Application of the Genetic Algorithm to Compact MOSFET Model Development and Parameter Extraction

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LSI Logic

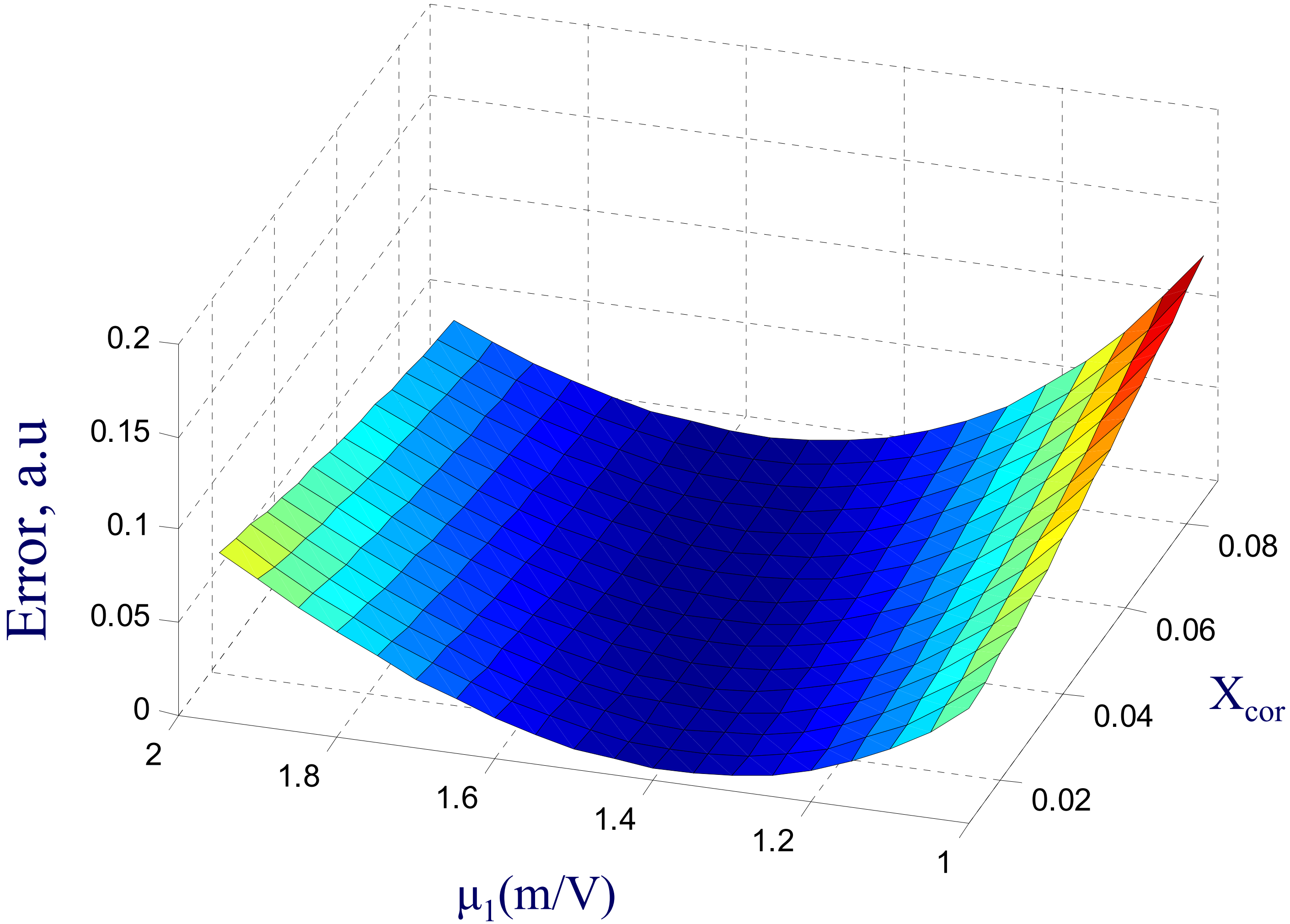
Outline

- Introduction
- Symmetric Linearized Charge Sheet Model
- Genetic Algorithm
- Results
- Conclusions

Introduction

- The large number of the compact MOSFET model parameters necessitate an elaborate extraction process
- Problems of gradient-based methods:
  - Numerous local minima of the error function
  - Strong dependence on the initial values of parameters
  - Possibility of convergence outside physical range
  - Numerical noise for computing derivatives

Error Surface



MOSFET Model

- Long/wide devices only
- Subset of SP with 8 parameters is sufficient

$$I_d = \mu\,(W/L)\,C_{ox}(q_{im} + \alpha_m \phi_t)(\phi_{sd} - \phi_{ss})$$

μ -- effective mobility

W,L -- device dimensions

C_{ox} -- oxide capacitance (per unit channel area)

q_{im} -- inversion charge at potential midpoint

α_m -- linearization coefficient; $\alpha_m = 1 + (\gamma/4)(\phi_{ss} + \phi_{sd} - 2\phi_t)^{-1/2}$

Φ_t -- thermal voltage

Φ_{ss}, Φ_{sd} -- surface potential at the source and drain ends of the channel

Mobility Model

$$\mu_{\text{eff}} = \frac{\mu_0(1+X_{cor}V_{\text{sb}})/(1+0.2X_{cor}V_{\text{sb}})}{1+(\mu_1 E_{\text{eff}})^{\theta} + C_s \cdot [q_{bm}/(q_{im}+q_{bm})]^2}$$

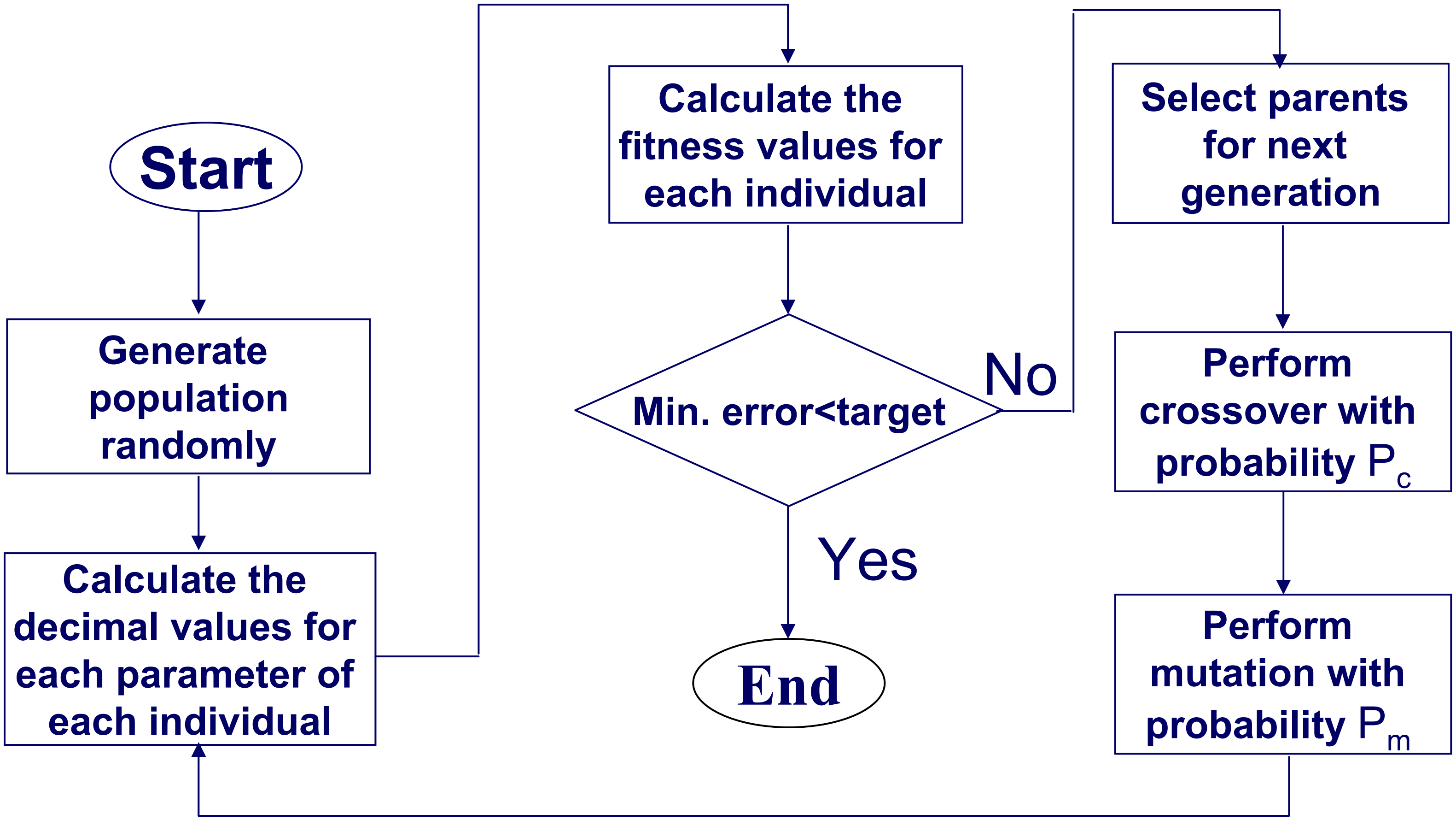
μ_0, μ_1, θ, C_s, X_{cor} – model parameters

V_m – inversion charge at the potential midpoint

q_{bm} – bulk charge density at the potential midpoint

E_{eff} – effective vertical field

GA Overview


Start

Generate population randomly

Calculate the decimal values for each parameter of each individual

Calculate the fitness values for each individual

Min. error<target

No

Yes

End

Select parents for next generation

Perform crossover with probability P_c

Perform mutation with probability P_m

Error Function

$$g = \sum_{V_{gs}=0.36}^{1.8} \left(g_1\big|_{V_{sb}=0.0} + g_1\big|_{V_{sb}=2.0} \right) + \sum_{V_{gs}=0.36}^{1.8} \left(g_2\big|_{V_{sb}=0.0} + g_2\big|_{V_{sb}=2.0} \right)$$

$$+ \sum_{V_{sb}=0}^{2.0} \left(g_3\big|_{V_{ds}=0.1} + g_3\big|_{V_{ds}=1.8} \right) + \sum_{V_{sb}=0}^{2.0} \left(g_4\big|_{V_{ds}=0.1} + g_4\big|_{V_{ds}=1.8} \right)$$

$$g_1 = \sum_{V_{ds}=0}^{1.8} \left[\left(I_{d,lab} - I_{d,SP} \right) \Big/ \sum_{V_{ds}=0}^{1.8} I_{d,lab} \right]^2$$

$$g_3 = \sum_{V_{gs}=0}^{1.8} \left[\left(\log I_{d,lab} - \log I_{d,SP} \right) \Big/ \sum_{V_{gs}=0}^{1.8} \log I_{d,lab} \right]^2$$

$$g_2 = \sum_{V_{ds}=0}^{1.8} \left[\left(g_{d,lab} - g_{d,SP} \right) \Big/ \sum_{V_{ds}=0}^{1.8} g_{d,lab} \right]^2$$

$$g_4 = \sum_{V_{gs}=0}^{1.8} \left[\left(g_{m,lab} - g_{m,SP} \right) \Big/ \sum_{V_{gs}=0}^{1.8} g_{m,lab} \right]^2$$

Table 1. GA application (T=298)

Name	Unit	Min	Max	Optimal	
				$C_s \neq 0$	$C_s = 0$
T_{ox}	nm	3.9	4.1	3.928	3.949
N_{sub}	$10^{17} cm^{-3}$	2.0	5.0	2.554	2.875
V_{fb}	V	-1.1	-0.9	-0.929	-0.974
μ_0	cm^2/Vs	300	800	566.9	428.1
μ_1	m/V	0	3	1.143	0.863
θ	none	0	5	1.658	2.585
X_{cor}	V^{-1}	0.01	0.1	0.0597	0.044
C_s	none	0	3	0.5734	0.0
Error	a.u.	27.76	1.9	9.35e-4	1.29e-3

Table 2. GA application (T=218)

Name	Unit	Min	Max	Optimal	
				$C_s \neq 0$	$C_s = 0$
T_{ox}	nm	3.9	4.1	3.928	3.928
N_{sub}	$10^{17}cm^{-3}$	2.0	5.0	2.554	2. 554
V_{fb}	V	-1.1	-0.9	-0.969	-0.963
μ_0	cm^2/Vs	300	800	750.5	587.7
μ_1	m/V	0	3	1.038	0.899
θ	none	0	5	2.615	3.930
X_{cor}	V^{-1}	0.01	0.1	0.0707	0.0344
C_s	none	0	3	0.624	0.0
Error	a.u.	27.76	1.9	1.1e-3	6.5e-3

- In agreement with MOSFET physics the effect of Coulomb scattering is relatively small at room temperature: the error is reduced by 38% when $C_S \neq 0$ is allowed (shown in Table 1).

- However the inclusion of the Coulomb scattering term (C_S) improves the fitting for low temperature ($T=-55^o$) by 490% (shown in Table 2).

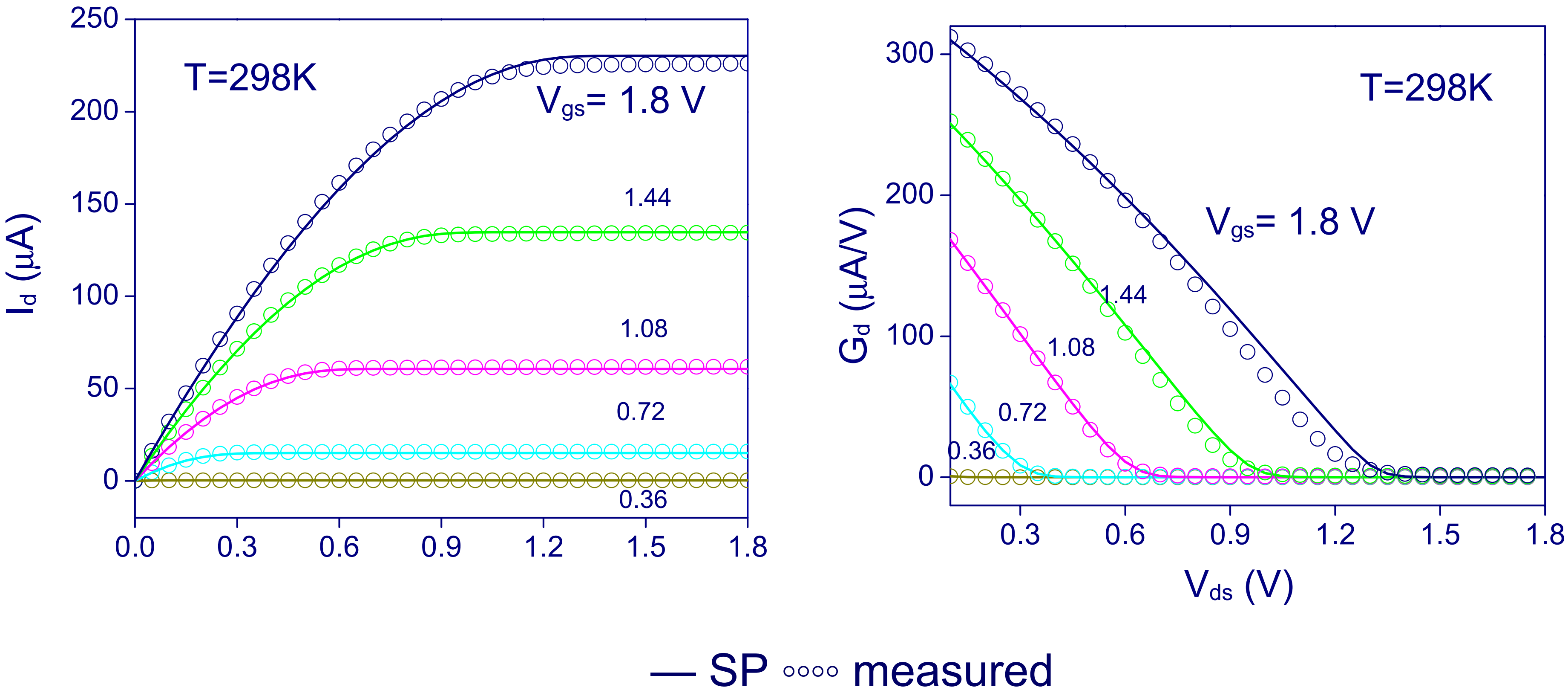
---- Coulomb scattering term is needed if the reduced temperature operation is important

---- GA is useful for both parameter extraction and model development

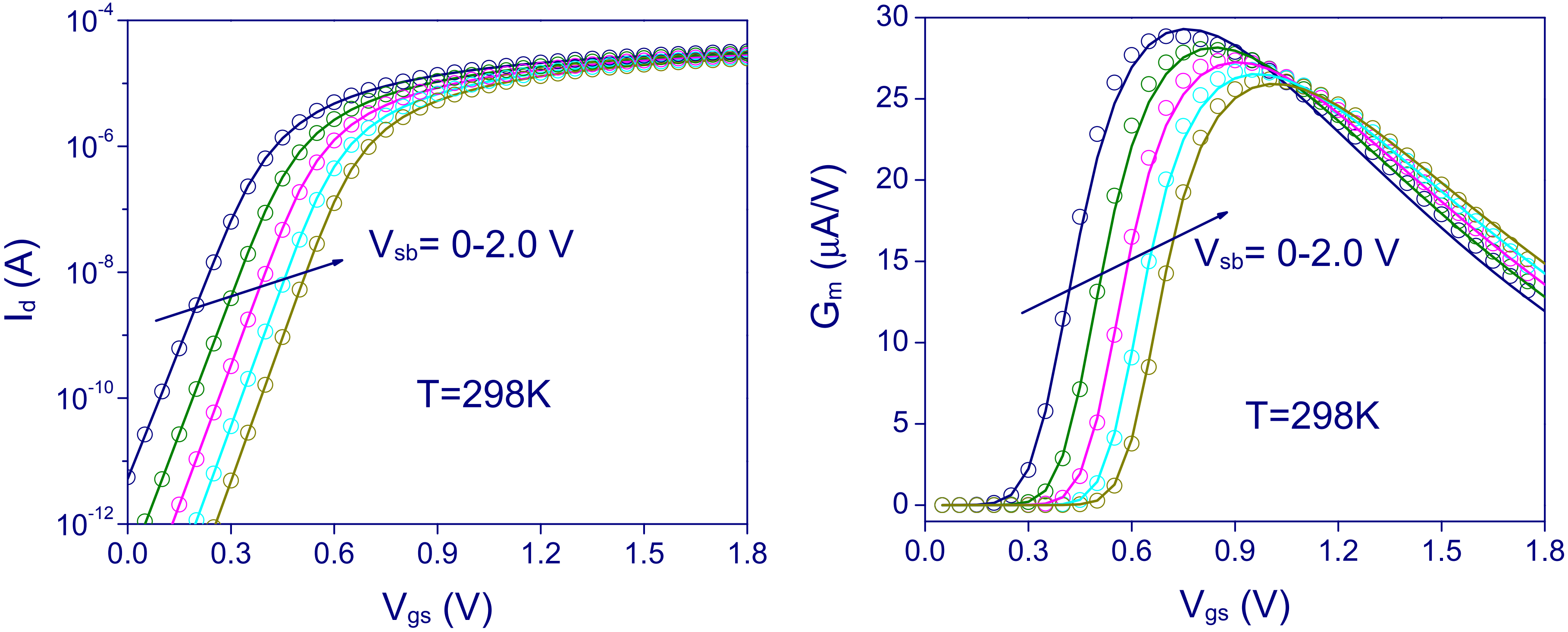
Table 3. LM application (T=298)

Name	LM1		LM2	
	Initial	Final	Initial	Final
T_{ox}	4.0	3.61	3.9	4.53
N_{sub}	3.0	3.017	2.0	1.877
V_{fb}	-1.0	-0.9415	-1.0	-0.9091
μ_0	600	597.6	400	788.6
μ_1	1.0	1.2317	1.0	1.6756
θ	2.0	1.4948	1.0	1.40
X_{cor}	0.04	0.0402	0.04	0.0403
C_s	1.0	0.8789	2.0	0.934
Error	0.26	1.49e-3	2.895	1.58e-3

Results (1)

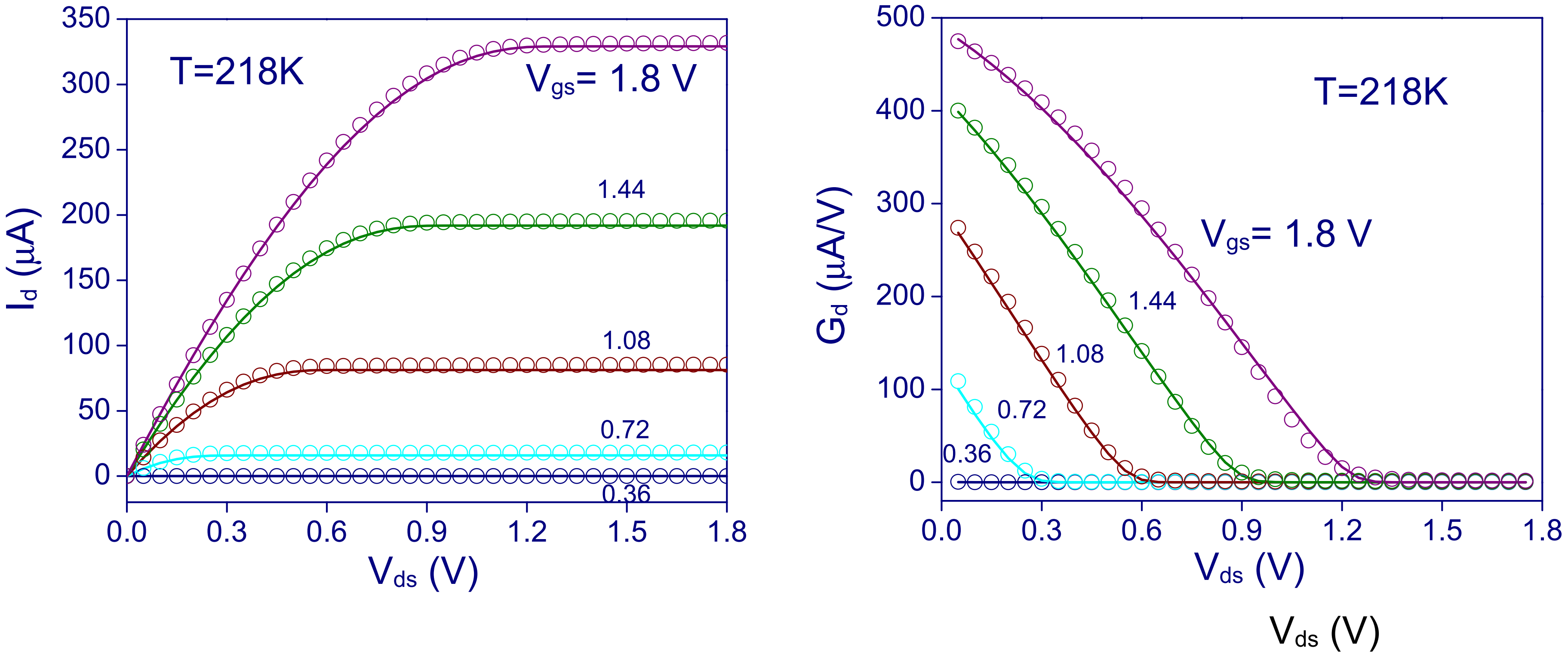

T=298K
V_{gs}= 1.8 V
1.44
1.08
0.72
0.36
I_d (μA)
250
200
150
100
50
0
0.0
0.3
0.6
0.9
1.2
1.5
1.8
T=298K
V_{gs}= 1.8 V
1.44
1.08
0.72
0.36
G_d (μA/V)
300
200
100
0
0.3
0.6
0.9
1.2
1.5
1.8
V_{ds} (V)
— SP ○○○○ measured

Results (2)



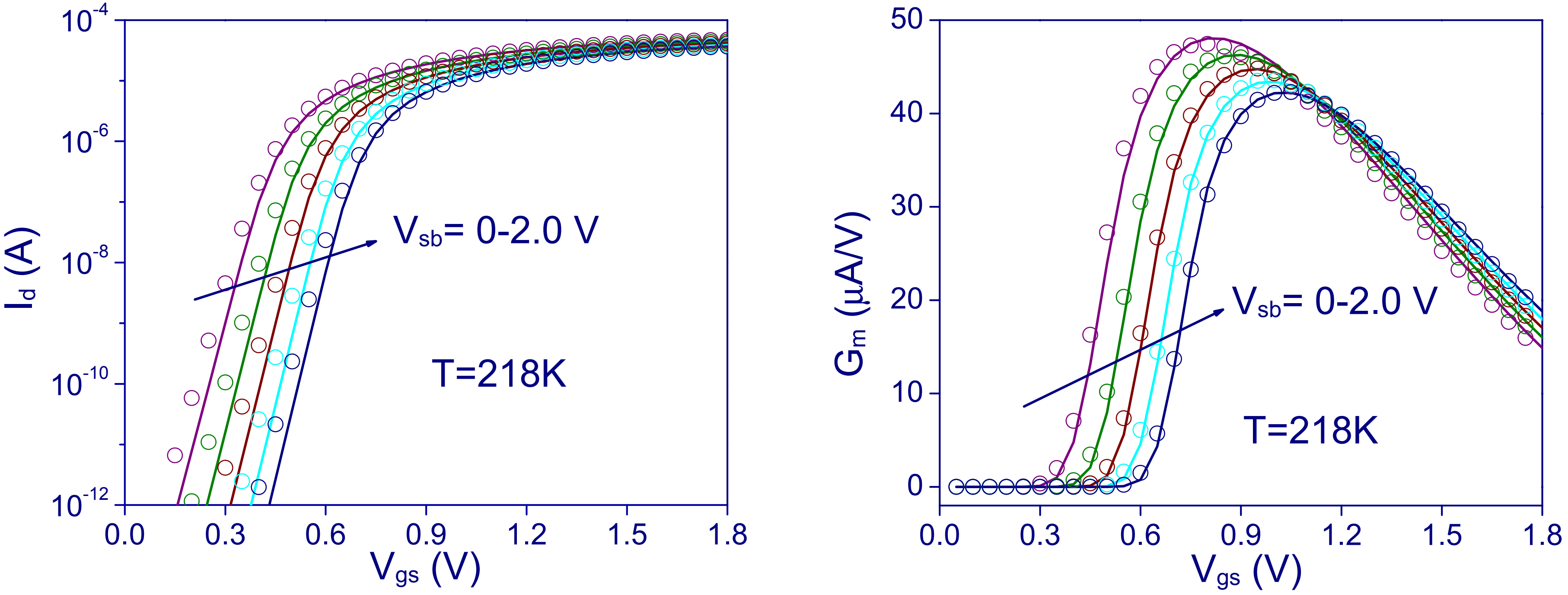
— SP ∘∘∘∘ measured

Results (3)



— SP ∘∘∘∘ measured

Results (4)



— SP ○○○○ measured

Conclusions

- GA – feasible to locate near-optimal solutions
- No convergence problems
- Physical based parameter ranges can be enforced easily
- Insensitive to the numerical noise
- Useful to explore the need for including new device physics
- Combination of GA and gradient-based method may save time but is less robust
  - GA to obtain good initial values within physical range
  - gradient-based method to refine the fit

Reference

[1] J. Watts, C. Bittner, D. Heaberlin and J. Hoffmann, ICMSM, 176, (1999)

[2] T.L. Chen and G. Gildenblat, Electronics Letters, 37, 791, (2001)

[3] T.L. Chen and G. Gildenblat, ICMSM, 657-661, (2002)

[4] N. Arora, ”MOSFET Models for VLSI Circuit Simulations”, Springer-Verlag, NY, (1993)

[5] C.L. Huang and N.D. Arora, Solid State Electronics, 37, 97, (1994)

[6] C.L. Karr, D.A. Stanley and B.J. Scheiner, Dept. of the Interior, Bureau of Mines, Washington, D.C., (1991)

[7] D.E. Goldberg, ”Genetic algorithms in search, optimization, and machine learning”, Addison-Wesley, MA, (1989)