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MOS Transistor Mismatch in a 0.35um HV-Process
Test Structures and Parameter Extraction
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MOS-AK
2006/03/24
a leap ahead

INTRO / MOTIVATION

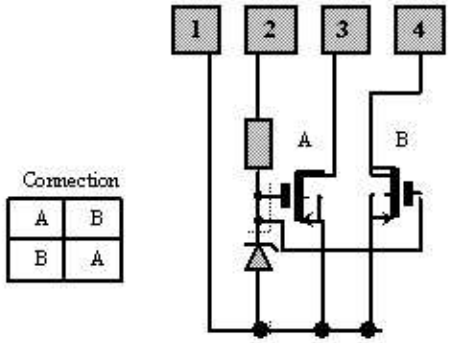
What: Mismatch, HV-MOS

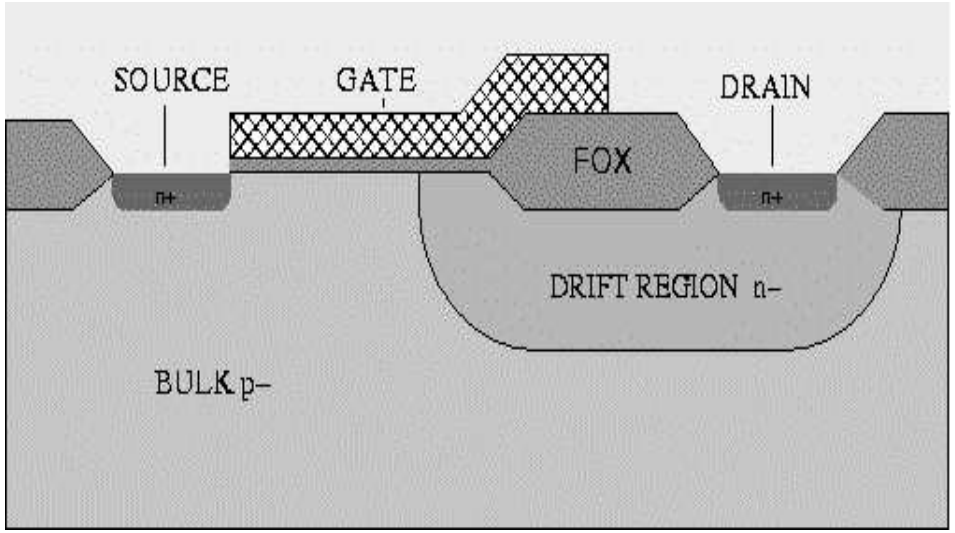
Why: structures of HV-MOSFET,

different effects (RON)

Needed: Short and long distance

mismatch characterisation





Goal:

Parameters for

Simulator Implementation

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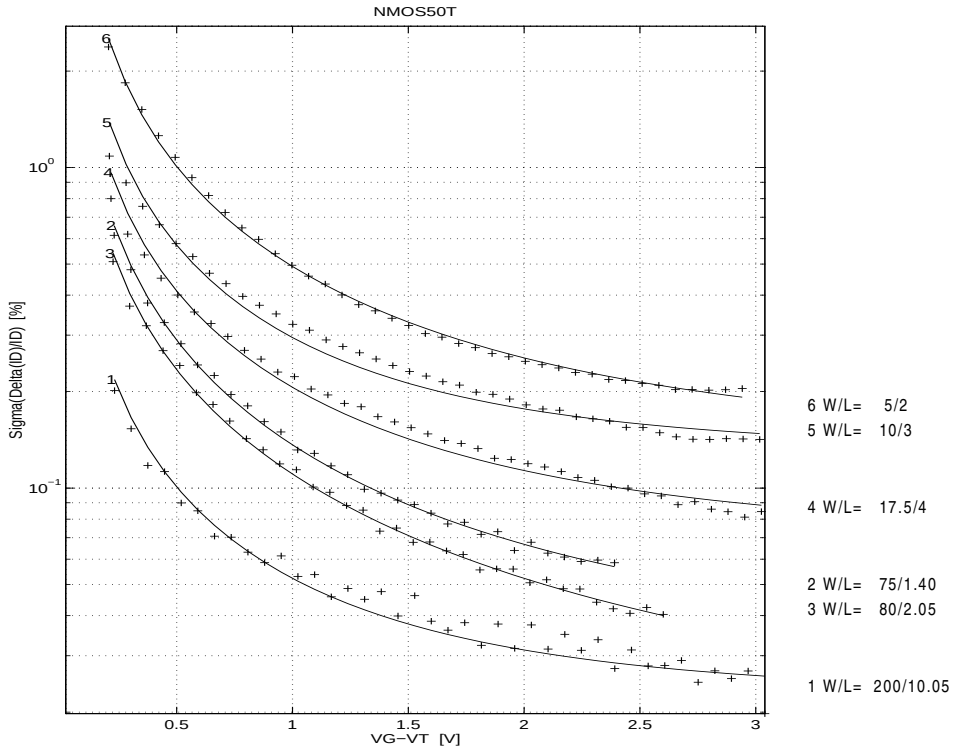
Drain current mismatch

Relative Drain current mismatch:

$$\Delta ID / ID = \frac{2 \cdot (ID_1 - ID_2)}{(ID_1 + ID_2)}$$

Variance of Drain current mismatch:

$$\sigma(\Delta ID / ID) = \sigma\left(\frac{2 \cdot (ID_1 - ID_2)}{(ID_1 + ID_2)}\right)$$



NMOS50T relative drain current mismatch vs. VG-VT, +...measurement, —...mismatch model

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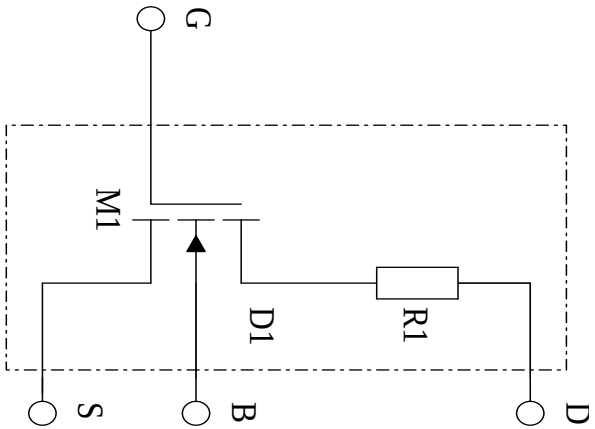
Mismatch Modeling

Mismatch Modeling:

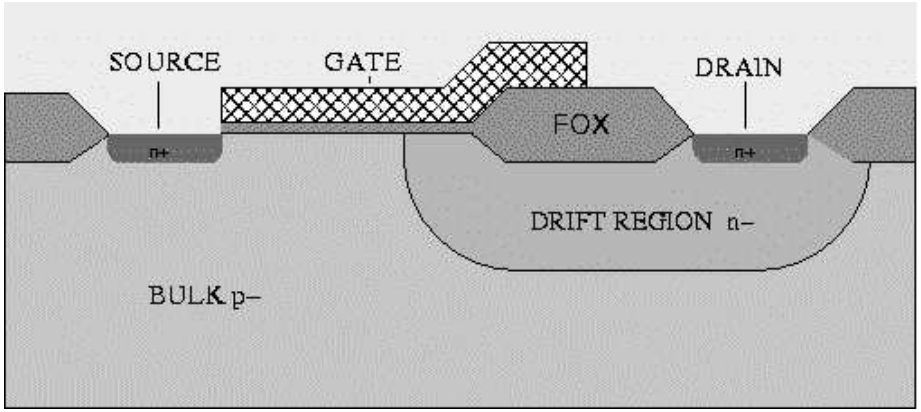


What is needed:

mobility

threshold

resistances (drift region)



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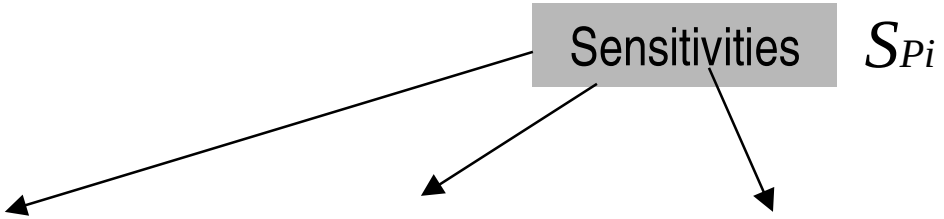
Variance Model

Drain current:

$$I_D = f(P_1, P_2, ..., P_n)$$

Varinance Model:



$$\frac{\Delta I_D}{I_D} = \frac{1}{I_D}\left(\frac{\partial f}{\partial P_1}\right)\Delta P_1 + \frac{1}{I_D}\left(\frac{\partial f}{\partial P_2}\right)\Delta P_2 + \cdots + \frac{1}{I_D}\left(\frac{\partial f}{\partial P_n}\right)\Delta P_n + corr.$$

$$\sigma^2\left(\frac{\Delta I_D}{I_D}\right) = S_{P1}{}^2\,\sigma^2(\Delta P_1) + S_{P2}{}^2\sigma^2(\Delta P_2) + \cdots \quad + S_{Pn}{}^2\sigma^2(\Delta Pn) \quad + corr$$

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Example

Example:

V_T threshold voltage

κ current gain factor

θ mobility reduction

R_D drain resistance

drain current saturation region:.....Saturation region

$$I_D = \frac{W}{L}\frac{\kappa}{2}\frac{(V_G - V_T)^2}{1+\theta(V_G - V_T)}$$

drain current linear region:

$$I_D = \frac{W}{L}\frac{\kappa(V_G - V_T)\cdot VDS}{1+(\theta+\alpha_r)\cdot(V_G - V_T)}, \qquad \alpha_r = \frac{W}{L}\cdot\kappa\cdot R_D$$

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Example Sensitivities

Sensitivities linear region

$$\frac{\Delta I_D}{I_D} = -\left(\frac{1}{(V_G - V_T)(1+(\theta+\alpha_r)(V_G - V_T))}\right)\Delta V_T - \left(\frac{V_G - V_T}{1+(\theta+\alpha_r)(V_G - V_T)}\right)\Delta\theta$$

Sensitivities

$$+\left(\frac{1+\theta(V_G - V_T)}{\kappa(1+(\theta+\alpha_r)(V_G - V_T))}\right)\Delta\kappa - \left(\frac{W}{L}\frac{\kappa(V_G - V_T)}{1+(\theta+\alpha_r)(V_G - V_T)}\right)\cdot\Delta R_D$$

$$-\frac{I_D}{VDS}$$

Sensitivities saturation region

$$\frac{\Delta I_D}{I_D} = -\left(\frac{2+\theta(V_G - V_T)}{(V_G - V_T)(1+\theta(V_G - V_T))}\right)\Delta V_T + \frac{1}{\kappa}\Delta\kappa - \left(\frac{V_G - V_T}{1+\theta(V_G - V_T)}\right)\Delta\theta$$

Sensitivities

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Strategy saturation region

m: *number of matched pairs*, $n = 2m$: *number of measured curves*

1) *Extract transistor parameters* $V_{T\,i}$, κ_i *and* θ_i $(i = 1 \ldots n)$ *from measured curves of ID vs. VG and* $VD >> VG - VT$.

2) *Calculate averaged parameters*

$$V_T = \frac{1}{n}\sum V_{T_i}, \kappa = \frac{1}{n}\sum \kappa_i, \theta = \frac{1}{n}\sum \theta_i$$

3) *Calculate*

$$S_{VT}{}^2 = \left(-\frac{2 + \theta(V_G - V_T)}{(V_G - V_T)(1 + \theta(V_G - V_T))} \right)^2 \qquad S_{\kappa}{}^2 = \frac{1}{\kappa^2} \qquad S_{\theta}{}^2 = \left(-\frac{V_G - V_T}{1 + \theta(V_G - V_T)} \right)^2$$

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Strategy linear region

m: *number of matched pairs,* $n = 2m$:*number of measured curves*

1) *Extract transistor parameters* $V_{Ti}, (\kappa_i, \theta_i)$ *and* RD_i $(i = 1 \ldots n)$ *from measured curves of ID vs. VG and* $VD << VG - VT$.

2) *Calculate averaged parameters*

$$V_T = \frac{1}{n}\sum V_{T_i}, \qquad RD = \frac{1}{n}\sum RD_i, \qquad \left(\kappa = \frac{1}{n}\sum \kappa_i, \theta = \frac{1}{n}\sum \theta_i\right)$$

3) *Calculate*

$$S_{VT}{}^2 = \left(-\frac{1}{(V_G - V_T)(1+(\alpha_r + \theta)(V_G - V_T))}\right)^2 \qquad S_\theta{}^2 = \left(-\frac{V_G - V_T}{1+(\alpha_r + \theta)(V_G - V_T)}\right)^2$$

$$S_\kappa{}^2 = \left(\frac{1+\theta(V_G - V_T)}{\kappa(1+(\alpha_r + \theta)(V_G - V_T))}\right)^2 \qquad S_{RD}{}^2 = \left(-\frac{\kappa\frac{W}{L}(V_G - V_T)}{1+(\alpha_R + \theta)(V_G - V_T)}\right)^2 = \left(-\frac{ID}{VDS}\right)^2$$

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Extraction of Mismatch parameters

Mismatch consists of:

$$\sigma^2\left(\frac{\Delta I_D}{I_D}\right) = S_{V_T}{}^2\ \sigma^2(\Delta V_T) + S_\kappa{}^2\sigma^2(\Delta\kappa) + S_\theta{}^2\sigma^2(\Delta\theta) + S_R{}^2\sigma^2(\Delta R)$$

1. Step, saturation region: Extraction of

$$\sigma(\Delta V_T),\quad \sigma(\Delta\kappa),\quad \sigma(\Delta\theta)$$

2. Step, linear region: Extraction of

$$\sigma(\Delta V_T),\quad \sigma(\Delta R)$$

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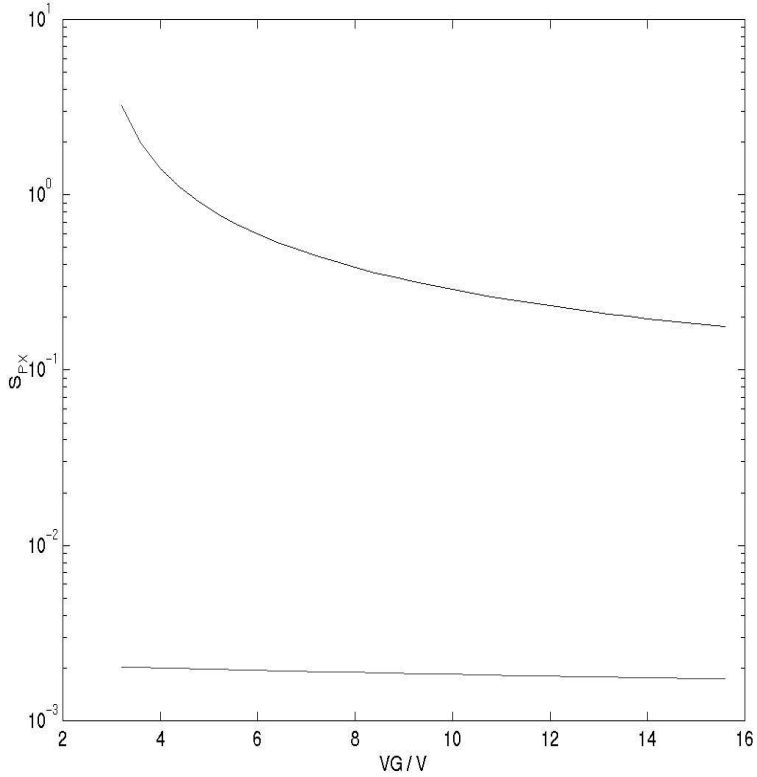
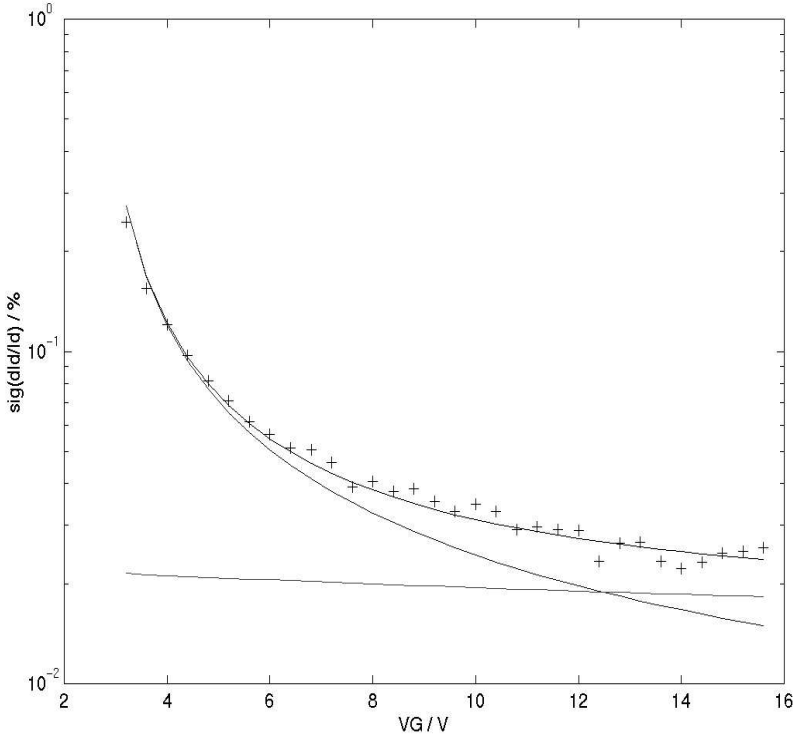
SATURATION





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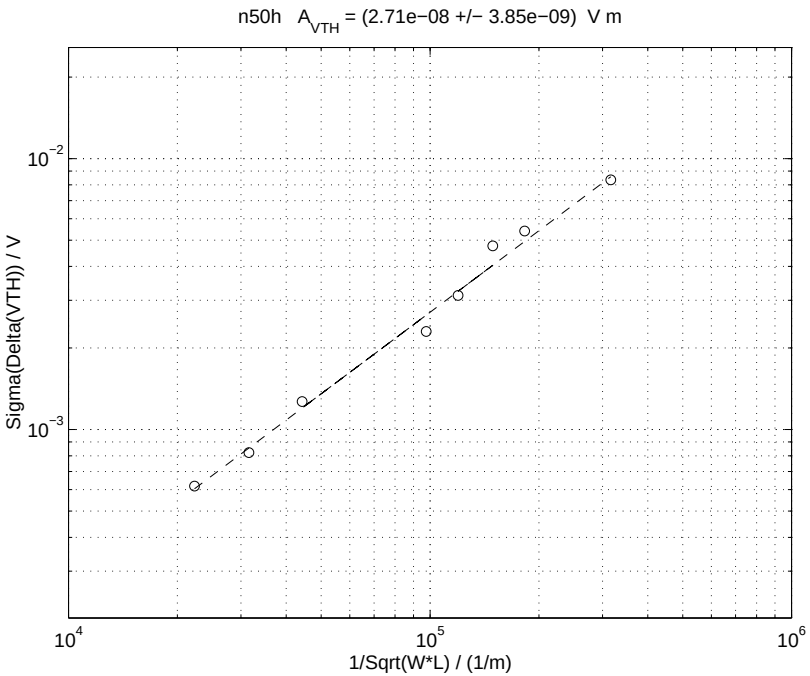
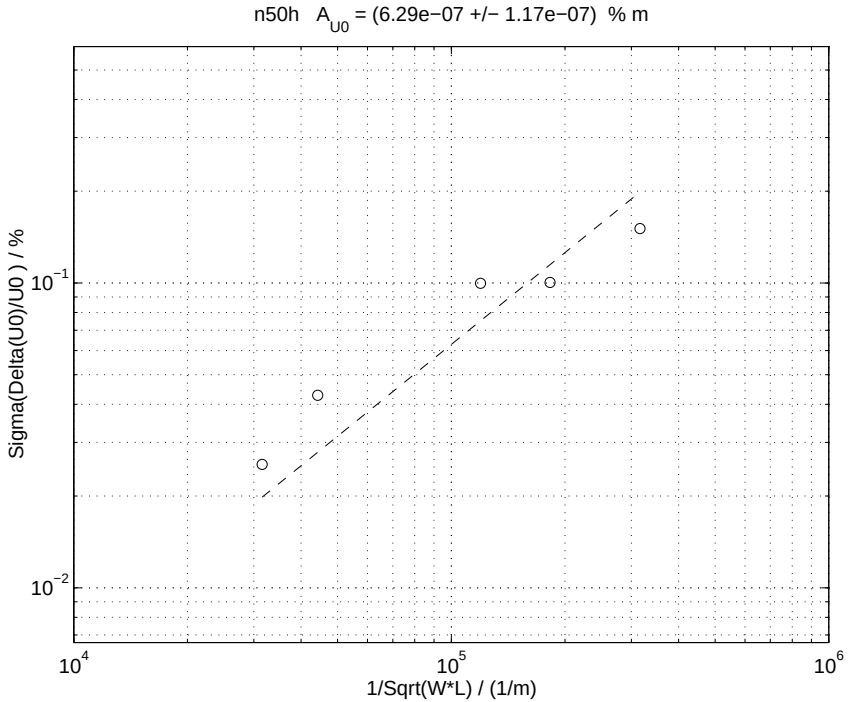
RESULTS SATURATION





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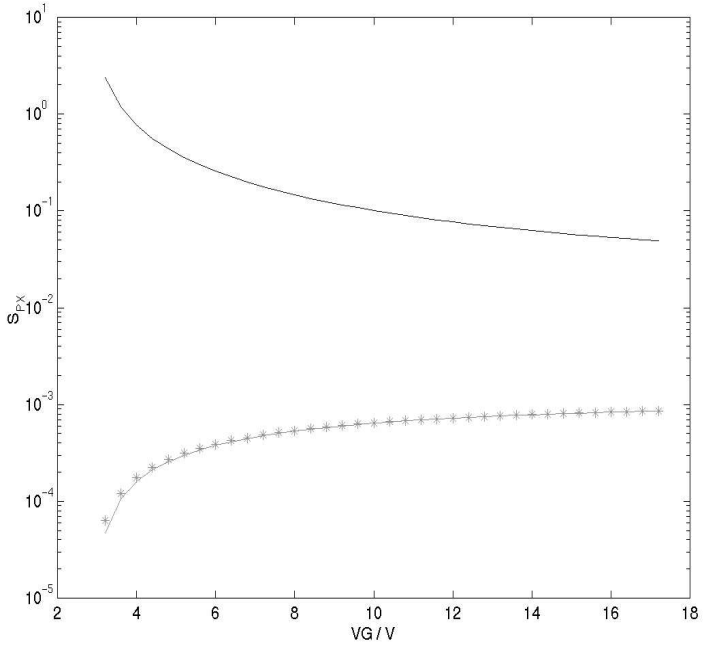
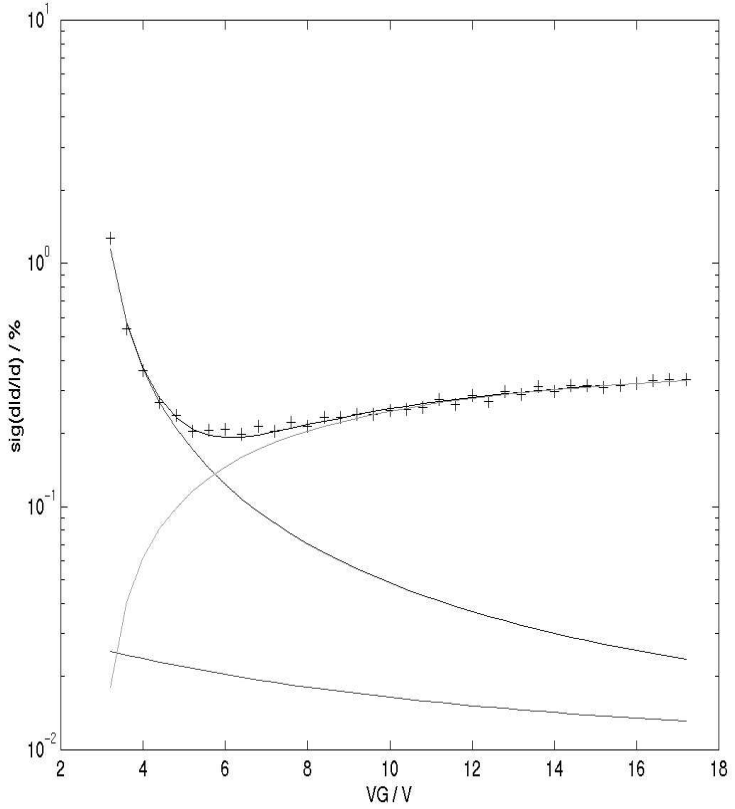
LINEAR REGION





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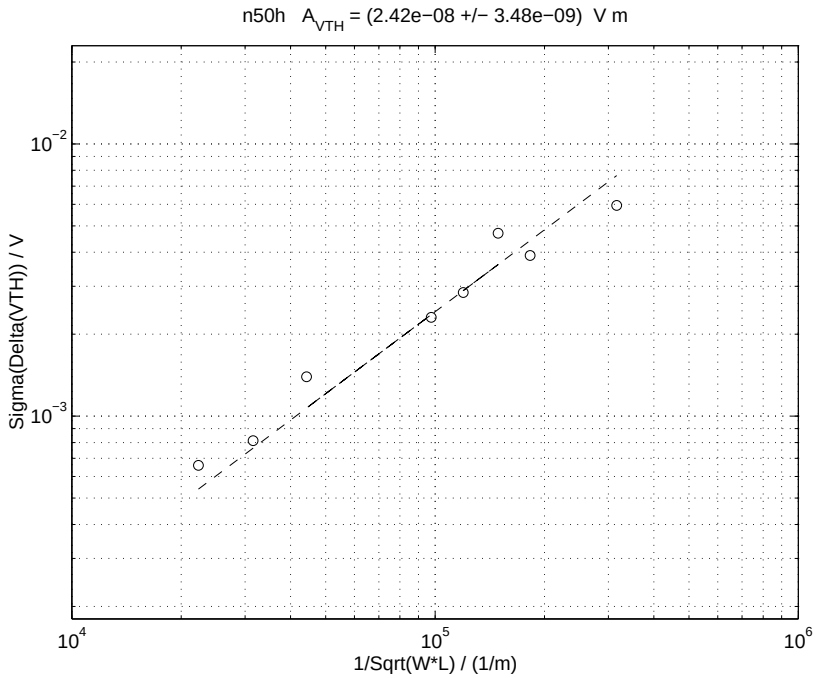
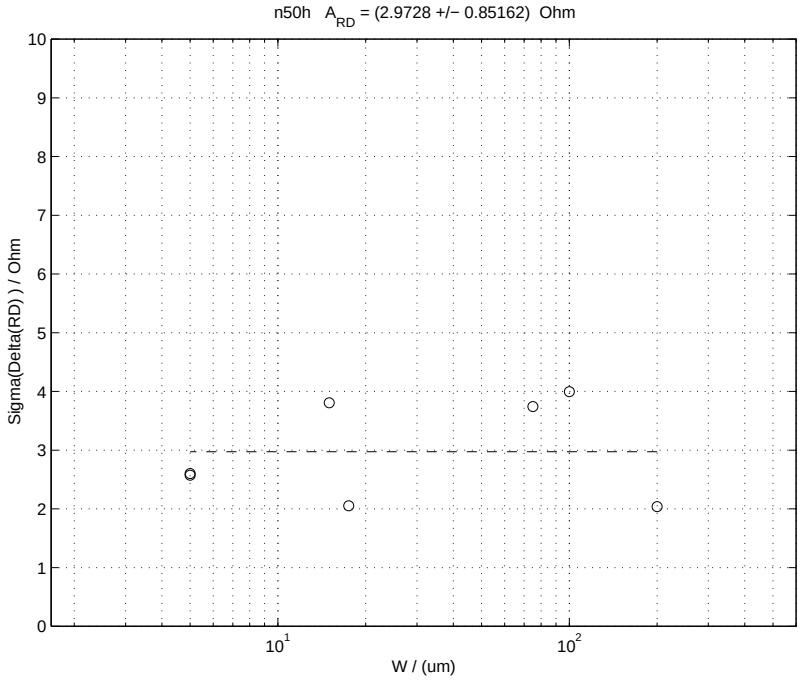
RESULTS LINEAR REGION

Results for linear region (RON)





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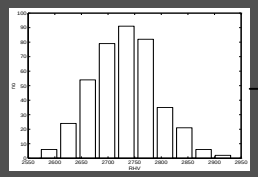
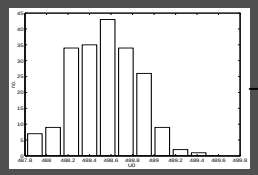
Verification of the Strategy

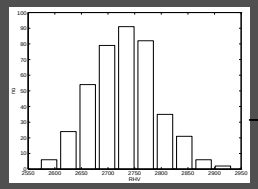
BSIM3v3 MODEL Parameters



VTH0

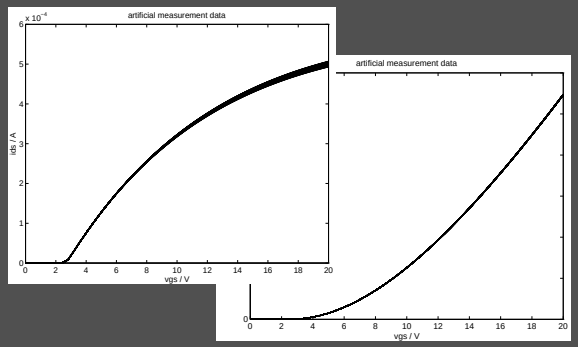


U0



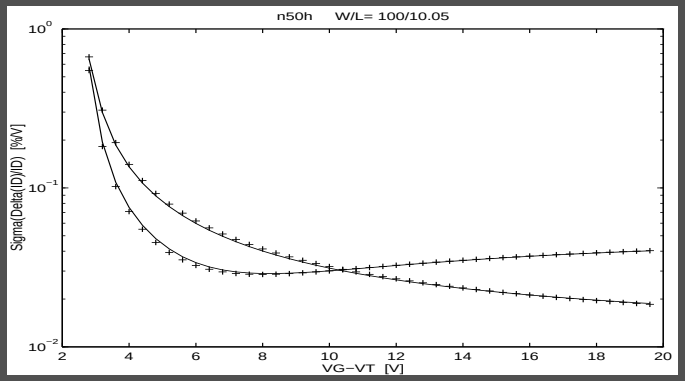
RHV

SPICE SIMULATOR



Parameter Extraction:

$$\sigma^2\left(\frac{\Delta I_D}{I_D}\right) = f\left(\sigma(\Delta V_T), \sigma(\Delta\kappa), \sigma(\Delta R_D)\right)$$



Does Extracted Data correspond to input data?

Yes: Strategy ok

No: change Strategy

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MATCHING TC

Test Chip:

automatic measurement system

serial addressing

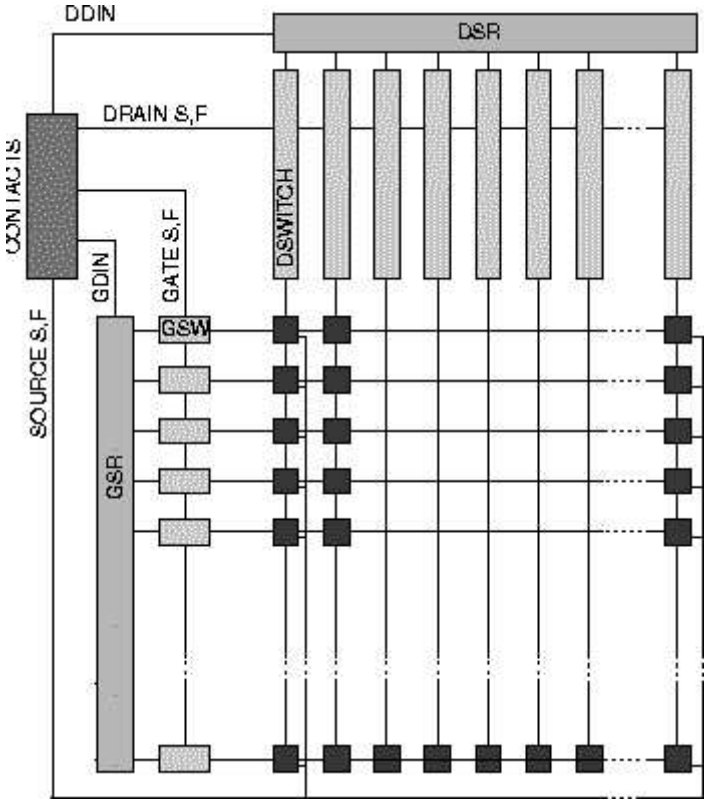
compensation of contact resistances

with Kelvin probes

number of devices is extendable

usabe for: short distance mismatch

long distance mismatch



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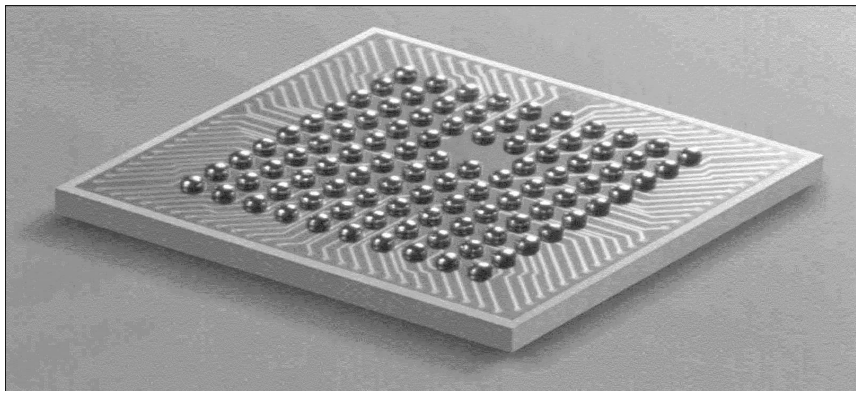
THANK YOU



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