameters are extracted for the transistor, operated at specific room temperature. Before the extraction of the model parameters, we need to provide the process parameters. The extracted parameters require above process parameters for its extraction strategy.

TABLE 1
PARAMETER EXTRACTION STEPS

Extracted Parameters	Device Geometries	Experimental Characteristics
VTH0, K1, K2	Large size devices (Large W~4000nm and Large L~1000nm)	Ids-Vgs @ Vds=50mV, Vbs parameter (0 to -5V)
LPEB, LPE0, DVT0, DVT1, DVT2	Large fixed W and small different L devices (500 to 300nm)	Ids-Vgs @ Vds=50mV, Vbs parameter (0 to -5V)
K1W1, K1W2, K3, K3b, W0	Large fixed L and small different W devices (1000 to 600nm)	Ids-Vgs @ Vds=50mV, Vbs parameter (0 to -5V)
DVT0W, DVT1W, DVT2W	Small different L (500 to 300nm) and small different W devices (1000 to 600nm)	Ids-Vgs @ Vds=50mV, Vbs parameter (0 to -5V)
Dsub, Eta0, Etab	Large fixed W and small different L devices (500 to 300nm)	Ids-Vgs @ Vds=5V, Vbs parameter (0 to -5V)
DVTP0, DVTP1, DVTP2, DVTP3, DVTP4	Large fixed W and small different L devices	Ids-Vgs @ Vds=5V, Vbs parameter (0 to -5V)

The different device geometries and bias conditions used in the extraction procedure are given in TABLE 1.

3.2 Extraction Equations

The parameters are extracted from the (1), by splitting it according to the required criteria.

3.2.1 Parameters representing Body Bias Effect:

For extracting the parameters representing body bias effect [7]: K1, K2, K1w1, K1W2, LPEB, LPE0 we consider the following (2).

$$\left(K_{1ox} sqrtPhisExt - K_{1eff}\sqrt{\varphi_s}\right)\sqrt{1+\frac{LPEB}{L_{eff}}} - K_{2ox}V_{bseff} + K_{1ox}\left(\sqrt{1+\frac{LPE0}{L_{eff}}}-1\right)\sqrt{\varphi_s} = V_{th} - V_{th0} \qquad (2)$$

where K1 and K2 accounts for threshold voltage variation in long channel length and width devices with uniform substrate doping concentration.

In some technologies, [16] the doping concentration near the source or drain is higher than that in the middle of the channel, referred as lateral non-uniform doping. As the channel length becomes shorter, lateral non-uniform doping will cause Vth to increase in magnitude due to increase in the average doping concentration in the channel. The parameter LPEB and LPE0 models the body bias dependence of the lateral non-uniform doping effect. The increase in K1 with decrease in the channel width is captured by K1W1 and K1W2.

3.2.2 Parameters representing Narrow Width Effect:

The parameters for narrow width effect: $\mathbf{K_3}$, $\mathbf{K_{3b}}$, $\mathbf{W_0}$ are extracted using the following (3) and (4) is used to extract the parameters of narrow width effect for small channel lengths: $\mathbf{D_{VT0W}}$, $\mathbf{D_{VT1W}}$, $\mathbf{D_{VT2W}}$.

$$(K_3+K_{3b})\frac{T_{ox}}{W_{eff}+W_0}\varphi_s = V_{th} - V_{th0} - \left(K_{1ox} sqrtPhisExt - K_{1eff}\sqrt{\varphi_s}\right)\sqrt{1+\frac{LPEB}{L_{eff}}} + K_{2ox}V_{bseff} \qquad (3)$$

$$D_{VT0W}(e^{-D_{VT1W}\frac{W_{eff}L_{eff}}{2l_{tw}}} + 2e^{-D_{VT1W}\frac{W_{eff}L_{eff}}{l_{tw}}})\ (V_{bi} - \varphi_s)$$

$$= V_{th0} + (K_{1ox}sqrtPhisExt - K_{1eff}\sqrt{\varphi_s})\sqrt{1 + \frac{LPEB}{L_{eff}}}$$

$$-K_{2ox}V_{bseff} + (K_3 + K_{3b})\frac{T_{ox}}{W_{eff}+W_0}\varphi_s + K_{1ox}$$

$$\left(\sqrt{1 + \frac{LPE0}{L_{eff}}} - 1\right)\sqrt{\varphi_s} - V_{th} \qquad (4)$$

The actual depletion region in the channel is always larger than one-dimensional analysis (considering channel length alone), due to the existence of the fringing fields. This effect becomes very substantial as the channel width decreases [11] and the depletion region underneath the fringing field becomes comparable to the classical depletion layer formed from the vertical field. This results in the increase of the V_{th} with reduction in the channel width, modelled by the parameters K_3 and W_0. K_{3b} describes the body-bias dependence of K_3.

3.2.3 Parameters representing Short Channel Effect:

The extraction of parameters for short channel effect: DVT0, DVT1, DVT2 and DIBL effect: Dsub, Eta0, Etab are done using (5) and (6) respectively.

$$D_{VT0}(e^{-D_{VT1}\frac{W_{eff}L_{eff}}{2l_t}} + 2e^{-D_{VT1}\frac{W_{eff}L_{eff}}{l_t}})\ (V_{bi} - \varphi_s)$$

$$= V_{th0} + (K_{1ox}sqrtPhisExt - K_{1eff}\sqrt{\varphi_s})\sqrt{1 + \frac{LPEB}{L_{eff}}}$$

$$-K_{2ox}V_{bseff} + +K_{1ox}\left(\sqrt{1 + \frac{LPE0}{L_{eff}}} - 1\right)\sqrt{\varphi_s} - V_{th} \qquad (5)$$

$$\left(e^{-D_{sub}\frac{L_{eff}}{2l_{t0}}} + 2e^{-D_{sub}\frac{L_{eff}}{l_{t0}}}\right)(E_{ta0} + E_{tab}V_{bseff})V_{ds}$$

$$= V_{th0} + (K_{1ox}sqrtPhisExt - K_{1eff}\sqrt{\varphi_s})\sqrt{1 + \frac{LPEB}{L_{eff}}}$$

$$-K_{2ox}V_{bseff} + +K_{1ox}\left(\sqrt{1 + \frac{LPE0}{L_{eff}}} - 1\right)\sqrt{\varphi_s} - V_{th}$$

$$-D_{VT0}(e^{-D_{VT1}\frac{W_{eff}L_{eff}}{2l_t}} + 2e^{-D_{VT1}\frac{W_{eff}L_{eff}}{l_t}})\ (V_{bi} - \varphi_s) \qquad (6)$$

In semiconductor fabrication industries the channel length is reduced to increase both the operation speed and the number of components per chip, which in-turn gives rise to short channel effects [10]. Some of the short channel effects are DIBL [6], surface scattering and velocity saturation. In short channel devices the channel length is in the same order of magnitude as the depletion layer widths of the source and drain junction.

3.2.4 Parameters representing non-uniform doping profile:

(7) is used to extract parameters for non-uniform doping profile: DVTP0, DVTP1, DVTP2, DVTP3, DVTP4.

$$nv_t\frac{L_{eff}}{L_{eff} + DVTP0(1 + e^{-DVTP1V_{DS}})} + \frac{DVTP2}{L_{eff}^{\ DVTP3}}tanh(DVTP4.V_{DS})$$

$$= V_{th0} + (K_{1ox}sqrtPhisExt - K_{1eff}\sqrt{\varphi_s})\sqrt{1 + \frac{LPEB}{L_{eff}}}$$

$$-K_{2ox}V_{bseff} + +K_{1ox}\left(\sqrt{1 + \frac{LPE0}{L_{eff}}} - 1\right)\sqrt{\varphi_s} - V_{th}$$

$$-D_{VT0}(e^{-D_{VT1}\frac{W_{eff}L_{eff}}{2l_t}} + 2e^{-D_{VT1}\frac{W_{eff}L_{eff}}{l_t}})\ (V_{bi} - \varphi_s)$$

$$-\left(e^{-D_{sub}\frac{L_{eff}}{2l_{t0}}} + 2e^{-D_{sub}\frac{L_{eff}}{l_{t0}}}\right)(E_{ta0} + E_{tab}V_{bseff})V_{ds} \qquad (7)$$

In recent technologies, the doping concentration near the source and drain is higher than in the middle of the channel, referred to as lateral non-uniform doping. As the channel becomes shorter, lateral non-uniform doping will cause Vth to increase in magnitude.

4 Extracted Parameters

Using the above procedure 22 of unknown BSIMSOI4.3 parameters are extracted, completely describing the threshold voltage of N-type SOIMOSFET by analytical method. The extracted parameter values are given in the (TABLE II).

TABLE 2
EXTRACTED VALUES OF 22 BSIMSOI PARAMETERS

Parameter	Parameter Description	Extracted Value
V_{TH0}	Threshold voltage for long and wide devices @ Vbs=0V	0.65V
K_1	First order body effect coefficient	0.6766 V1/2
LPEB	Lateral non-uniform doping effect on K1	1.7293e-8 m
K_{1W1}	First body effect width dependent parameter	4.779e-9 m
K_{1W2}	Second body effect width dependent parameter	-8.2138e-7 m
K_2	Second order body effect coefficient	-0.0101
LPE0	Lateral non-uniform doping parameter	1.7671e-9
K_3	Narrow width coefficient	84.9416
K_{3b}	Body effect coefficient of K3	2.642 V-1
W_0	Narrow width parameter	4.7379e-7 m
D_{VT0W}	First coefficient of narrow width effect on Vth for small channel length	0.0661
D_{VT1W}	Second coefficient of narrow width effect on Vth for small channel length	7.0096e-4
D_{VT2W}	Body bias coefficient of narrow width effect on Vth for small channel length	-0.3092V-1
D_{VT0}	First coefficient of short channel effect on Vth	-0.0252

ISSN 2229-5518

D_{VT1}	Second coefficient of short channel effect on Vth	9.2371e-10
D_{VT2}	Body bias coefficient of short channel effect on Vth	-0.1466V-1
D_{sub}	DIBL coefficient lithography	1.3555e+7
Eta0	DIBL coefficient in subthreshold region	0.0018
Etab	Body bias coefficient for subthreshold DIBL effect	0.3126V-1
DVTP0	First parameter for Vth shift due to pocket	2.764e-5
DVTP1	Second parameter for Vth shift due to pocket	-0.0404
DVTP2	Third parameter for Vth shift due to pocket	6.7587

5 Simulation Results

The Ids-Vgs characteristics of N-type SOIMOSFET is simulated using SPICE. We chose MOSFET devices with different geometries to depict the efficiency of the extracted parameters in considering their dimensions into account. The simulations are done by varying body bias voltage Vbs between 0V to -5V. The Vds used for simulation is 50mV. The Ids-Vgs simulation is done for both analytical extracted parameter and default parameter values. The effect of Vgs is alone studied on threshold voltage by considering Vds=50mV and results show that Vds does not have impact on the threshold voltage.

The Fig. 1 shows the Ids-Vgs characteristics for large size devices. We have chosen channel length of the device to be 1000nm and the channel width of the device to be 4000nm. We infer that the extracted parameter values have lead to a lesser threshold voltage compared with the default parameter values for both the Vbs values plotted.

Fig. 2 illustrates the transfer characteristics obtained through SPICE simulation for short channel devices, having channel length of the device to be 300nm and the channel width of the device to be 4000nm.

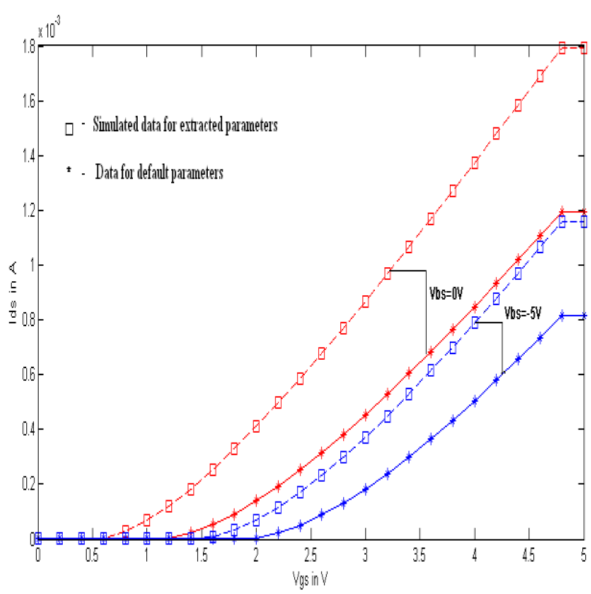

Fig. 1 Large Channel Length and Width devices (Leff=1000nm, Weff=4000nm) Ids-Vgs characteristics, Vbs para

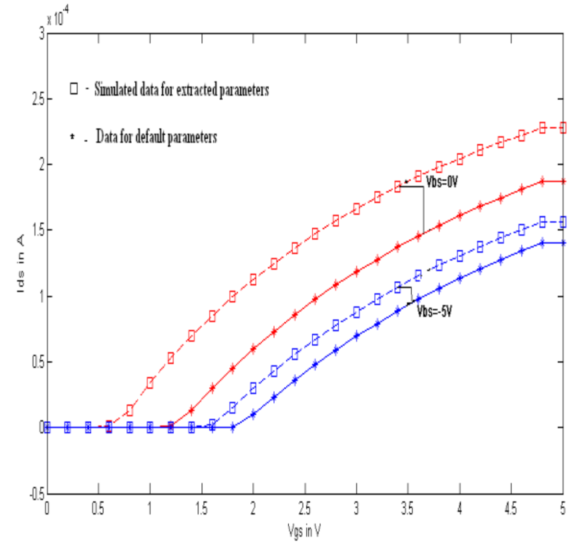

Fig. 2 Short Channel devices (Leff=300nm, Weff=4000nm) Ids-Vgs characteristics, Vbs parameter, VDS=50mV

From the Fig. 2 we infer that the extracted parameter values have lead to a lesser threshold voltage compared with the default parameter values for the plotted Vbs.

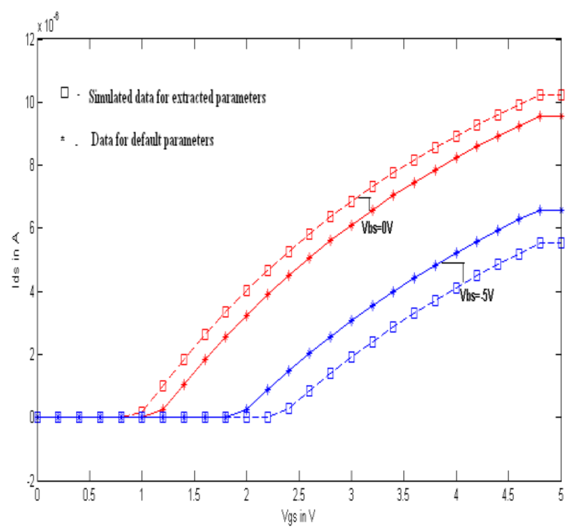

Fig. 3 Narrow Width devices (Leff=1000nm, Weff=600nm) Ids-Vgs characteristics, Vbs parameter, VDS=50mV

Fig. 3 shows the characteristics for narrow width devices that have channel length of the device to be 1000nm and the channel width of the device to be 600nm. From Fig. 3 we infer that the extracted parameter values have lead to a lesser threshold voltage compared with the default parameter values for Vbs =0V and the extracted parameter values have lead to a greater threshold voltage compared with the default parameter values for Vbs=-5V.

For clarity purpose, the simulation results only show the Ids-Vgs plots for Vbs=0V and Vbs=-5V. The (TABLE III) shows the threshold voltage obtained for all the range of the Vbs considered (0V to -5V).

ISSN 2229-5518

TABLE 3
Threshold Voltage for Various device geometries

Body bias voltage applied	Threshold voltage in V					
	Large size devices (large length and large width)		Short channel devices (short length and large width)		Narrow width devices (large length and short width)	
	Calculated using parameter's		Calculated using parameter's		Calculated using parameter's	
	Default values	Extracted values	Default values	Extracted values	Default values	Extracted values
Vbs=0V	1.2	0.57	1.2	0.61	1.4	1.21
Vbs=-1V	1.6	0.85	1.6	0.90	1.8	1.64
Vbs=-2V	1.8	1.07	1.8	1.11	2.0	1.97
Vbs=-3V	2.0	1.24	1.8	1.28	2.2	2.23
Vbs=-4V	2.0	1.39	1.8	1.43	2.2	2.46
Vbs=-5V	2.0	1.52	2.0	1.56	2.4	2.66

For large size devices, the threshold voltage from extracted parameters varies gradually with respect to Vbs, but default parameters have threshold voltage high and constant for Vbs greater than -3V. In short channel devices, the threshold voltage varies gradually with Vbs for the extracted parameters. The default parameters respond a higher and constant value of Vth for Vbs from -2V to -4V. Similarly the Vth response of the narrow width devices is studied. The studied results infer an inverse effect as that of short channel and long size devices.

7 Conclusion

The threshold voltage increases with increase in body bias voltage Vbs and it increases with the shrinking dimensions. The proportionality of increase is given accurately by the extracted parameters. VT0, the threshold voltage at Vbs=0V, is obtained accurately from the extracted values. All the parameters have significant effect on Vth, which are also interdependent. Default Vth values deviates a lot from the accurate results, which clearly implies the significance of parameter extraction for circuit simulation and modeling of device.

References

[1] Suayb Yener , Hakan Kuntman, "Algorithm on the Extraction of BSIM MOSFET Model Parameters via Measurement data", IEEE,2010;55(1):233-244

[2] Yiming Li, "An automatic parameter extraction technique for advanced CMOS device modeling using genetic algorithm", Microelectronic Engineering 2007;84 :260–272

[3] Dr. Wenwei Yang, Dr. Chung-Hsun Lin, Dr. Tanvir Hasan Morshed, Mr. Darsen Lu, Prof. Ali Niknejad, Prof. Chenming Hu,"BSIMSOI4.3 MOSFET Model Users Manual", 2009,UC Berkeley, Department of EECS.

[4] Dr. Xuemei(Jane) Xi, Dr. Jin He, Mr. Mohan Dunga, Prof. Ali Niknejad, Prof. Chenming Hu,"BSIM4.3.0 MOSFET Model Users Manual", 2003,UC Berkeley, Department of EECS.

[5] Bing J.Sheu, Donald L.Scharfetter, Ping-Keung Ko, Min-Chie Jeng, "BSIM: Berkeley Short-Channel IGFET Model for MOS Transistors", IEEE Journal of Solid-State Circuits, 1987; 4: 22

[6] Shunpei Abe, Yoshiyasu Miyazawa, Yoshikata Nakajima, Tatsuro Hanajiri, Toru Toyabe, Takuo Sugano, "Suppression of DIBL in deca nano SOI MOSFET by controlling permittivity and thickness of BOX layers", IEEE 2009;50:174-178

[7] Hyeokjae Lee, Hyunchul Nah, Jong-Ho Lee, Dae-Gwan Kang, Young June Park, Hong Shick Min, "Analysis of body bias effect with PD-SOI for analog and RF applications", Solid-State Electronics 2002;46:1169-1176

[8] Rodrigo Picos, Oscar Calvo, Benjamin Iniguez, Eugeni Garcia Moreno, Rodolfo Garcia, Magali Estrada, " Optimized parameter extraction using fuzzy logic", Solid-State Electronics 2007;51:683-690

[9] R.A.Thakker, M.B.Patil, K.G.Anil, "Parameter extraction for PSP MOSFET model using hierarchical particle swarm optimization", Engineering applications of Artificial Intelligence 2009;22 : 317-328

[10] Jatmiko E.Suseno, Munawar A.Riyadi, Razali Ismail, "Short Channel Effect of SOI Vertical Sidewall MOSFET", ICSE 2008 Proceedings, 2008.

[11] Arash Daghighi, Azam Asgari Khoshooie, "A width dependent body voltage model to obtain body resistance in PD SOI MOSFET technology", Solid-IEEE 2010;53 :1246–1251

[12] G.Hyvert, F.Calmon, T.Nguyen, A.Poncet, C.Plossu, " Accurate electron mobility extraction in nMOSFETs by RF split CV", Microelectronics Engineering 2009;86:1665-1667

[13] Ortiz-Conde, A.D. Latorre Rey a, W. Liu b, W.-C. Chen c, H.-C. Lin c, J.J. Liou b,d, J. Muci a,F.J. García-Sánchez ,"Parameter extraction in polysilicon nanowire MOSFETs using new double integration-based procedure",Solid-State Electronics 2010;54(6):635–641

[14] Yang Tang, Li Zhang, Yan Wang,"Accurate small signal modeling and extraction of silicon MOSFET for RF IC application", Solid-State Electronics 2010; 54 (11):1312–1318