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MOS PARAMETER EXTRACTION AND OPTIMIZATION WITH GENETIC ALGORITHM

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ABSTRACT

Extracting an optimal set of parameter values for a MOS device is great importance in contemporary technology is a complex problem. Traditional methods of parameter extraction can produce far from optimal solutions because of the presence of local optimum in the solution space. Genetic algorithms are well suited for finding near optimal solutions in irregular parameter spaces.

In this study, We have applied a genetic algorithm to the problem of device model parameter extraction and are able to produce models of superior accuracy in much less time and with less reliance on human expertise. MOS transistor's parameters have been extracted and optimized with genetic algorithm. 0.35μm fabricated by C35 process have been used for the results of experimental studies of parameter extraction. Extracted parameters' characteristic data results have been compared with measurement results. Different values of parameters of genetic algorithm, such as population size, crossover rate , and generation size are compared by different tests.*

Keywords: *Genetic Algorithm, BSIM3V3, Model Parameter Extraction*

I. INTRODUCTION

In this study, MOS transistor's Parameters have been extracted and optimized with genetic algorithm. MOS transistors' parameters extracted is a complex problem. Genetic algorithm (GA) has been used for the correct values. In order to make simplification of model equation and complex computation such as gradient and inverse Hessian matrix like Least square, Newton Raphson or Marquardt [1], parameters of BSIM3V3 are extracted at once using global optimization without making any simplification of model equations.

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Although SaPOSM [2] and Fast Diffusion [3] are the global optimization methods but they have been using the derrivative in calculation the extraction process will be very slowly and extraction process will be difficult. Because of the complexity of the model and data, these methods allow optimization of only a few parameters at a time. Optimization also leads to local optima which do not result in a model that is accurate enough to be useful [2]. Traditional model-extraction methods are based on a combination of direct parameter extraction that uses mathematical simplification of the model equations, and optimization that uses the full, highly non-linear model equations [1].

Most of the circuits which have been produced by contemporary Very Large Scale Integration (VLSI) technology included in MOS transistors and their connections. To predict and evaluate the circuit performance of the VLSI systems before the actual fabrication of a designed circuit, device model for circuit simulation has to be accurate and robust.

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Good model gets great benefit to improving the transistors and training with prospective effects. On this account it needs to transistor model should give the accurate results for designing circuit. We also need MODELS to predict the behaviour of the device or component designed. These models, designed mathematically, can predict the real time behaviour of the component.

In this context, there is a lot of work to realize MOS transistor modelling, and given hundreds of models with the development technology, decreasing the dimensions of transistors, developing technology and novel methods get new point of view. It has not been finished the problem after the determination of the correct model of the physical behaviour of the component. The component which tried to be modelled has same physical properties and this specificattions tried to be modelled some mathematical ways [1-7]. For that reason the parameters which are included in model have to be modelled, giving the optimum result.

To realize accurate parameter extraction, we proposed a genetic algorithm based parameter extraction method for threshold voltage related and mobility related model parameters [8].

II. BSIM3V3 MODELLING

BSIM3V3 model is based on deep understanding of submicrometer MOSFET and is a physical model including major short channel effects. BSIM3V3 has fewer parameters and every parameter has its own physical meaning. Because of the simple analytical nature of the model, BSIM3V3 can be used to explain how the various physical parameters will affect device performance [2,3].

BSIM3V3 model can be used to predict the scaling effects on the output characteristics of deep-submicrometer MOSFETs. It is applicable for both digital and analog circuit simulations. It also has a fast option for digital circuit simulation and an accurate option for analog circuit simulation. As all device currents and their first order derivatives are continuous, convergence of simulation has been improved and the number of iterations has been reduced. Furthermore, time consulting functions are excluded in BSIM3V3 in order to achieve computational efficiency.

The default set of parameters is highly usable for light doped drain devices. BSIM3V3 model is good for devices with a variety of transistor width and length down to 0,2 μm, and gate oxide thickness down to 5nm. Because of the physical nature of the model, the parameters extracted from an old process can be used to predict the device behaviours of future generation.

Users can easily use BSIM3V3 model to predict MOSFET performance and scaling effects before the device is fabricated. BSIM3V3 makes some simplifying assumptions which reduce the accuracy but help reveal the physics of the device operation and improve the calculation efficiency through a simple analytical expression for the drain current. Physical parameters extracted from the process can be used to characterize device fabrication and then simulate circuit performance.

III. GA PARAMETER EXTRACTON STRATEGIES

MOSFET model parameters determining step were applied to five different strategy. These steps are described below respectively.

Strategy 1: This local strategy is applied for the wide (W=10μm) and long (L=10μm) device only and the parameters are those in equation 1 and equation 2. Target parameters are **VTH0, K1, K2, μ0, UA, UB** and **UC.** It requires I_d vs V_{gs} data at V_{ds} equals low voltage with different V_{bs} values [7,10].

$$V_{th} = V_{TH0} + K_1\left(\sqrt{\phi_s - V_{bs}} - \sqrt{\phi_s}\right) - K_2 V_{bs} \qquad (1)$$

$$\mu_{eff} = \frac{\mu_0}{1 + \left(U_a + U_c V_{bs}\right)\left(\frac{V_{gst} + 2V_{th}}{Tox}\right) + U_b\left(\frac{V_{gst} + 2V_{th}}{Tox}\right)^2} \qquad (2)$$

In Equation 3, μ_{eff} is Effective Mobility, μ_0 is Mobility at tempereture=27°C, U_a is first order mobility degradation coefficient, U_b is second order mobility degradation coefficient and U_c is body bias sensitivity coefficient of mobility, V_{gs} is Gate Voltage, Tox is gate oxide thickness and $V_{gst} = V_{gs} - V_{th}$.

Strategy 2: This local strategy is applied for the narrow W and long L device only and the parameters are those in equation (3). Target parameters are **K3, W0 ve K3B.** It requires I_d vs V_{gs} data at V_{ds} equals low voltage with different V_{bs} values [7, 9].

$$\begin{aligned} V_{th} &= V_{TH0} + K_1\left(\sqrt{\phi_s - V_{bseff}} - \sqrt{\phi_s}\right) - K_2 V_{bseff} \\ &+ K_1\left(\sqrt{1 + \frac{N_{LX}}{L_{eff}}} - 1\right)\sqrt{\phi_s} + \left(K_3 + K_{3B} V_{bseff}\right)\frac{T_{OX}}{W'_{eff} + W_0}\phi_s \\ &- D_{VT0}\left(\exp\left(-D_{VT1}\frac{L_{eff}}{2l_t}\right) + 2\exp\left(-D_{VT1}\frac{L_{eff}}{l_t}\right)\right)\left(V_{bi} - \phi_s\right) \\ &- \left(\exp\left(-D_{SUB}\frac{L_{eff}}{2l_{to}}\right) + 2\exp\left(-D_{SUB}\frac{L_{eff}}{l_{to}}\right)\right)\left(E_{TA0} + E_{TAB} V_{bseff}\right)V_{ds} \end{aligned} \qquad (3)$$

Strategy 3: This local strategy is applied for the wide W and short L device only and the parameters are those in equation 4 and 5. **RDSW, DVT0, DVT1, DVT2, NLX,**

PRWG and **PRWB** were determined by using wide W and short L device used [7, 9].

$$V_{th} = V_{THO} + K_1\left(\sqrt{\phi_s - V_{bseff}} - \sqrt{\phi_s}\right) - K_2 V_{bseff}$$
$$+ K_1\left(\sqrt{1+\frac{N_{LX}}{L_{eff}}} - 1\right)\sqrt{\phi_s} + \left(K_3 + K_{3B}V_{bseff}\right)\frac{T_{OX}}{W_{eff}^{'} + W_0}\phi_s \quad (4)$$
$$- D_{VT0}\left(\exp\left(-D_{VT1}\frac{L_{eff}}{2l_t}\right) + 2\exp\left(-D_{VT1}\frac{L_{eff}}{l_t}\right)\right)\left(V_{bi} - \phi_s\right)$$
$$- \left(\exp\left(-D_{SUB}\frac{L_{eff}}{2l_{to}}\right) + 2\exp\left(-D_{SUB}\frac{L_{eff}}{l_{to}}\right)\right)\left(E_{TA0} + E_{TAB}V_{bseff}\right)V_{ds}$$

$$R_{ds} = \frac{R_{DSW}\left(1 + P_{RWG}V_{gsteff} + P_{RWB}\left(\sqrt{\phi_s - V_{bseff}} - \sqrt{\phi_s}\right)\right)}{\left(10^6 W_{eff}^{'}\right)^{W_r}} \quad (5)$$

Strategy 4: This local optimization strategy is applied for the small device size only (short channel and narrow width). In this step the fixed channel width (W = 10μm) and short-channel transistor large-sized multi-transistor (L = 0.35μm, L = 0.7μm, L = 1μm) was used for determining **A0** and **AGS** parameters, a fixed channel length (L = 10μm) with large channel width of transistors and other small sized transistors (W = 0.35μm, W = 0.7μm, W = 1μm) were used for determinining **B0, B1,** and **KETA** parameters. Id - Vds curves obtained from different values of Vgs and Vbs with the condition of zero. The parameter values obtained by the following Equation 7 by using genetic algorithms Id - Vds values were used on the basis [7, 9].

$$A_{bulk} = \left(1 + \frac{K_{1ox}}{2\sqrt{\phi_s - V_{bseff}}}\left(\frac{A_0 L_{eff}}{L_{eff} + 2\sqrt{X_J X_{dep}}}\left(1 - A_{gs}V_{gsteff}\left(\frac{L_{eff}}{L_{eff} + 2\sqrt{X_J X_{dep}}}\right)^2\right) + \frac{B_0}{W_{eff}^{'} + B_1}\right)\right) \cdot$$
$$\cdot \frac{1}{1 + KetaV_{bseff}} \quad (7)$$

Strategy 5: In this step, **DVT0W, DVT1W** and **DVT2W** parameters were determined by using a short channel length (L = 0.35μm) and narrow channel width (W = 0.35μm) small-sized transistor. $I_d - V_{gs}$ curves obtained from diffrent values of Vbs (0V, -1.1V, -2.2V, and -3.3V) and V_{ds} = 0.05V, have been determined by using Equation 8 with genetic algorithms $I_d - V_{gs}$ values were used on the basis [7, 9].

$$V_{th} = V_{THO} + K_1\left(\sqrt{\phi_s - V_{bseff}} - \sqrt{\phi_s}\right) - K_2 V_{bseff} \quad (8)$$
$$+ K_1\left(\sqrt{1+\frac{N_{LX}}{L_{eff}}} - 1\right)\sqrt{\phi_s} + \left(K_3 + K_{3B}V_{bseff}\right)\frac{T_{OX}}{W_{eff}^{'} + W_0}\phi_s$$
$$- D_{VT0}\left(\exp\left(-D_{VT1}\frac{L_{eff}}{2l_t}\right) + 2\exp\left(-D_{VT1}\frac{L_{eff}}{l_t}\right)\right)\left(V_{bi} - \phi_s\right)$$
$$- \left(\exp\left(-D_{SUB}\frac{L_{eff}}{2l_{to}}\right) + 2\exp\left(-D_{SUB}\frac{L_{eff}}{l_{to}}\right)\right)\left(E_{TA0} + E_{TAB}V_{bseff}\right)V_{ds}$$
$$- D_{VT0W}\left(\exp\left(-D_{VT1W}\frac{W_{eff}^{'}L_{eff}}{2l_{tw}}\right) + 2\exp\left(-D_{VT1W}\frac{W_{eff}^{'}L_{eff}}{l_{tw}}\right)\right)\left(V_{bi} - \phi_s\right)$$

III. Determination of the Parameters with GA Process

Before any model parameters can be extracted, some process parameters have to be provided. They are listed below in Table 1.

Table 1 Prerequisite input parameters prior to extraction process

Parameter	Description
T_{ox}	Gate oxide thickness
N_{ch}	Doping concentration in the channel
T	Temperature at which the data is taken
L_{drawn}	Mask level channel length
W_{drawn}	Mask level channel width
X_j	Junction depth

Determination of parameters in the process shown in Figure 1 as the channel length (L) and channel width (W) larger than a transistor, the channel length and width is small, with a transistor with a different width, but fixed-size transistors, and variable length but constant width transistors are used [10].

One large size device and two sets of smaller-sized devices are needed to extract parameters, as shown in Figure 1.

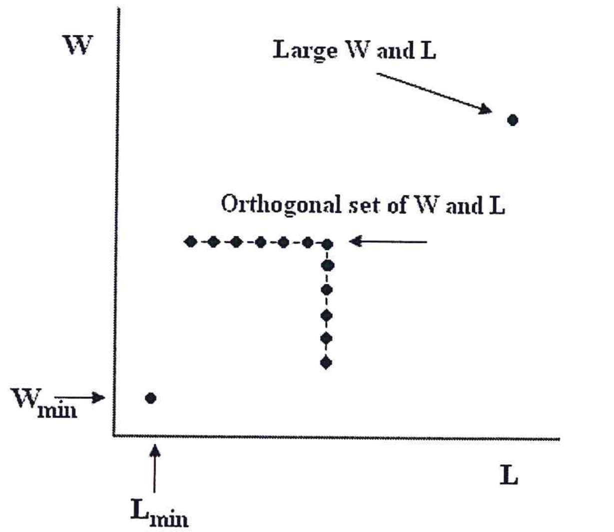

Figure 1 Geometric features used in the extraction of transistor [1]

Applied in determining the parameters of the GA flow chart is given in Figure 2. MOS transistor's parameters have been extracted and optimized with genetic algorithm. 0.35μm fabricated by C35 process have been used for the results of experimental studies of parameter extraction. Extracted parameters are **VTHO, K1, K2, U0, UA, UB, UC, Dsub, NLX, DVT0, DVT1, DVT2, RDSW, PRWB, PRWG, W0, K3, K3B, A0, AGS, B0 , B1, KETA, DVT0W, DVT1W, DVT2W**.

Current values of the parameters in Equation 9 to determine the fitness function used as fitness function is determined.

$$f = \sum (I_{d,lab} - I_{d,\text{model}})^2 \qquad (9)$$

Where f is the fitness function, $I_{d,lab}$, $I_{d,model}$ corresponded to the simulated and extracted values of I_{ds} of the MOSFET respectively.

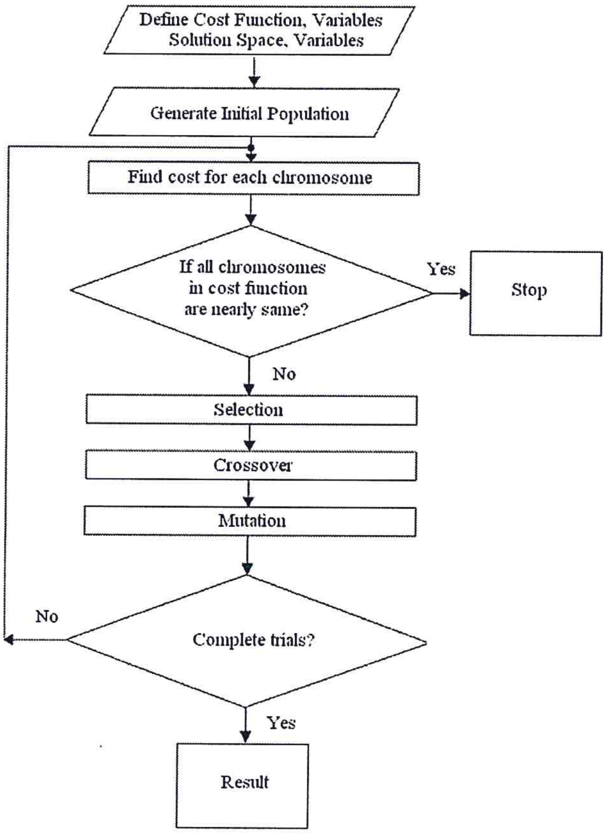

Figure 2: Main program flowchart of genetic algorithm

After selecting individuals for crossover operator can be applied. Randomly chosen as parents for the crossover again with randomly determined by multiplying the crossover rate to obtain new individuals. β, is chosen on the interval [0, 1] and the offspring variable values

$$p_{new} = \beta p_{mn} + (1-\beta) p_{dn} \qquad (10)$$

Here, β is the random number on the interval [0, 1], p_{mn} is the nth variable in the mother chromosome and p_{dn} is the nth variable in the father chromosome [11].

The number of parameters was determined by multiplied the number of chromosomes (Nkromozon) and the number of genes (Ngen) and user-specified mutation rate (Mrate). Eventually, number of mutation (Msayı) is determined as seen in Equation 11.

$$\text{Msayı} = \text{Mrate} * \text{Nkromozon} * \text{Ngen} \qquad (11)$$

After recombination, a mutation operator can be applied. Each member in the population can be mutated with some low probability m; typically the mutation rate is applied with less than 1% probability. From the function optimization viewpoint, the mutation operator may be viewed as a combination of a random search method and a local search method. It ensures that the population maintains reasonable variability and also provides the means for making small changes to number. After the process selection, recombination and mutation are complete, the next population can be evaluated. Actually, GA is formed by the processes of selection, recombination, mutation and reproduction.

Different combinations of GA parameters were used to find the best fitness chromosome. The result were recorded and shown in Table 2.

Table 2: Results of trial runs with different GA parameters

Test No	**Population Size**	**Initial Mutation Rate**	**Crossover Rate**	**Min % Error obtained**
1	500	0,02	0,9	3,0
2	500	0,05	0,9	1,9
3	500	0,07	0,9	1,98
4	500	0,01	0,9	2,5
5	500	0,05	0,7	1,8
6	500	0,05	0,7	2,9
7	500	0,05	0,5	1,7
8	500	0,05	0,5	1,4

The result of trial runs were used to study performance of the parameters. Figure 3 showed the performance of GA extraction with the different initial mutation rates, while Figure 4 depicted the population size on the performance of GA extraction.

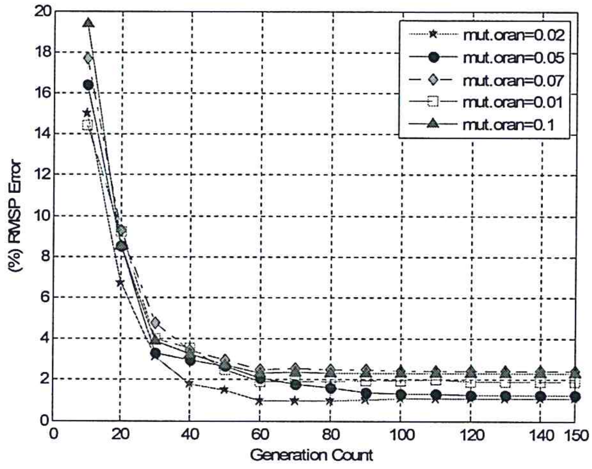

Figure 3: A graph of comparison between different initial mutation rate

As shown in Table 2 GA was improved by incresing initial mutation probability from 0,07 to 0,05 and 0,02; but degraded as mutation probability reached 0,1. Although increasing the mutation rate will maintain sufficient diversity of population for continuing improvement, too high the mutation rate will make the searching process resemble of a simple random search, and thus, the performance will be degraded. It was also found that eiher too small or too large a population would degrade the performance of GA. Too small population size would suffer from the sampling errors due to too small a searching area. On the other extreme, if the population size was too large, the system would spend most of time in function evaluation other than searching. It should be noted that the performance of GA mainly depends on the processes of selection and recombination.

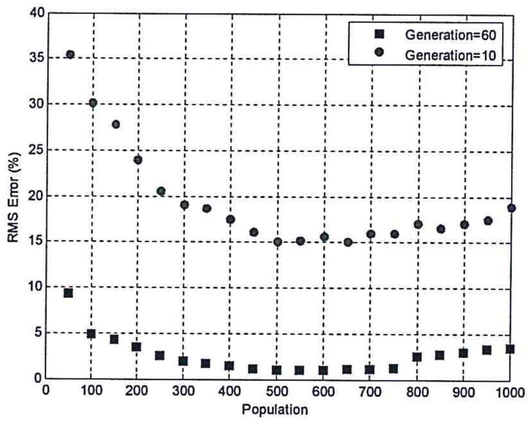

Figure 4: A graph of comparison between different population size

Extracted parameter values and the real model parameters values are given in Table 2.

Table 2: Meausered and Extracted Values of parameters

Parameters	Measured	Extracted
VTHO	$4.979\cdot10^{-1}$	$5.003\cdot10^{-01}$
K1	$5.0296\cdot10^{-01}$	$4.8451\cdot10^{-01}$
K2	$3.3985\cdot10^{-02}$	$3.4712\cdot10^{-02}$
U0	$4.758\cdot10^{+02}$	$4.618\cdot10^{+02}$
UA	$4.705\cdot10^{-12}$	$4.595\cdot10^{-12}$
UB	$2.137\cdot10^{-18}$	$1.7711\cdot10^{-18}$
UC	$1.000\cdot10^{-20}$	$5.1660\cdot10^{-17}$
NLX	$1.888\cdot10^{-7}$	$2.0317\cdot10^{-7}$
DVT0	$5.000\cdot10^{1}$	$4.513\cdot10^{1}$
DVT1	1.039	1.29139
DVT2	$-8.375\cdot 10^{-3}$	$-7.5576\cdot10^{-3}$
RDSW	$3.449\cdot10^{2}$	$3.710\cdot10^{2}$
PRWG	0	$9.921\cdot10^{-12}$
PRWB	$-2.416\cdot 10^{-1}$	$-1.966\cdot10^{-1}$
WR	1	1.0294
W0	$2.673\cdot10^{-7}$	$2.31\cdot 10^{-7}$
K3	-1.136	-1.529
K3B	$-4.399\cdot10^{-1}$	$-4.061\cdot 10^{-1}$
A0	2.541	2.479
AGS	$2.408\cdot10^{-1}$	$2.398\cdot10^{-1}$
B0	$4.301\cdot10^{-9}$	$4.59\cdot10^{-9}$
B1	0	$3.2300\cdot10^{-15}$
KETA	$2.032\cdot10^{-2}$	$2.320\cdot10^{-2}$
DVT0W	$1.089\cdot10^{-10}$	$1.199\cdot10^{-10}$
DVT1W	$6.671\cdot10^{4}$	$6.7702\cdot10^{4}$
DVT2W	$-1.352\cdot10^{-2}$	$-1.505\cdot10^{-2}$

The values obtained, as compared to SPICE parameters directly, a result out of two very different results can be said to be really good. Here are the arguments as a group during the randomly obtain the results is taken into consideration is really nice.

IV. GA PARAMETER EXTRACTON

Different combinations of genetic algorithm parameters were used to find the best fitness chromosome. We took the default generation count is 100. If the result of the first run after 100 generations were not satisfoctary and had an error greater than 10%, then second run with a different random seed number would be executed. Moreover, this genetic algorithm is applied during the simulation the population as the number of parameters is chosen as 500, as the number of generations is chosen as 100 and mutation rate is chosen as 0.02.

Table 2 shows that the extracted and measured MOSFET BSIM3V3 model parameters. Figure 4, Figure 5, Figure 6, Figure 7 show the result of the fitted drain current using BSIM3V3 model. SPICE parameters obtained from the curves are indicated by straight lines, as SPICE and extracted parameter with GA expressed with the dots. Simulation were realized by using different size of transistors.

The average rms error obtained using the BSIM3V3 model was about 1,4% after 60 generations. The Root

Mean Squared Percentage Errors were presented in Table 3.

Table 3: Root Mean Squared Percentage Errors

		Root Mean Squared Percentage Error (%)
W=10µm L=10µm	Vds=0.05V	1.7331
	Vds=3.3V	0.8961
W=10µm L=0.35µm	Vds=0.05V	0.6460
	Vds=3.3V	1.0108
W=0.35µm L=10µm	Vds=0.05V	0.9988
	Vds=3.3V	1.3809
W=0.35µm L=0.35µm	Vds=0.05V	2.0934
	Vds=3.3V	0.8122

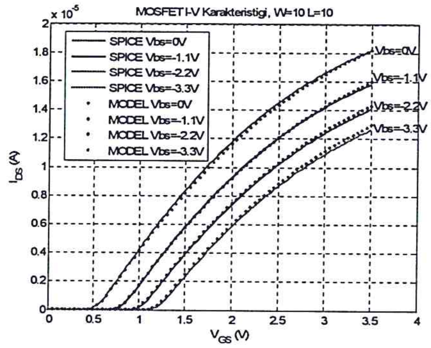

Figure 4 Large size (W = 10µm L = 10µm) ID-VGS characteristics of MOSFET, Vds = 0.05V, VBS parameter

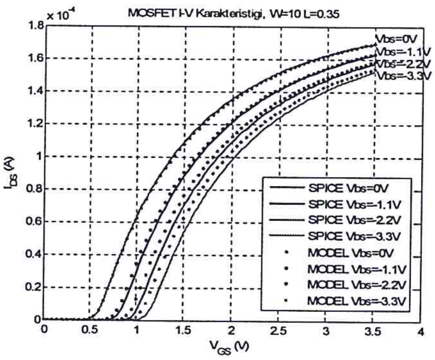

Figure 5 Short-channel (W = 10µm L = 0.35µm) MOSFET Id-VGS characteristics, Vds = 0.05V, VBS parameter

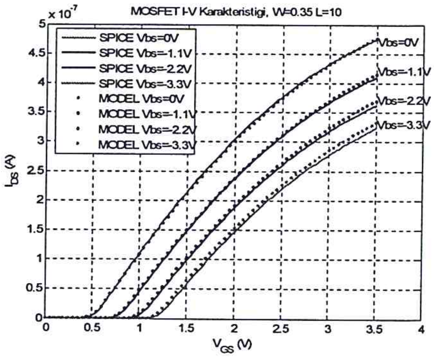

Figure 6 Narrow-channel (W = 0.35µm L = 10µm) ID-VGS characteristics of MOSFET, Vds = 0.05V, VBS parameter

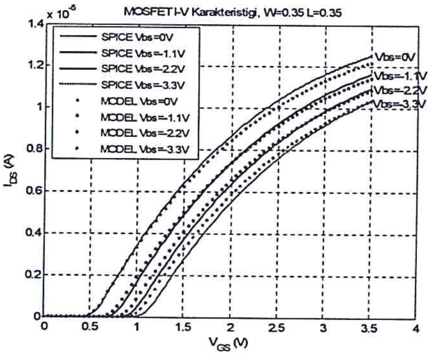

Figure 7 Small size (W = 0.35µm L = 0.35µm) MOSFET Id-VGS characteristics, Vds = 0.05V, VBS parameter

V. CONCLUSION

In this research, based on a global optimization algorithm, genetic algorithm was employed to find model parameter values for MOSFET. The problem has been addressed, such as numerical optimization problem. GA is deemed to be effective; to solve the non-linear and the transient problem. Because of the using the same determined parameters of the mathematical models extracted parameters' results and simulation results are closer. Values obtained in determining working conditions, especially as many transistor parameters such as $\mathbf{V_{THO}}$, $\mathbf{K_1}$, $\mathbf{K_2}$ and μ_0 has been found in high accuracy is the success of this working.

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