A Trial Report: HiSIM1.2 Parameter Extraction for 90 nm Technology

Yoshihisa Iino
SILVACO Japan

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HiSIM parameter extraction: equations

Drain current:

$$I_{\rm ds} = \frac{W_{\rm eff}}{L_{\rm eff}} \mu \frac{IDD}{\beta}$$

$$IDD = C_{\rm ox}(\beta V'_{\rm G} + 1)(\phi_{\rm SL} - \phi_{\rm S0}) - \frac{\beta}{2} C_{\rm ox}(\phi^2_{\rm SL} - \phi^2_{\rm S0})$$
$$- \frac{2}{3}\left(qN_{\rm sub}L_{\rm D}\sqrt{2}\right)\left[\left\{\beta(\phi_{\rm SL} - V_{\rm bs}) - 1\right\}^{\frac{3}{2}} - \left\{\beta(\phi_{\rm S0} - V_{\rm bs}) - 1\right\}^{\frac{3}{2}}\right]$$
$$+ \left(qN_{\rm sub}L_{\rm D}\sqrt{2}\right)\left[\left\{\beta(\phi_{\rm SL} - V_{\rm bs}) - 1\right\}^{\frac{1}{2}} - \left\{\beta(\phi_{\rm S0} - V_{\rm bs}) - 1\right\}^{\frac{1}{2}}\right]$$

equations (23) in HiSIM-1.2 User's manual

HiSIM parameter extraction: equations
Carrier mobility

Low field mobility model:

$$\frac{1}{\mu_0} = \frac{1}{\mu_{\mathrm{CB}}} + \frac{1}{\mu_{\mathrm{PH}}} + \frac{1}{\mu_{\mathrm{SR}}}$$

$$\mu_{\mathrm{CB}}(\mathrm{Coulomb}) = MUECB0 + MUECB1\frac{Q_{\mathrm{i}}}{q \times 10^{11}}$$

$$\mu_{\mathrm{PH}}(\mathrm{phonon}) = \frac{MUEPH1}{(T/300\mathrm{K})^{MUETMP} \times E_{\mathrm{eff}}^{MUEPH0}}$$

$$\mu_{\mathrm{SR}}(\mathrm{surface\ roughness}) = \frac{MUESR1}{E_{\mathrm{eff}}^{MUESR0}}$$

User parameters: MUECB0,MUECB1 MUPH1, MUESR1

equations (50), (51), (52)and (53) in HiSIM-1.2 User's manual

HiSIM parameter extraction: equations

Geometric effects

Reverse short channel effect:

$$\Delta V_{\mathrm{th,P}} = (V_{\mathrm{th,R}} - V_{\mathrm{th0}}) \frac{\epsilon_{\mathrm{Si}}}{C_{\mathrm{ox}}} W_{\mathrm{d}} \frac{dE_{y,\mathrm{P}}}{dy}$$

$$V_{\mathrm{th,R}} = V_{\mathrm{fbc}} + 2\Phi_{\mathrm{B}} + \frac{\sqrt{2qN_{\mathrm{sub}}\epsilon_{\mathrm{Si}}(2\Phi_{\mathrm{B}} - V_{\mathrm{bs}})}}{C_{\mathrm{ox}}}$$

$$V_{\mathrm{th0}} = V_{\mathrm{fbc}} + 2\Phi_{\mathrm{BC}} + \frac{\sqrt{2qN_{\mathrm{subc}}\epsilon_{\mathrm{Si}}(2\Phi_{\mathrm{BC}} - V_{\mathrm{bs}})}}{C_{\mathrm{ox}}}$$

$$\frac{dE_{y,\mathrm{P}}}{dy} = \frac{2(V_{\mathrm{bi}} - 2\Phi_{\mathrm{B}})}{PARL1 \cdot L_{\mathrm{p}}^2} \left(SCP1 + SCP2 \cdot V_{\mathrm{ds}} + SCP3 \cdot \frac{2\Phi_{\mathrm{B}} - V_{\mathrm{bs}}}{L_{\mathrm{p}}} \right)$$

$$N_{\mathrm{sub}} = \frac{N_{\mathrm{subc}}(L_{\mathrm{eff}} - L_{\mathrm{p}}) + N_{\mathrm{subp}} L_{\mathrm{p}}}{L_{\mathrm{eff}}}$$

equations (35), (36), (37), (38) and (39) in HiSIM-1.2 User's manual

User parameters: NSUBP(NSUB),LP SCP1, SCP2, SCP3

HiSIM parameter extraction: equations
Geometric effects

Standard short channel effect:

$$\Delta V_{\mathrm{th,SC}} = \frac{\epsilon_{\mathrm{Si}}}{C_{\mathrm{ox}}} W_{\mathrm{d}} \frac{dE_y}{dy}$$

$$W_{\mathrm{d}} = \sqrt{\frac{2\epsilon_{\mathrm{Si}}(2\Phi_{\mathrm{B}} - V_{\mathrm{bs}})}{qN_{\mathrm{sub}}}}.$$

$$\frac{dE_y}{dy} = \frac{2(V_{\mathrm{bi}} - 2\Phi_{\mathrm{B}}')}{PARL1(L_{\mathrm{eff}} - PARL2)^2} \left(SC1 + SC2 \cdot V_{\mathrm{ds}} + SC3 \cdot \frac{2\Phi_{\mathrm{B}} - V_{\mathrm{bs}}}{L_{\mathrm{eff}}} \right)$$

$$\Phi_{\mathrm{B}}' = \Phi_{\mathrm{B}} + PTHROU \cdot \left(\Phi_{\mathrm{B}}''(V_{\mathrm{gs}}) - \Phi_{\mathrm{B}} \right)$$

User parameters: PARL2, SC1, SC2, SC3, PTHROU

equations (28), (29), (30)and (31) in HiSIM-1.2 User's manual

HiSIM parameter extraction: equations

Carrier mobility

High field mobility:

$$\mu = \frac{\mu_0}{\left(1 + \left(\frac{\mu_0 E_y}{V_{max}}\right)^{BB}\right)^{\frac{1}{BB}}}$$

User parameters:
VMAX, VOVER, VOVERP

$$V_{max} = \frac{VMAX}{1.8 + 0.4(T/300\mathrm{K}) + 0.1(T/300\mathrm{K})^2}$$

$$V_{max} = \frac{V_{max}}{1 - \frac{VOVER}{L_{eff}^{VOVERP}}}$$

equations (60), (61) and (62) in HiSIM-1.2 User's manual

HiSIM parameter extraction: equations
Geometric effects

Narrow channel effect:

$$\Delta V_{\mathrm{th,W}} = \left(\frac{1}{C_{\mathrm{ox}}} - \frac{1}{C_{\mathrm{ox}} + 2C_{\mathrm{ef}}/(L_{\mathrm{eff}} W_{\mathrm{eff}})} \right) qN_{\mathrm{sub}} W_{\mathrm{d}}$$

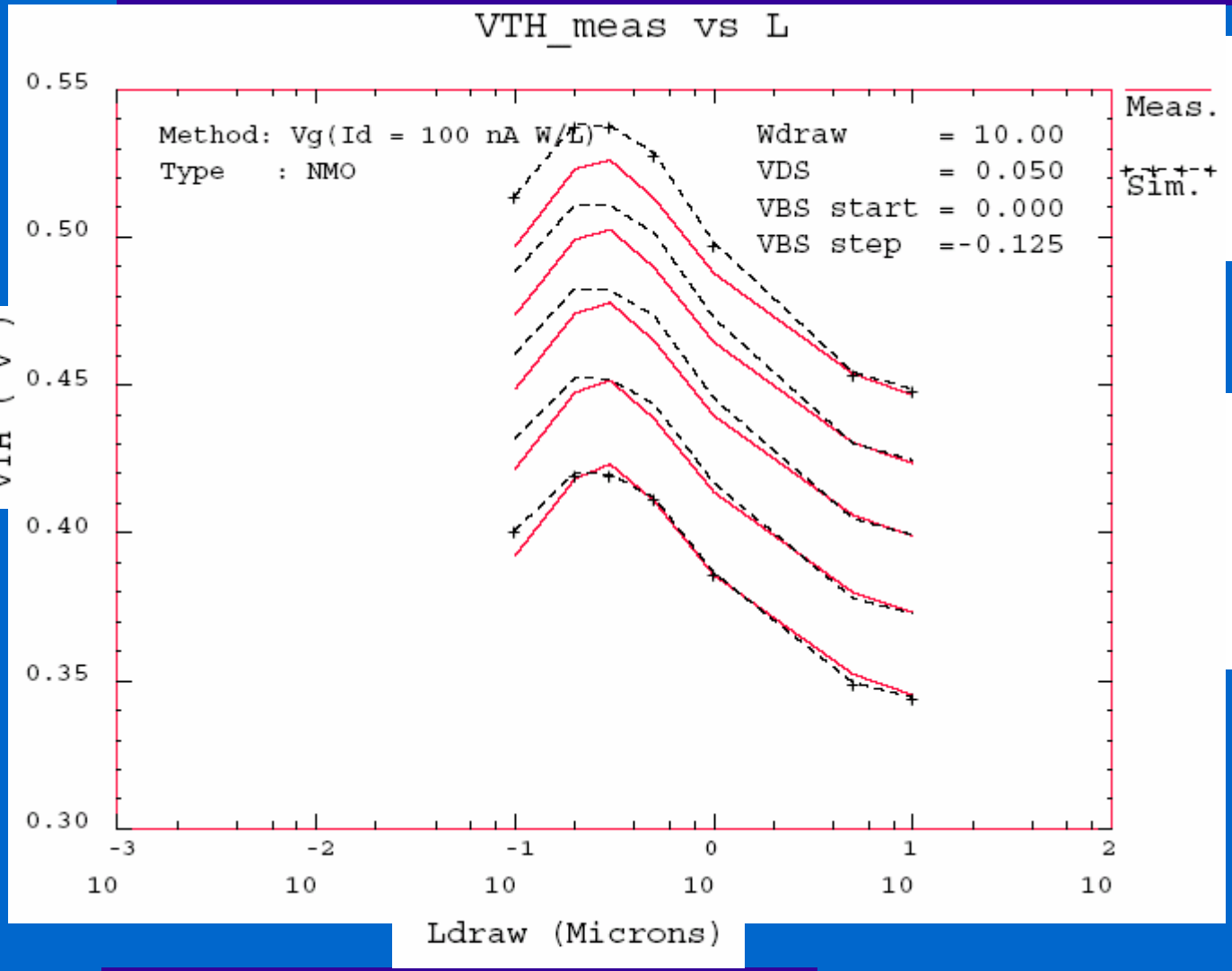
$$C_{\mathrm{ef}} = \frac{2\epsilon_{\mathrm{ox}}}{\pi} L_{\mathrm{eff}} \ln\left(\frac{2T_{\mathrm{fox}}}{T_{\mathrm{ox}}} \right) = \frac{WFC}{2} L_{\mathrm{eff}}$$

User parameters: WFC

equations (71), and (72)
in HiSIM-1.2 User's manual

HiSIM parameter extraction: results

Vth versus L-draw

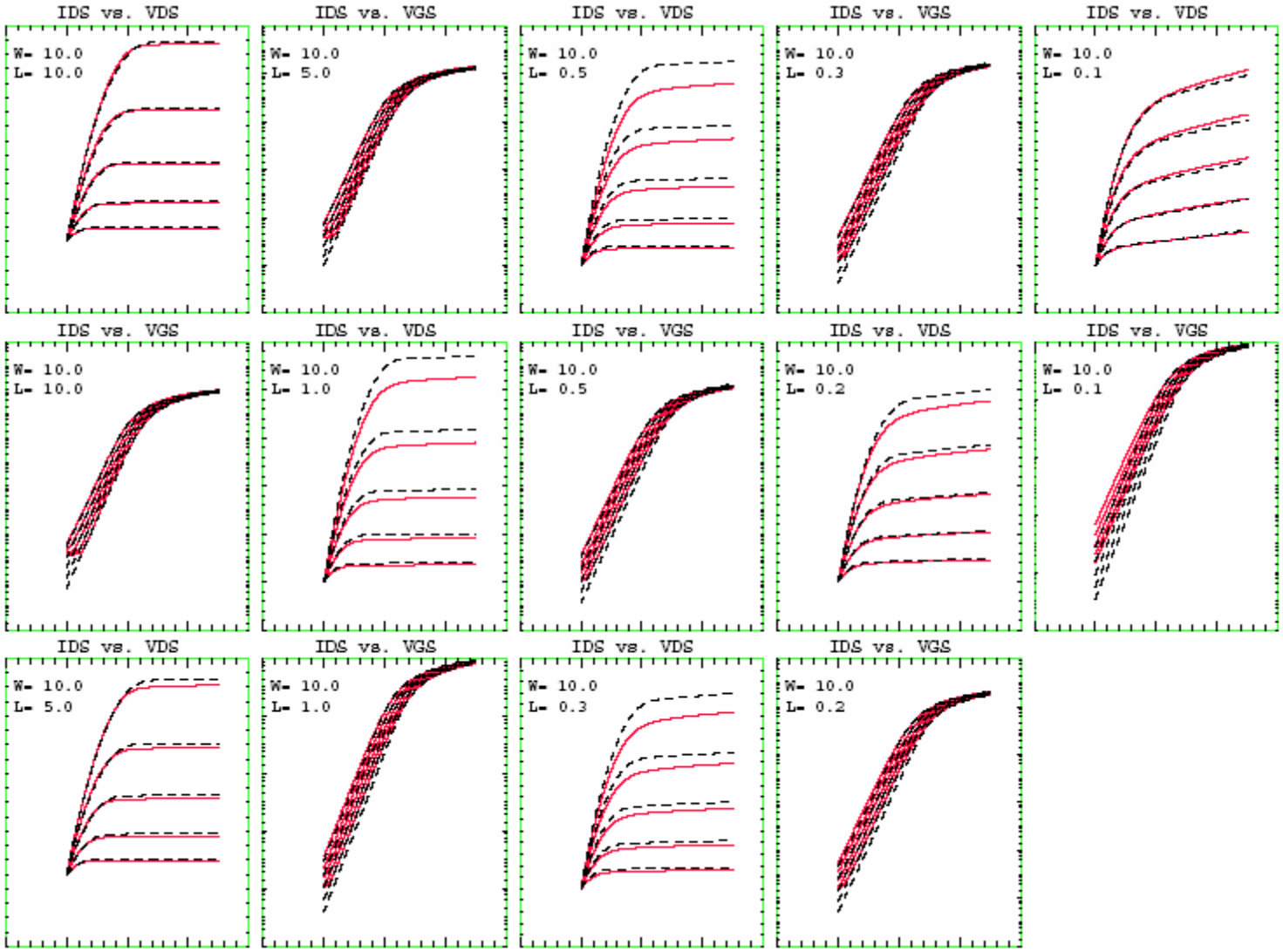


solid red: measurements
dashed black: HiSIM-1.2

The LP value dominated the gradual increase of Vth.
The value is 9E-7 [m] which exceeds the structural constraint.

HiSIM parameter extraction: results

L-array devices-1



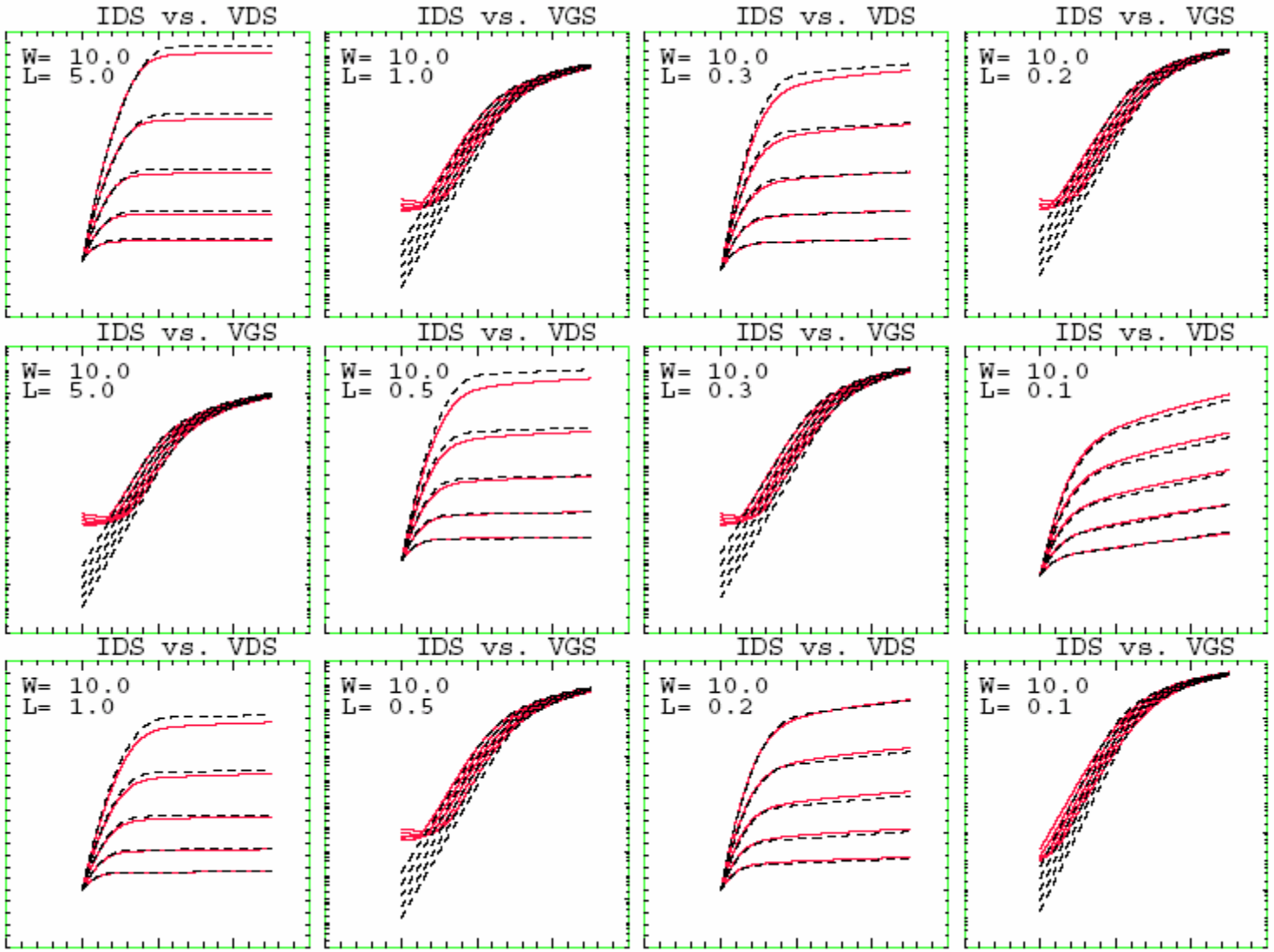
solid red:
measurements
dashed black:
HiSIM-1.2

Ids/Vds @Vbs=0
Vds = 0 -> 1.0V
Vgs = " nearVth"
-> 1.0V

Ids/Vgs@Vds=0.05V
Vgs = 0 -> 1.0V
Vbs = 0 -> -0.5V

HiSIM parameter extraction: results

L-array devices-2



solid red:
measurements
dashed black:
HiSIM-1.2

Ids/Vds@Vbs=-0.5V
Vds = 0 -> 1.0V
Vgs = " nearVth"
-> 1.0V

Ids/Vgs@Vds=1.0V
Vgs = 0 -> 1.0V
Vbs = 0 -> -0.5V

HiSIM parameter extraction: results

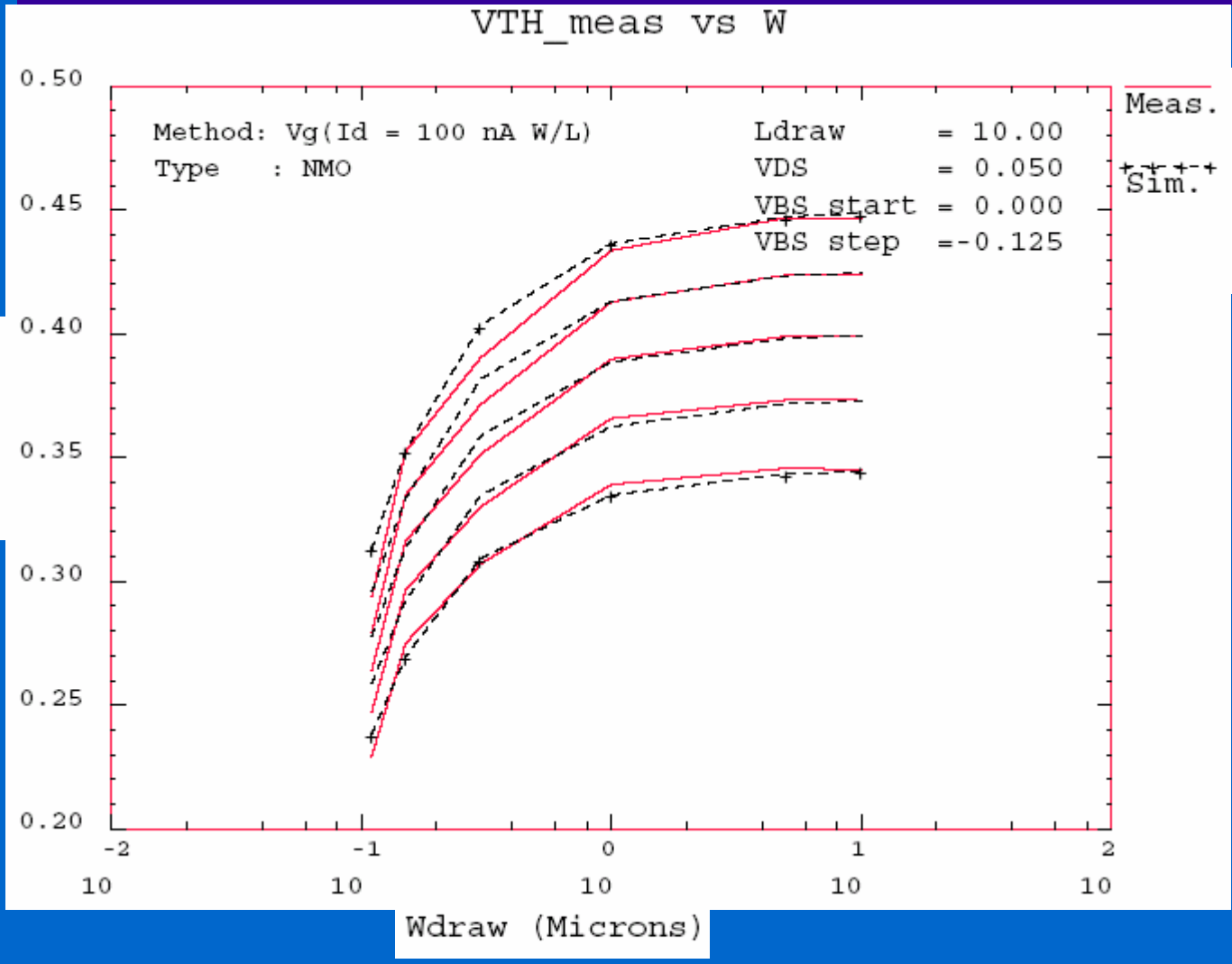
L-array R.M.S. Errors for Ids/Vds

W/L [um/um]	Ids/Vds @Vbs= 0[V] R.M.S. error [%] all regions : saturation	Ids/Vds @Vbs= -0.5[V] R.M.S. error [%] all regions : saturation
10/10	4.0 % : 2.3 %	N.A. % : N.A. %
10/5.0	5.8 % : 4.5 %	4.9 % : 4.3 %
10/1.0	10.0 % : 10.0 %	3.4 % : 3.4 %
10/0.5	12.0 % : 11.4 %	4.2 % : 3.6 %
10/0.3	11.1 % : 9.8 %	2.8 % : 2.2 %
10/0.2	4.4 % : 4.2 %	4.3 % : 4.0 %
10/0.1	3.0 % : 3.1 %	3.6 % : 3.8 %

The saturation region is Vds = 0.4 -> 1 [V] at the strong inversion Vgs.

HiSIM parameter extraction: results

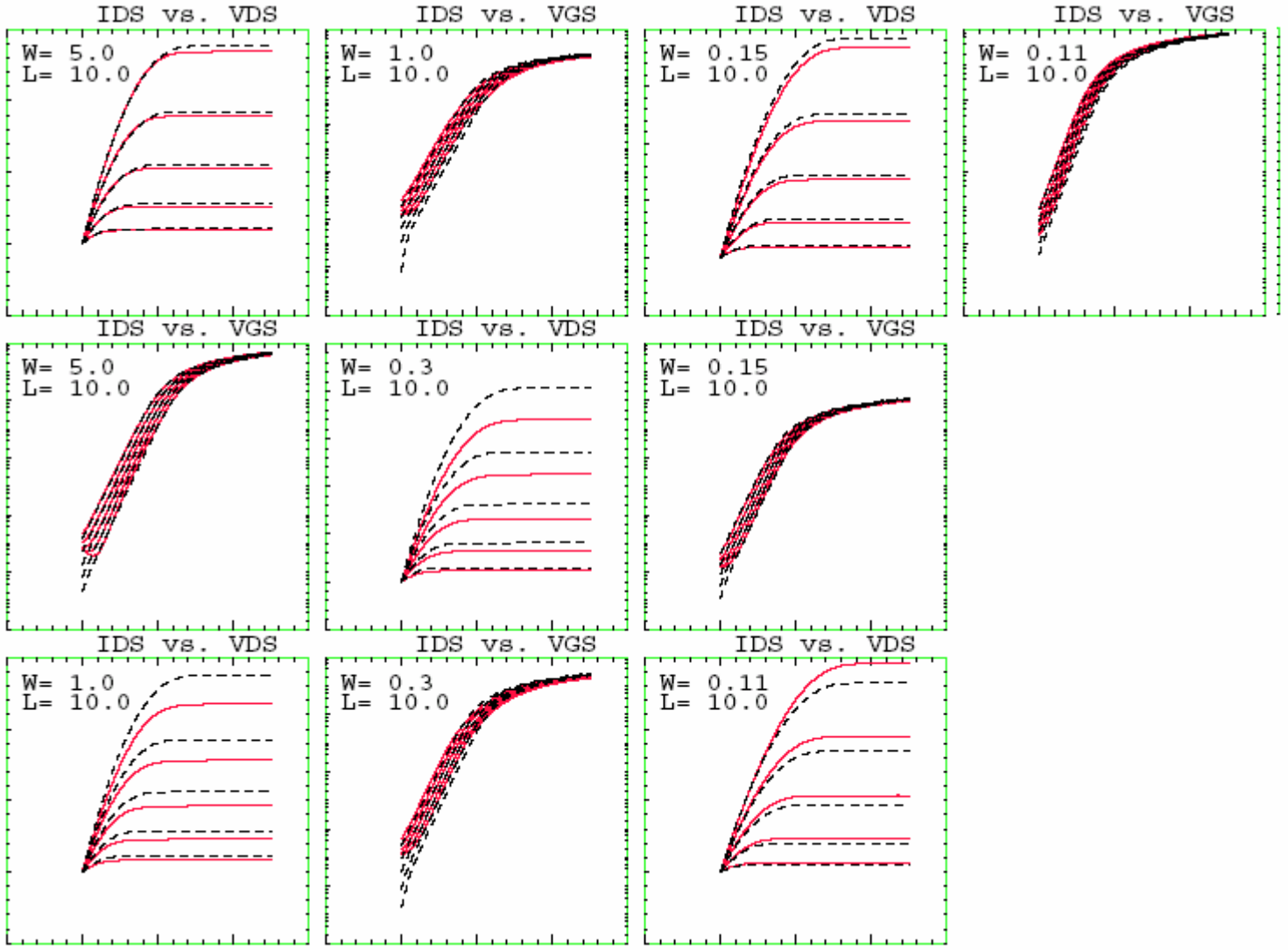
Vth versus W-draw



solid red: measurements
dashed black: HiSIM-1.2

HiSIM parameter extraction: results

W-array devices-1



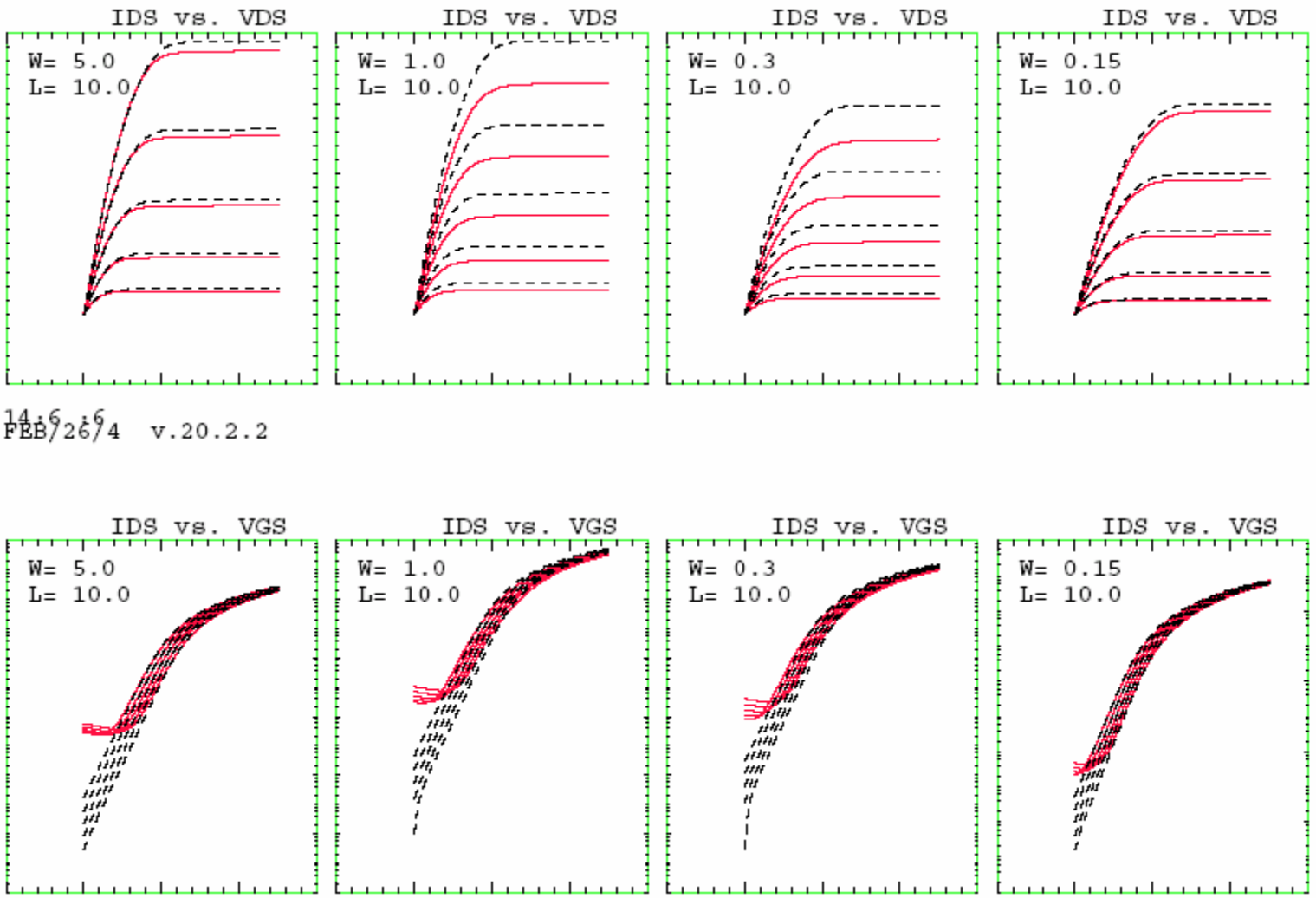
solid red:
measurements
dashed black:
HiSIM-1.2

Ids/Vds @Vbs=0
Vds = 0 -> 1.0V
Vgs = " nearVth"
-> 1.0V

Ids/Vgs@Vds=0.05V
Vgs = 0 -> 1.0V
Vbs = 0 -> -0.5V

HiSIM parameter extraction: results

W-array devices-2



solid red:
measurements
dashed black:
HiSIM-1.2

Ids/Vds@Vbs=-0.5V
Vds = 0 -> 1.0V
Vgs = " nearVth" -> 1.0V

Ids/Vgs@Vds=1.0V
Vgs = 0 -> 1.0V
Vbs = 0 -> -0.5V

HiSIM parameter extraction: results

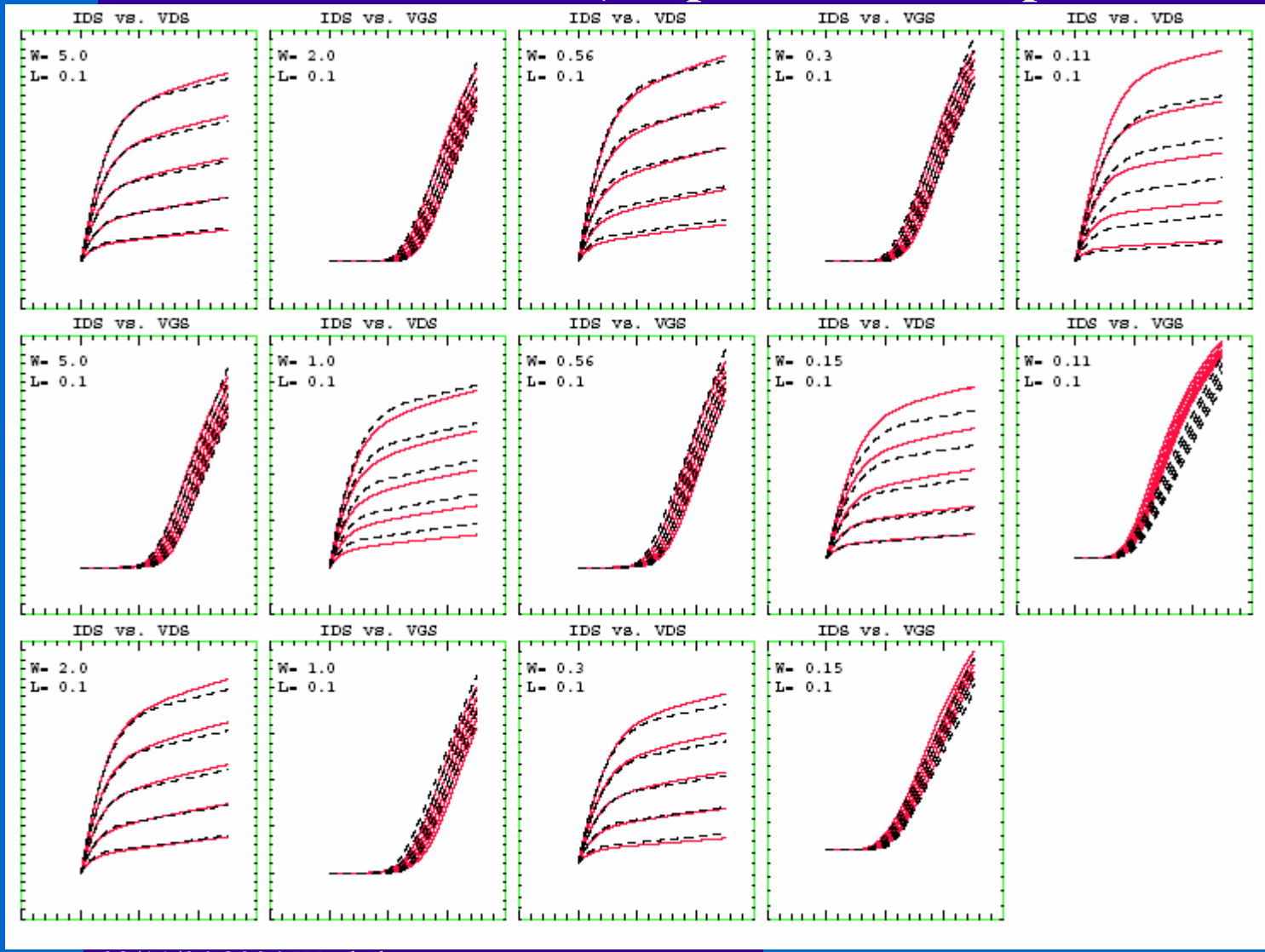
W-array R.M.S. Errors for Ids/Vds

W/L [um/um]	Ids/Vds @Vbs= 0[V] R.M.S. error [%] all regions : saturation	Ids/Vds @Vbs= -0.5[V] R.M.S. error [%] all regions : saturation
5.0/10	5.9 % : 4.6 %	5.6 % : 5.0 %
1.0/10	22.4 % : 20.9 %	22.6 % : 21.8 %
0.3/10	23.6 % : 22.6 %	22.9 % : 22.5 %
0.15/10	8.4 % : 6.5 %	6.7 % : 5.5 %
0.11/10	11.7 % : 11.4 %	N.A. : N.A.

The saturation region is Vds = 0.4 -> 1 [V] at the strong inversion Vgs.

HiSIM parameter extraction: results

Small devices-1 (No parameter is optimized for them.)



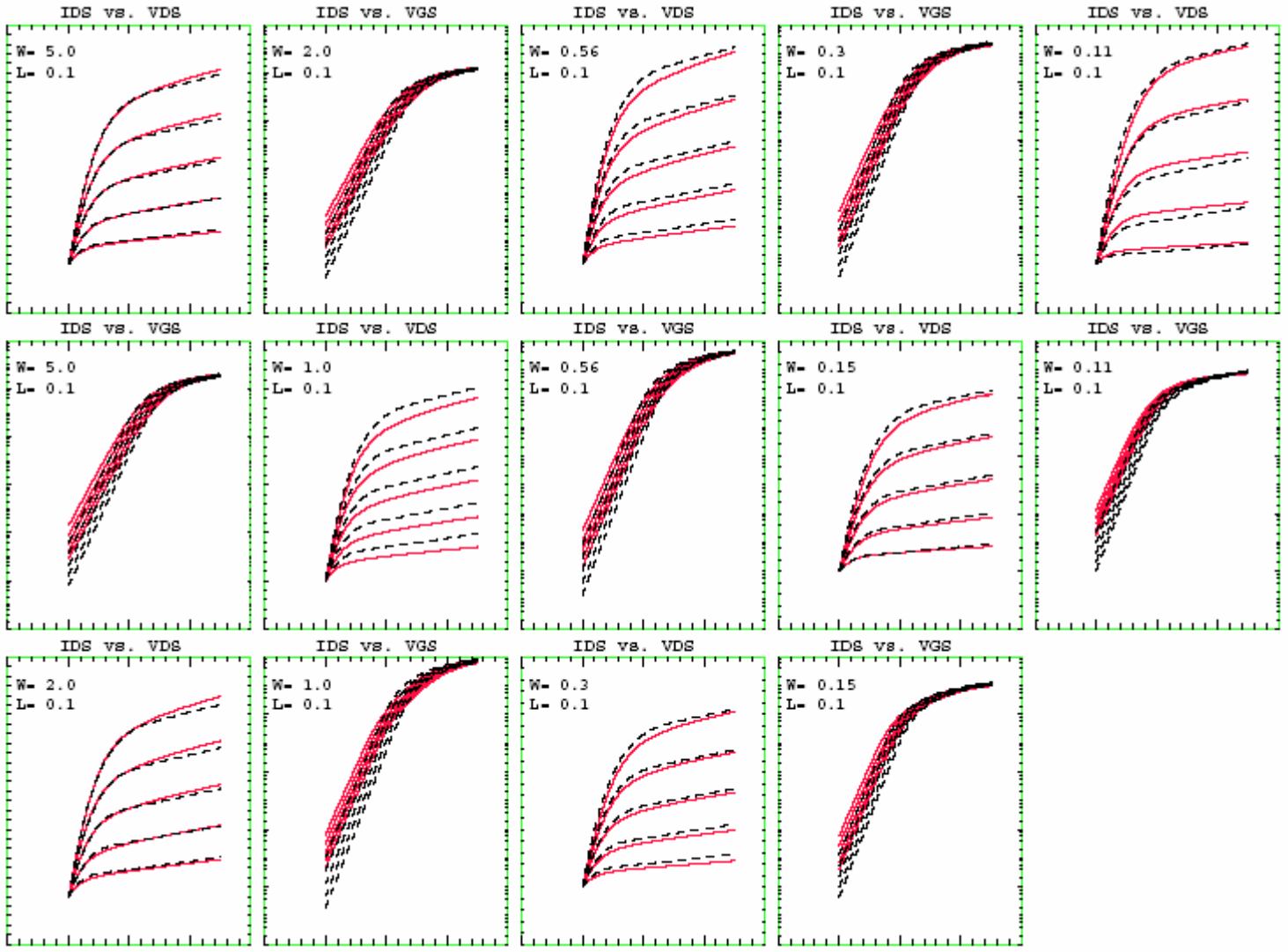
solid red:
measurements
dashed black:
HiSIM-1.2

Ids/Vds @Vbs=0
Vds = 0 -> 1.0V
Vgs = " nearVth"
-> 1.0V

Ids/Vgs@Vds=0.05V
Vgs = 0 -> 1.0V
Vbs = 0 -> -0.5V

HiSIM parameter extraction: results

Small devices-1+ (The XWD parameter is modified.)



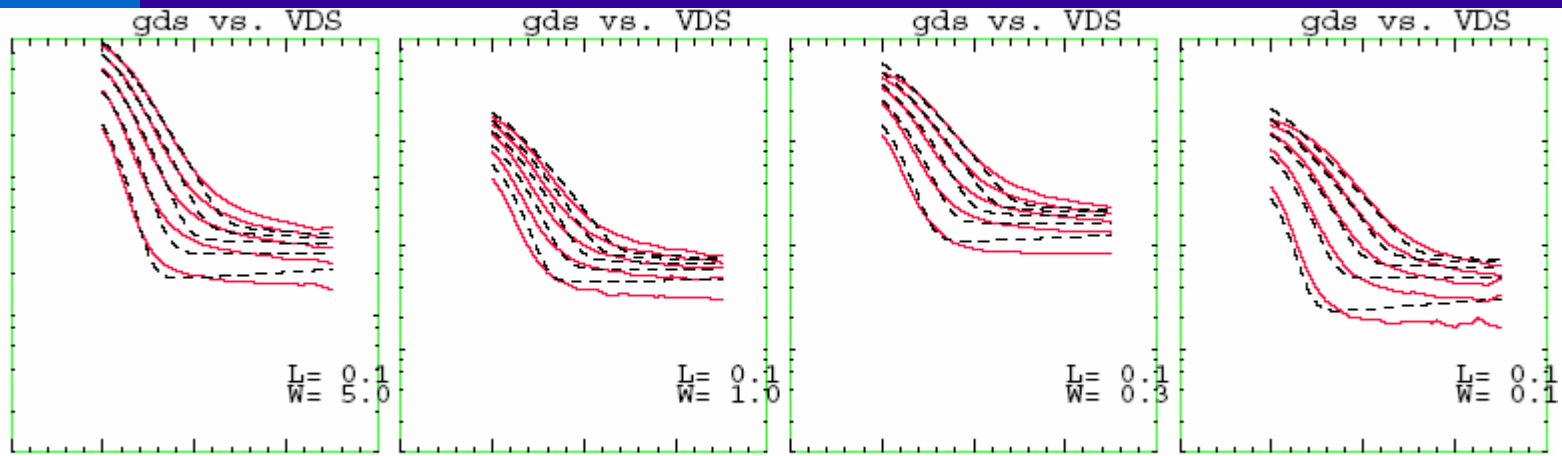
solid red:
measurements
dashed black:
HiSIM-1.2

Ids/Vds @Vbs=0
Vds = 0 -> 1.0V
Vgs = " nearVth"
-> 1.0V

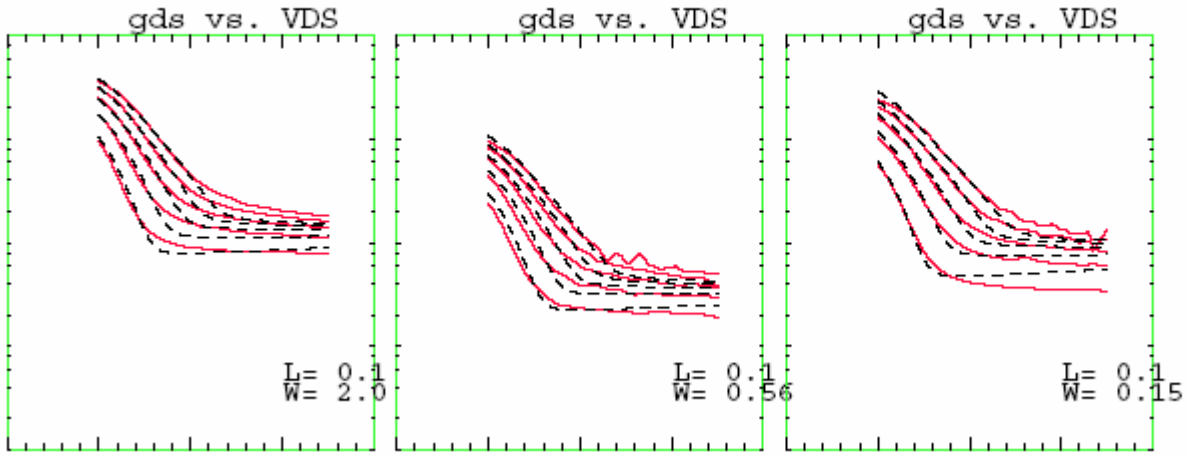
Ids/Vgs@Vds=0.05V
Vgs = 0 -> 1.0V
Vbs = 0 -> -0.5V

HiSIM parameter extraction: results

Small device-2 (The XWD parameter is modified.)



11:29:12
FEB/26/4 v.20.2.2

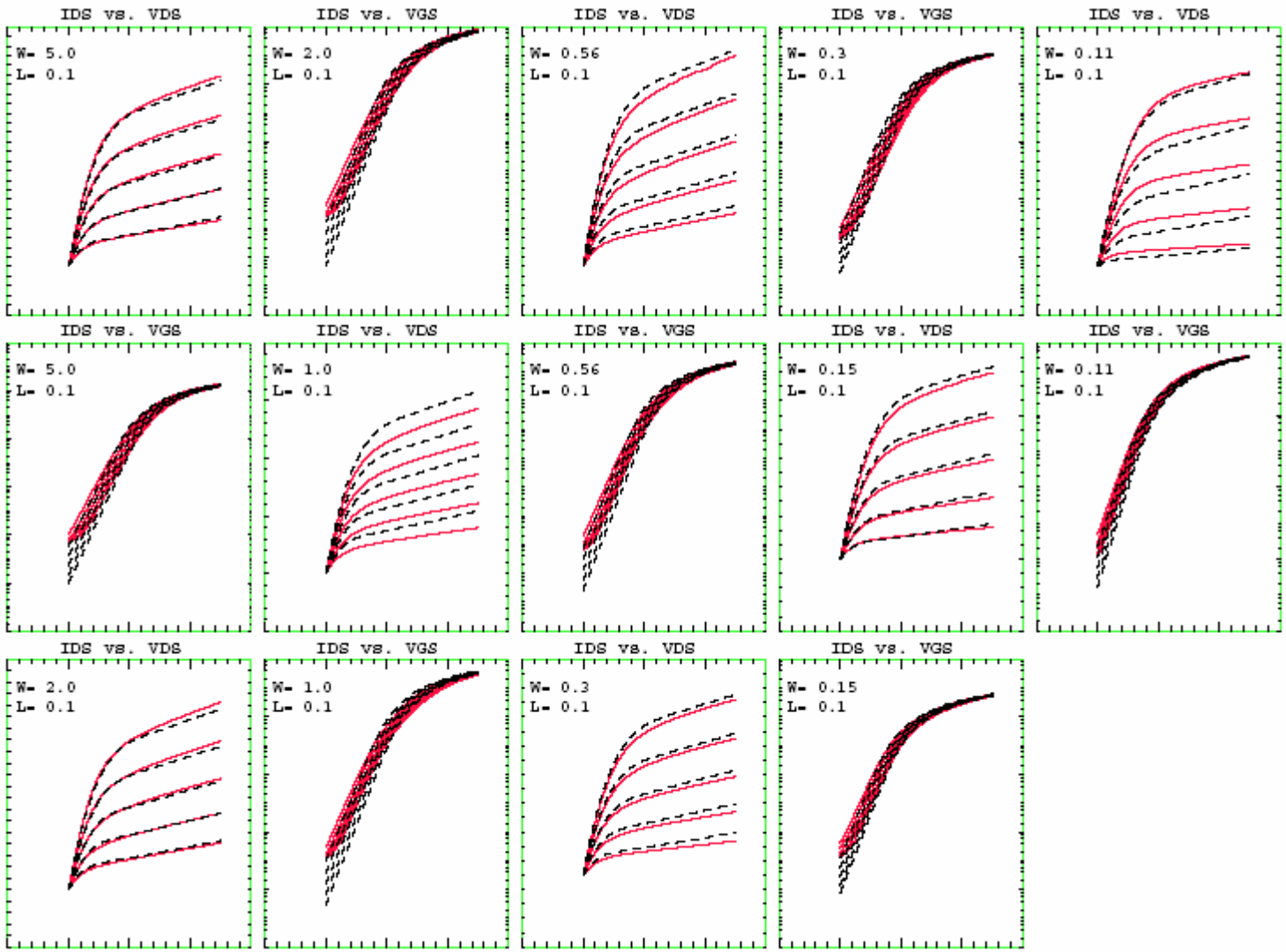


solid red:
measurements
dashed black:
HiSIM-1.2

gds/Vds@Vbs=0V
Vds = 0 -> 1.0V
Vgs = " nearVth"
-> 1.0V

HiSIM parameter extraction: results

Small devices-3 (The XWD parameter is modified.)



solid red:
measurements
dashed black:
HiSIM-1.2

Ids/Vds@Vbs=-0.5V
Vds = 0 -> 1.0V
Vgs = " nearVth"
-> 1.0V

Ids/Vgs@Vds=1.0V
Vgs = 0 -> 1.0V
Vbs = 0 -> -0.5V

HiSIM parameter extraction: results

Small device R.M.S. Errors for Ids/Vds

W/L [um/um]	Ids(gds)/Vds @Vbs= 0[V] R.M.S. error [%] all regions	: saturation	Ids(gds)/Vds @Vbs= -0.5[V] R.M.S. error [%] all regions	: saturation
5.0/0.1	3.7 (13.9)	: 2.0	2.8 (11.7)	: 2.3
2.0/0.1	4.7 (15.6)	: 2.7	3.8 (11.8)	: 2.5
1.0/0.1	22.4 (23.1)	: 14.7	23.0 (26.3)	: 18.3
0.56/0.1	12.4 (16.3)	: 6.9	10.5 (14.1)	: 6.6
0.3/0.1	13.0 (19.1)	: 5.8	11.1 (20.4)	: 6.6
0.15/0.1	6.5 (19.0)	: 5.0	5.3 (21.5)	: 5.1
0.11/0.1	12.2 (29.9)	: 7.7	20.2 (35.8)	: 13.3

The saturation region is Vds = 0.4 -> 1 [V] at the strong inversion Vgs.

Result : HiSIM-1.2 Model Parameter listing-1

The default values with this color.

.MODEL 100nm NMOS (LEVEL = 111
VERSION = 1.2 TOX = 2.287E-9 XLD = 0 XWD = 1E-8*
XPOLYD = 0 XDIFFD = 0 TPOLY = 0 NSUBC = 1.205709E18
VFBC = -1.0100703 LP = 9E-7 NSUBP = 1.46684E18 XQY = 0
KAPPA = 3.9 SCP1 = 1E-7 SCP2 = 0.2063246 SCP3 = 1.697679E-13
PARL1 = 1 PARL2 = 5.321228E-11 SC1= 38.6302179
SC2 = 89.4625364 SC3 = 4.415391E-11 PTHROU = 0
WFC = 4.405588E-14 W0 = 0 COISTI = 0 WVTHSC = 0
NSTI = 1E17 WSTI = 0 QME1 = 4E-11 QME2 = 3E-10 QME3 = 0
PGD1 = 0.01 PGD2 = 1 PGD3 = 0.8 RS = 8E-5 RD = 8E-5
RPOCK1 = 1E-4 RPOCK2 = 0.1 RPOCP1 = 1 RPOCP2 = 0.5
BGTMP1 = 9.025E-5 BGTMP2= 1E-7

** XWD=2.2E-8 for W_array devices(L=10 um).*

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Result : HiSIM-1.2 Model Parameter listing-2

The default values with this color.

MUECB0 = 324.9842471 MUECB1 =38.1824712 MUEPH0 = 0.3
MUEPH1 = 1.609843E4 MUEPH2 = 0 MUETMP = 1.5
MUESR0 = 2 MUESR1 = 2.974452E15 NDEP = 1 NINV = 0.5
NINVD = 1E-9 BB = 2 VMAX = 1.538012E7 VOVER = 4.886081E-3
VOVERP = 0.1218723 CLM1 = 0.7 CLM2 = 2 CLM3 = 1
COISUB = 0 SUB1 = 10 SUB2 = 20 SUB3 = 0.8 COGIDL = 0
COGISL = 0 GIDL1 = 5E-6 GIDL2 = 1E6 GIDL3 = 0.3
COIIGS = 0 GLEAK1= 1E4 GLEAK2 = 2E7 GLEAK3 = 0.3
GLPART1 = 0 GLPART2 = 0 VZADD0 = 0.01 PZADD0 =5E-3
CONOIS = 0 NFALP = 1E-16 NFTRP = 1E10 CIT = 0

(Several parameter values are carefully modified to preserve the overall characteristics without reproducing the actual drain current.)

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Acknowledgement

The author would like to thank Semiconductor Technology Academic Research Center (STARC), Yokohama, Japan, for permitting to use the device data.

Thank you for your attention.

And the presented results with the step by step observations are exhibited at the poster booth.