Reducing Statistical Variability in Conventional "Bulk" CMOS

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Synopsys
Semiwise

Statistical MOSFET variability

Matching properties of MOS transistors

MJM **Pelgrom**, ACJ Duinmaijer… - IEEE Journal of solid …, 1989 - ieeexplore.ieee.org

Abstract: The matching properties of the threshold voltage, substrate factor, and current factor of MOS transistors have been analyzed and measured. Improvements to the existing theory are given, as well as extensions for long-distance matching and rotation of devices.

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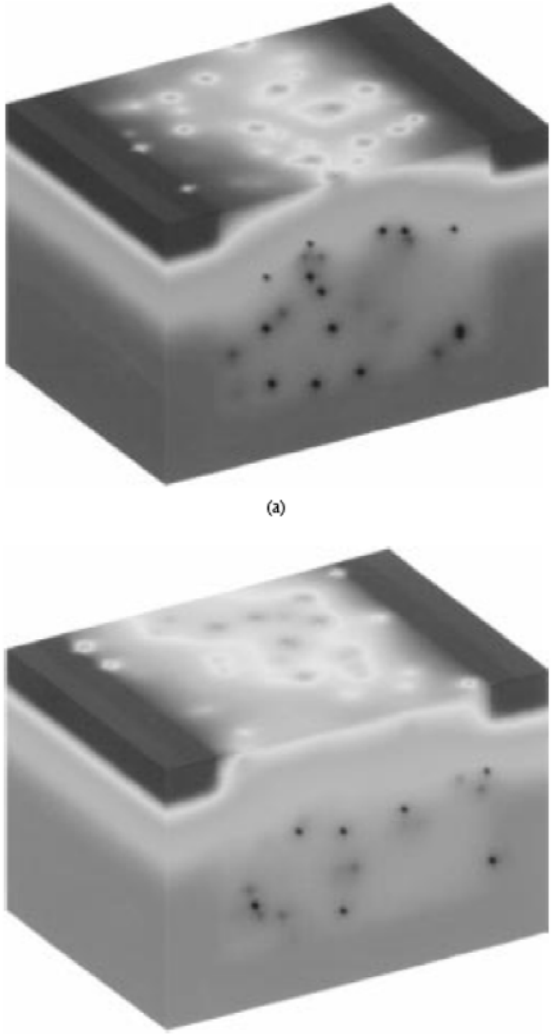


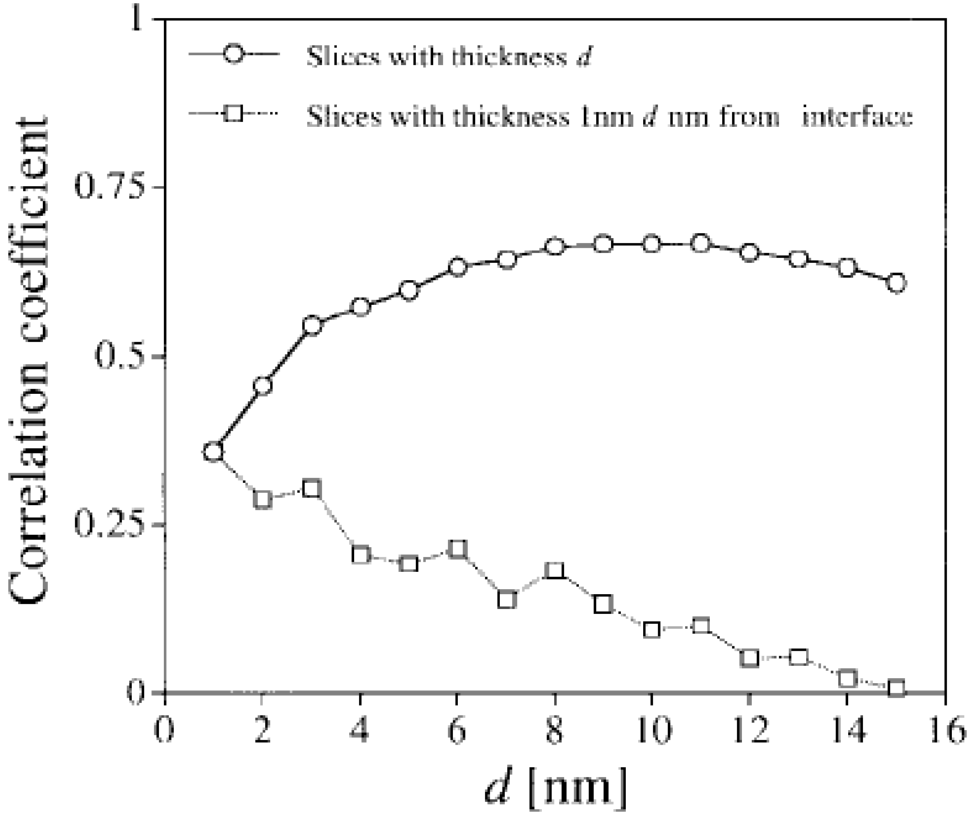
Numerical simulations of statistical MOSFET variability

Three-dimensional" atomistic" simulation of discrete random dopant distribution effects in sub-0.1/spl mu/m MOSFET's 265
HS Wong, Y Taur
Electron Devices Meeting, 1993. IEDM'93. Technical Digest., International …

Random dopant induced threshold voltage lowering and fluctuations in sub-0.1/spl mu/m MOSFET's: A 3-D" atomistic" simulation study 677
A Asenov
IEEE Transactions on Electron Devices 45 (12), 2505-2513 1998

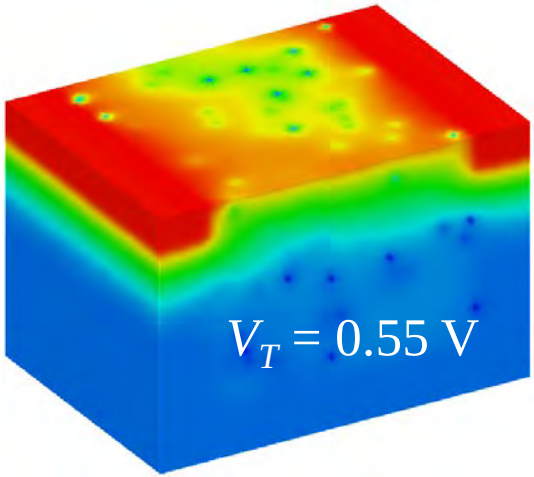
Dopants closely to the interface determine the statistical MOSFET variability

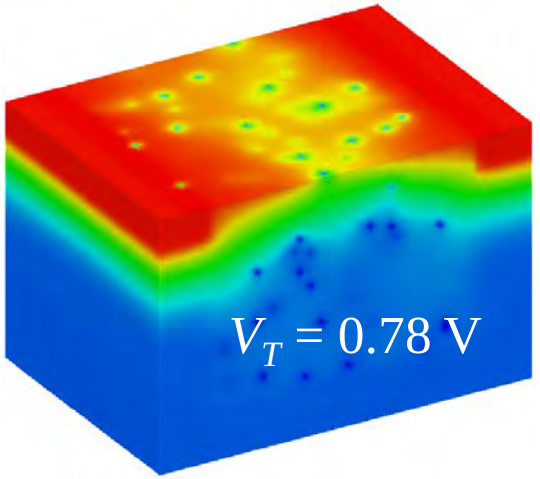


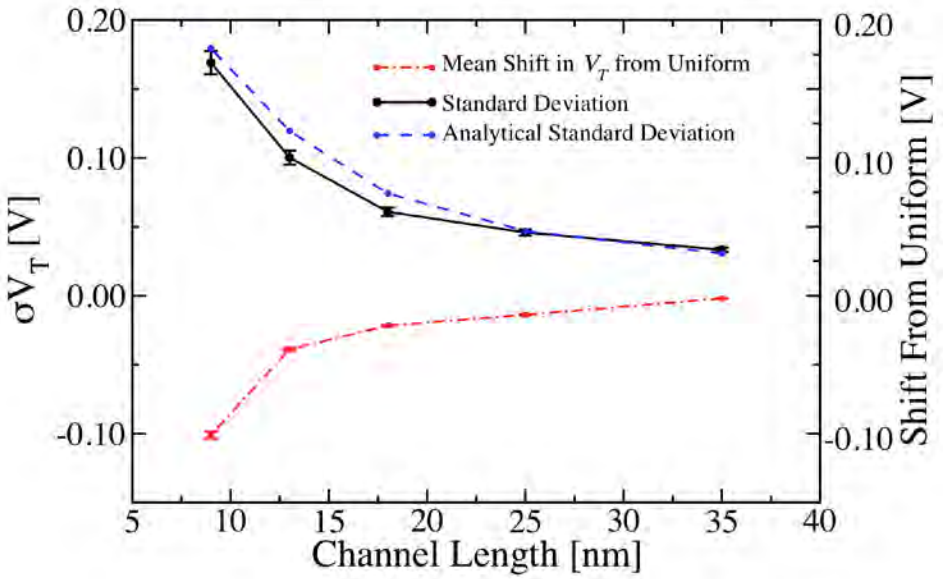


A. Asenov, IEEE TED, 98

Both number and positions of dopants matter



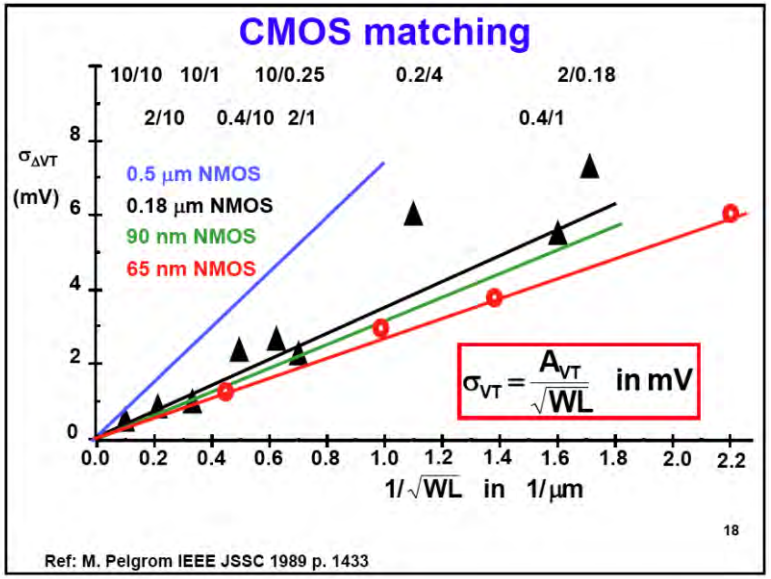


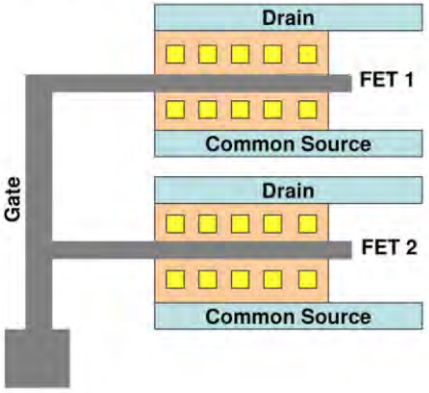


C2

$$\sigma V_T = \frac{'C \times EOT \times N_D^{0.4}'}{\sqrt{LW}}$$

Variability trends





$$\sigma V_T = \sigma \Delta V_T / \sqrt{2}$$

$$\sigma \Delta V_T = A_{VT} / \sqrt{WL}$$

$$\sigma V_T = C2 / \sqrt{WL}$$

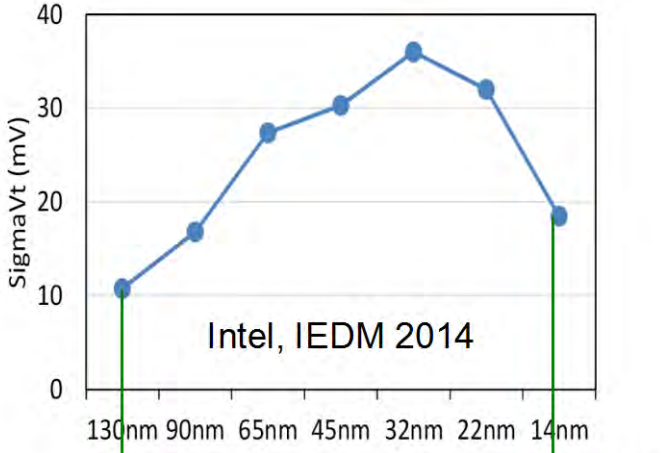
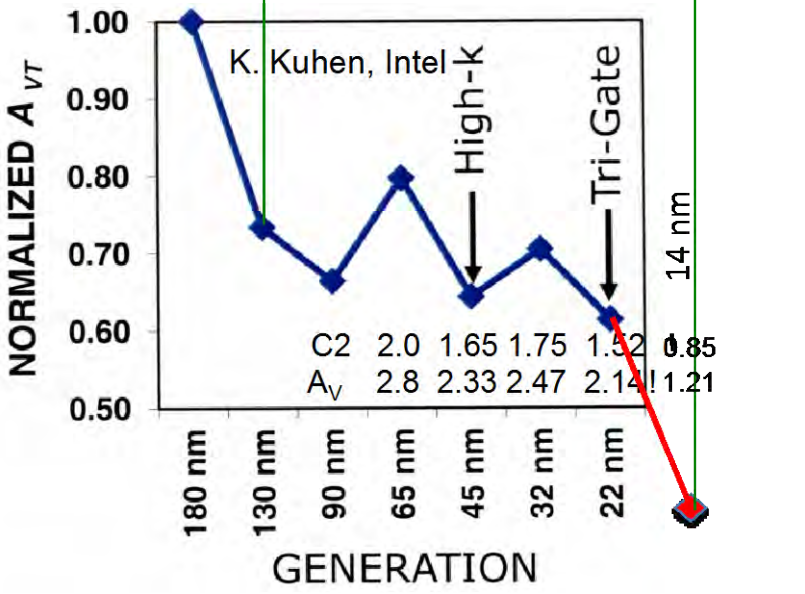


Figure 7: Random Varation Trend (σVt)

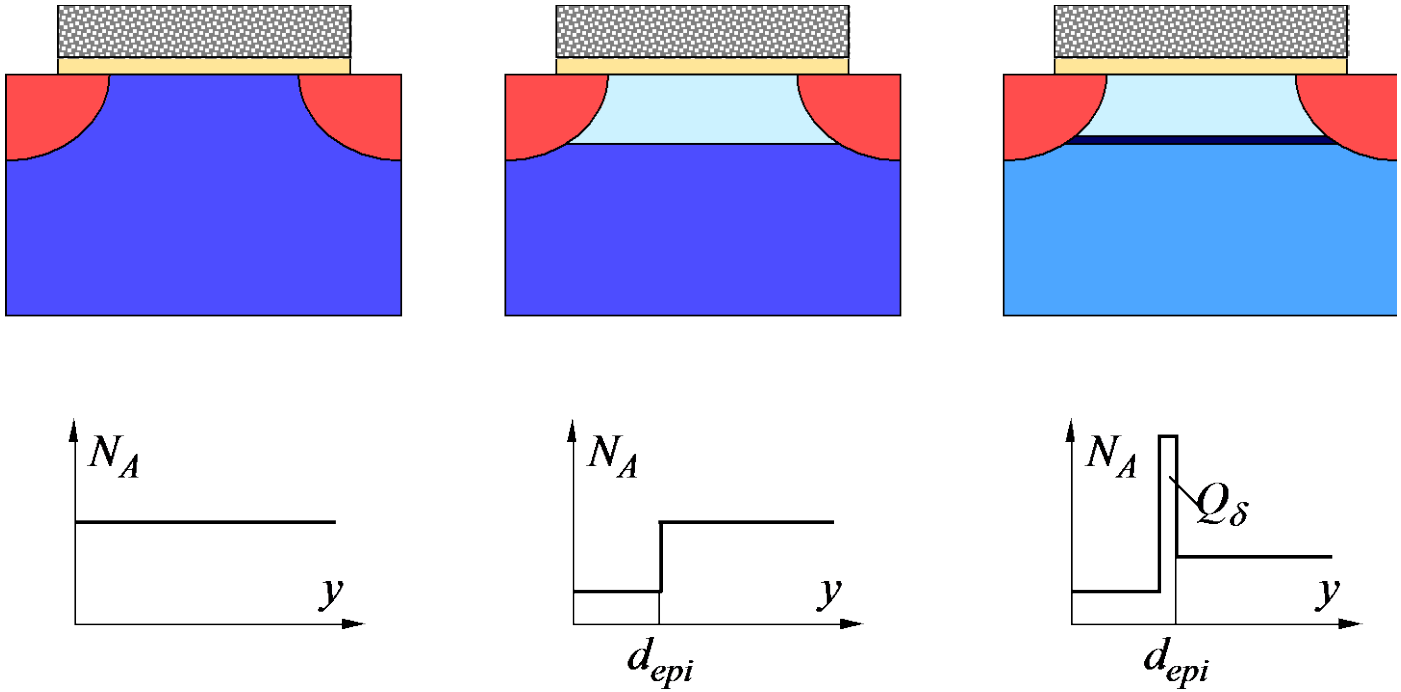


Reduction of statistical variability in epitaxial delta doped MOSFETS

Suppression of random dopant-induced threshold voltage fluctuations in sub-0.1-/spl mu/m MOSFET's with epitaxial and/spl delta/-doped channels 201

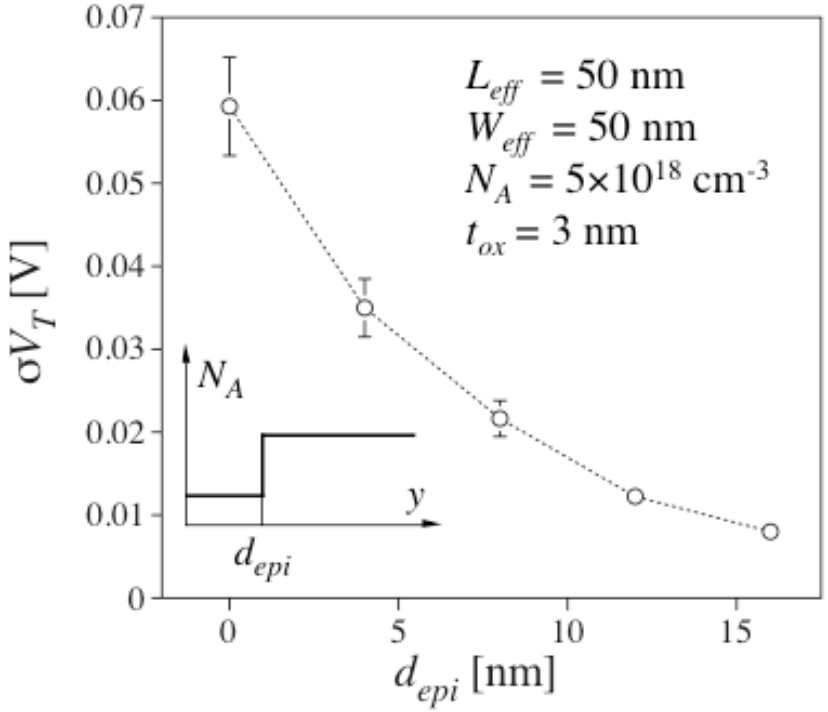
A Asenov, S Saini

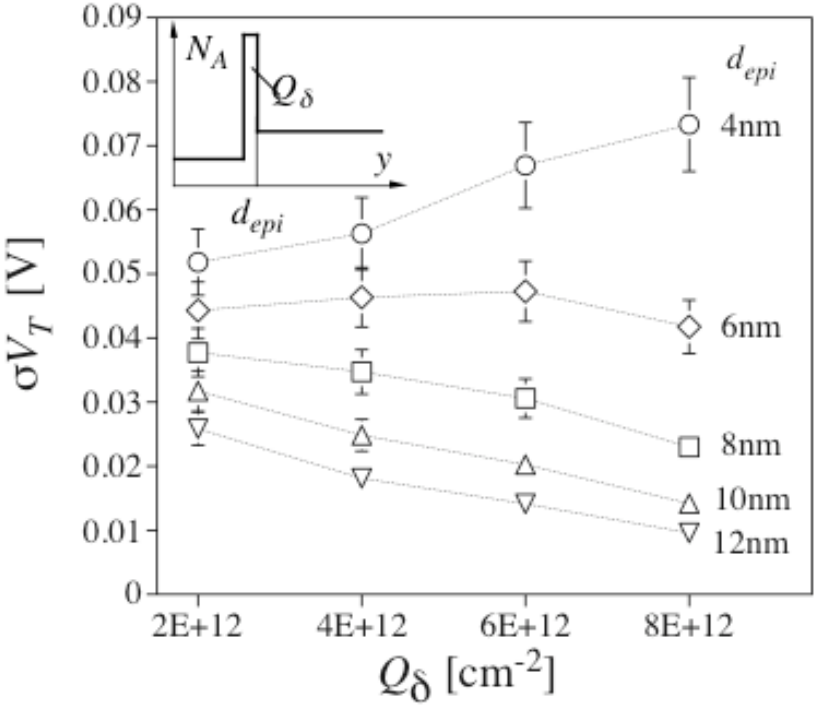
IEEE Transactions on Electron Devices 46 (8), 1718-1724 1999



A. Asenov, IEEE TED, 99

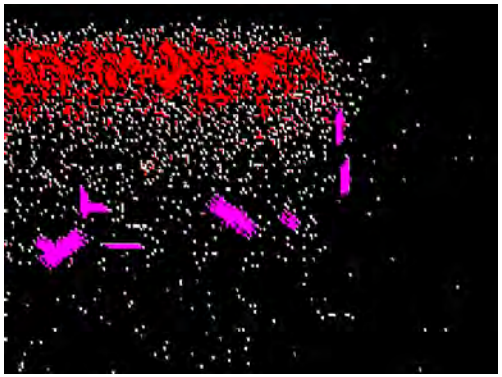
Reduction of statistical variability in epitaxial delta doped MOSFETS

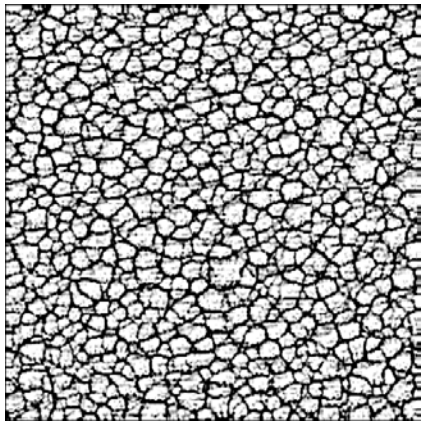


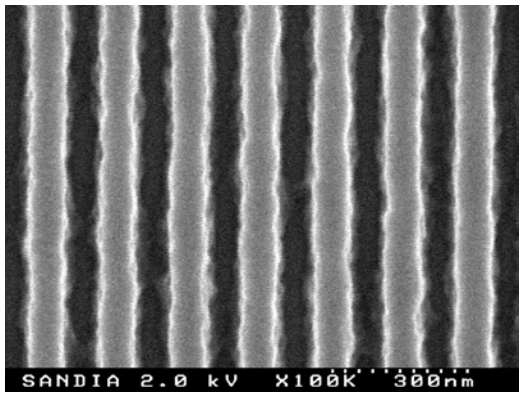


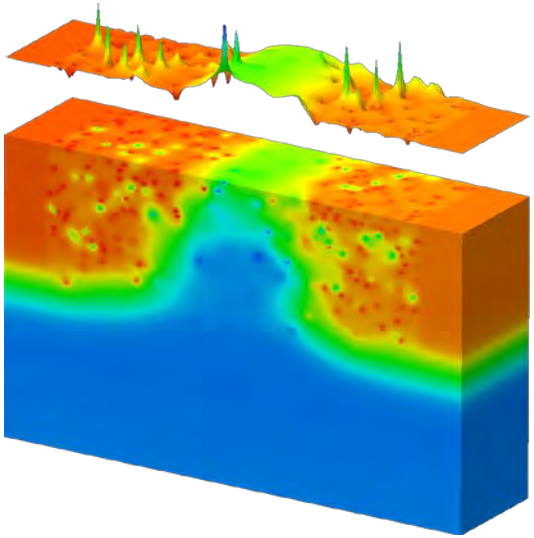
A. Asenov, IEEE TED, 99

Other sources of statistical variability

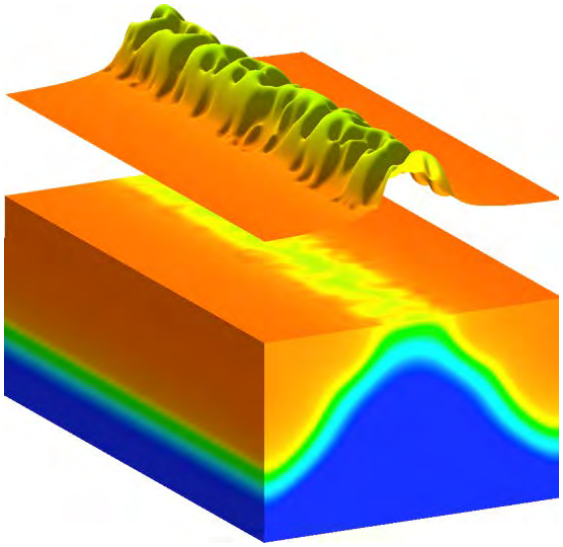




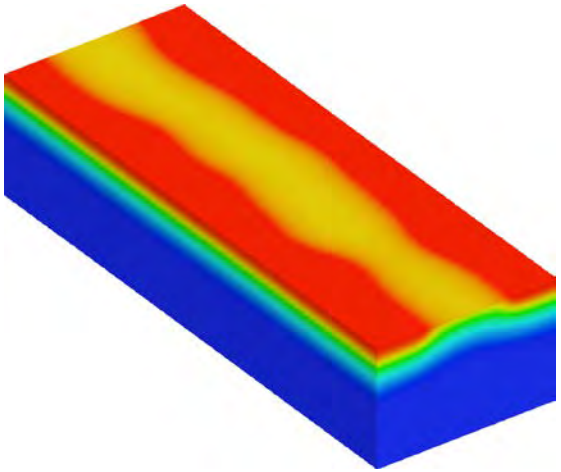




Random dopants



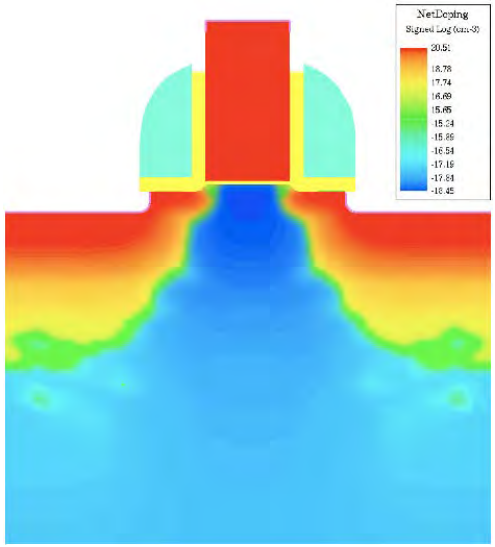
Metal gate or Polysilicon Granularity

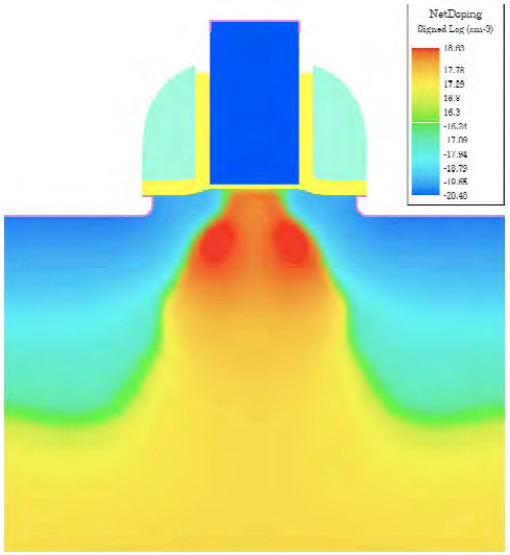


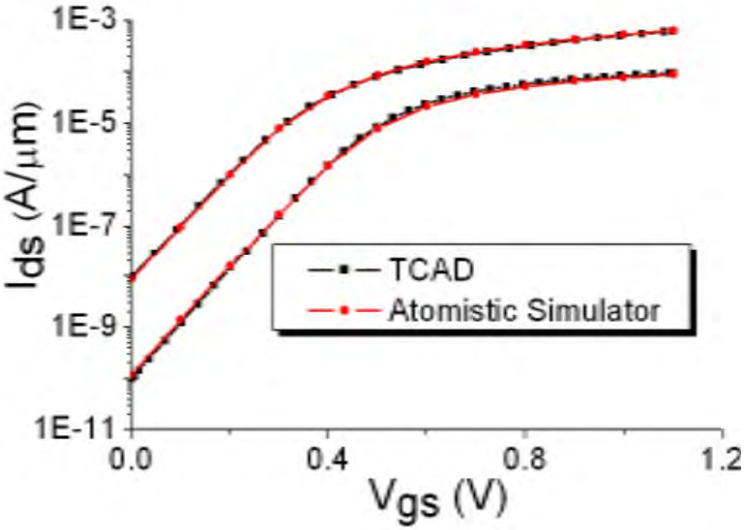
Line edge roughness

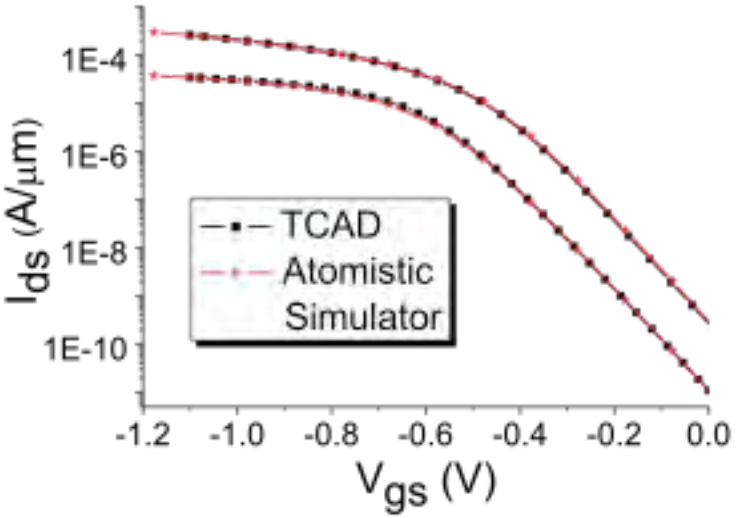
A. Asenov, IEEE TED, 03

The 3D ‘atomistic’ simulations are predictive – 40 nm



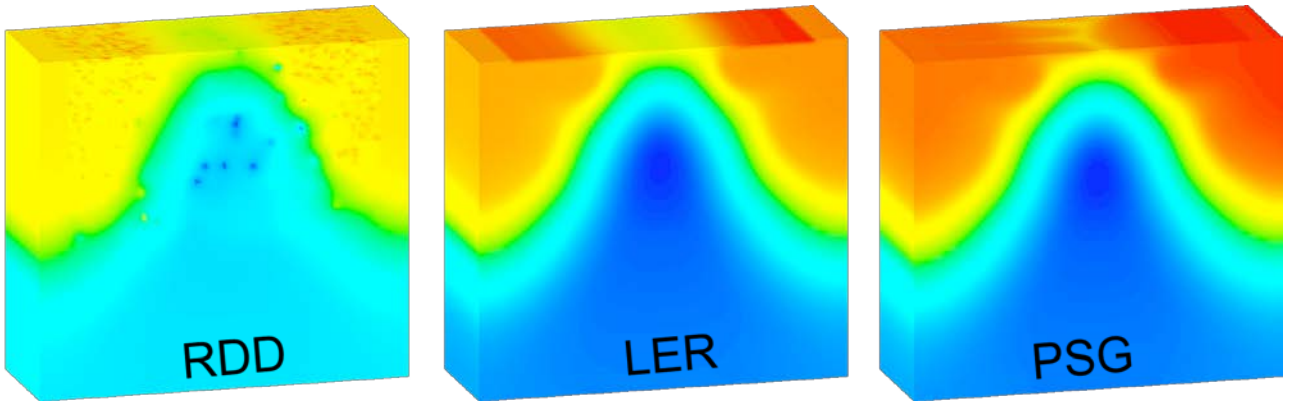






Collaboration with ST Microelectronics

The 3D ‘atomistic’ simulations are predictive – 40 nm



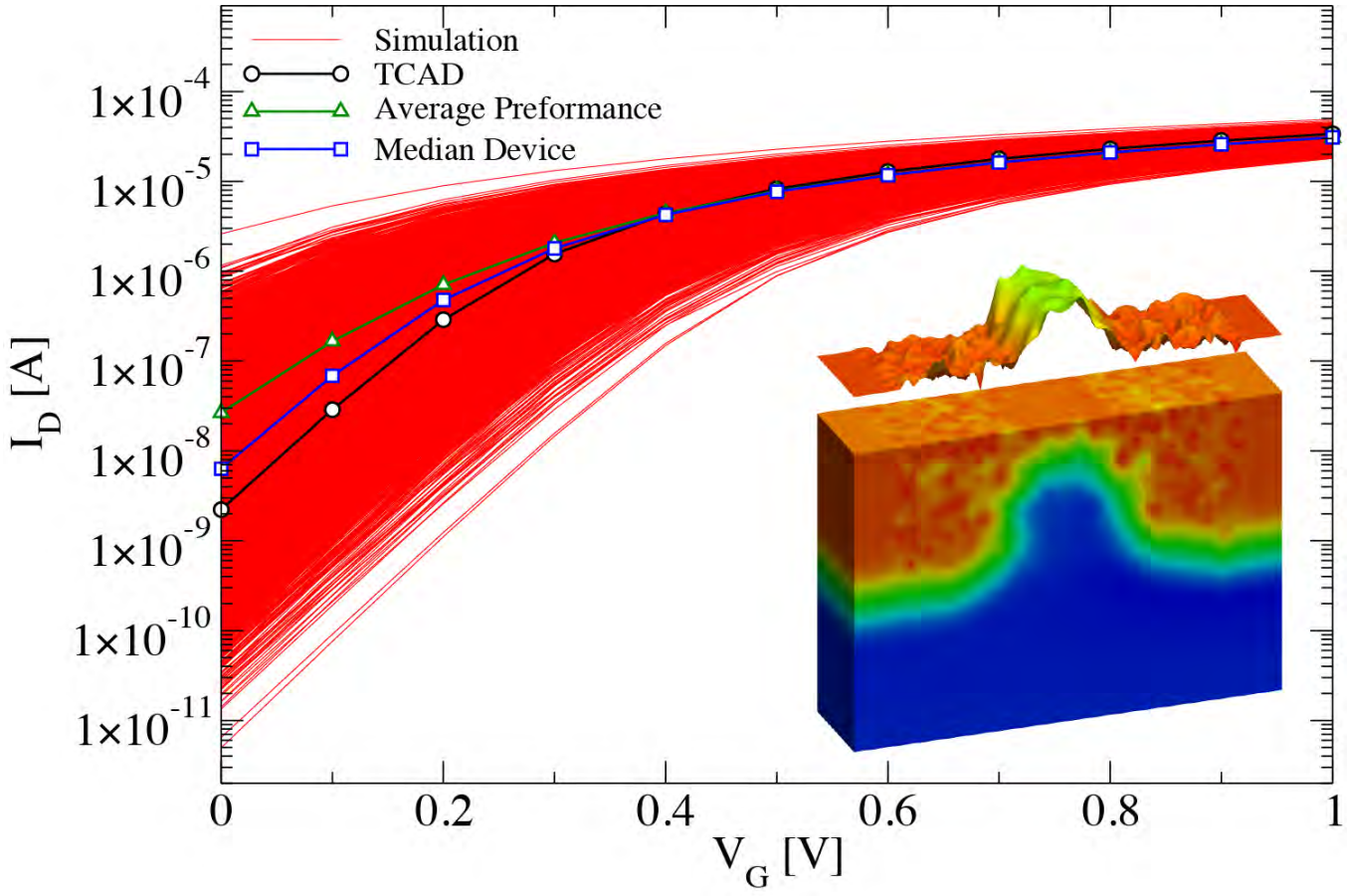
	n-channel MOSFET		*p*-channel MOSFET	
	σV_T [mV] (V_{DS}=0.05 V)	σV_T [mV] (V_{DS}=1.1 V)	σV_T [mV] (V_{DS}=0.05 V)	σV_T [mV] (V_{DS}=1.1 V)
RDD	50	52	51	54
LER	20	33	13	22
PSG	30	26	-	-
Combined	62	69	53	59
Experimental	62	67	54	57

=

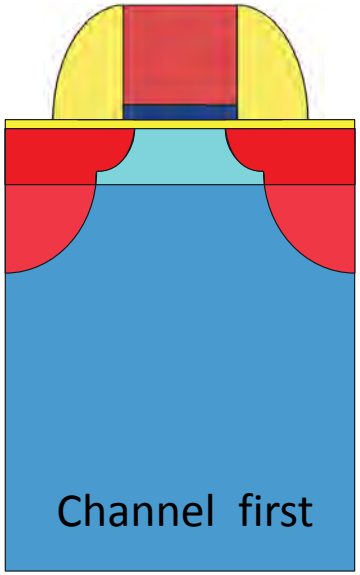
A_{VT}=2.8

Collaboration with ST Microelectronics

Variability at the ultimate bulk CMOS scaling (20 nm)



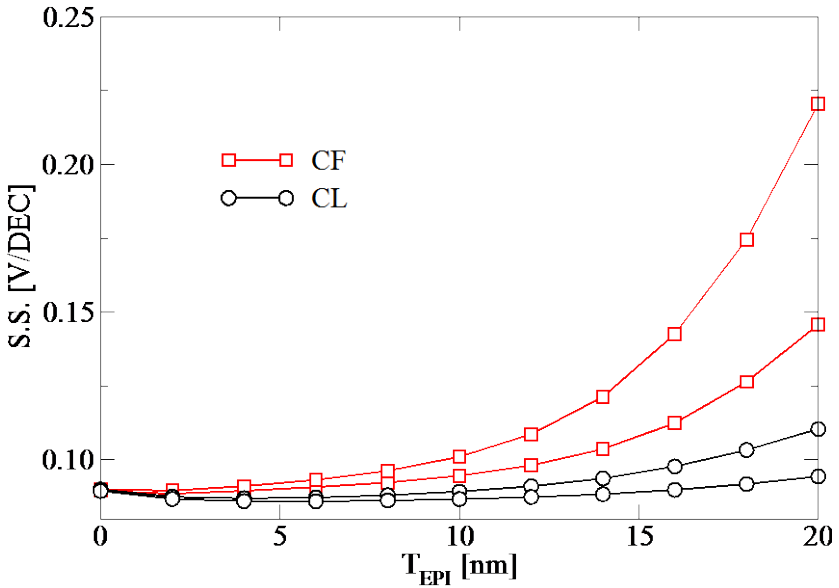
Epitaxial channel transistors – 20 nm CMOS



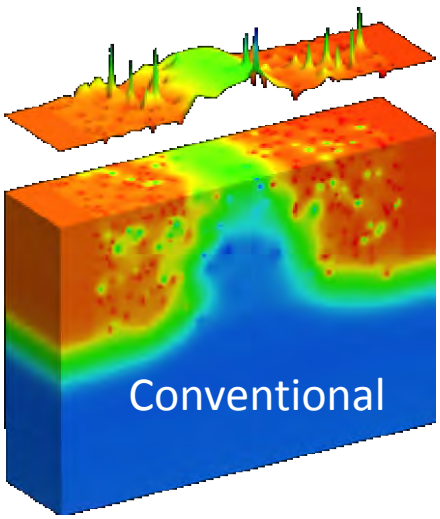
Conventional

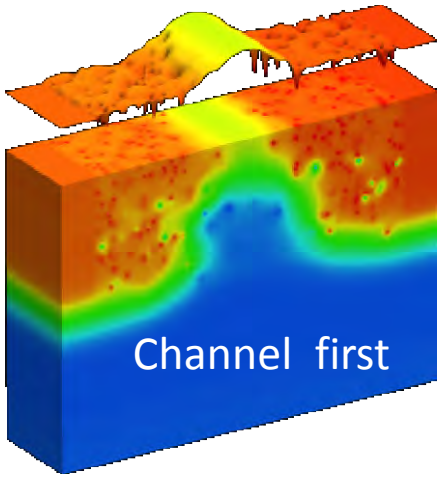
Channel first

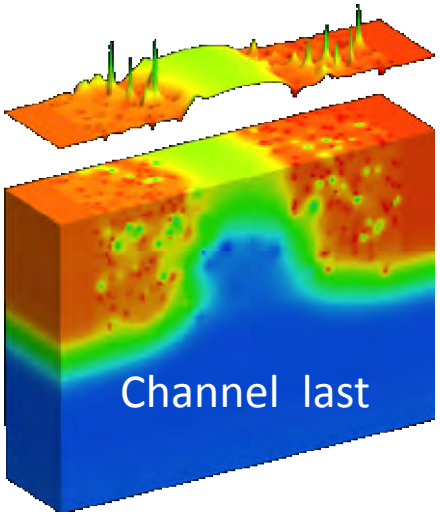
Channel last



Epitaxial channel transistors – 20 nm CMOS

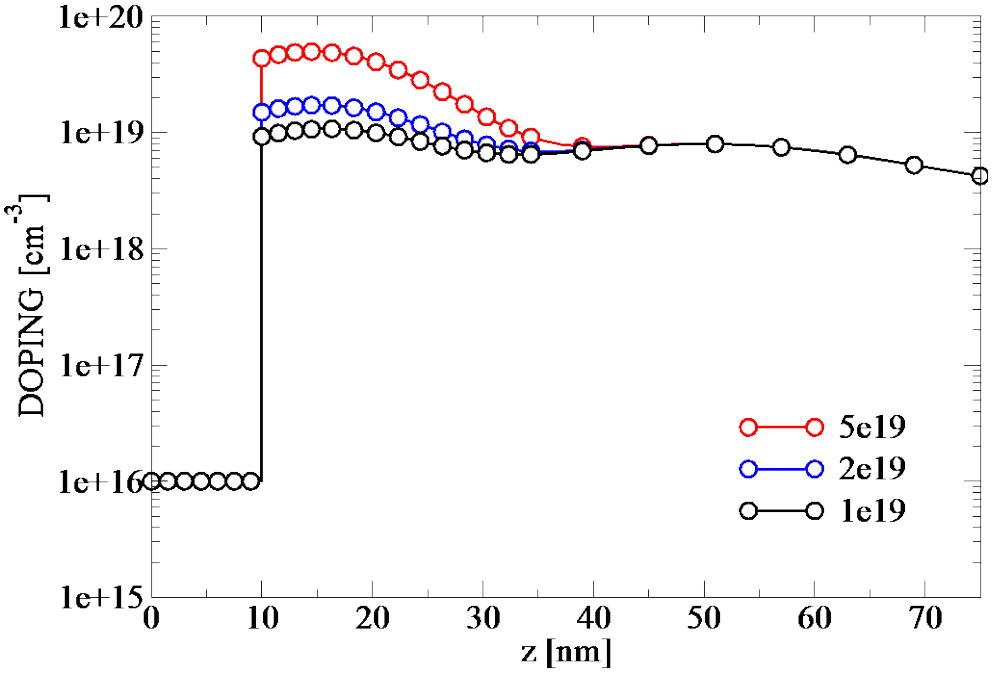






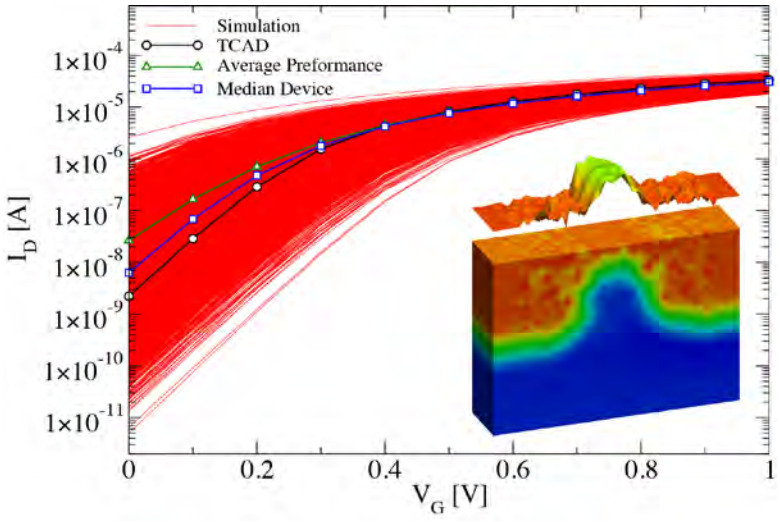
σV_T [mV]	RDD	LER	LER+RDD 3D sim.	LER+RDD Analytical	C2
Template	59	23	63	63	2.22
CF	31	47	54	56	1.91
CL	22	23	30	31	1.06

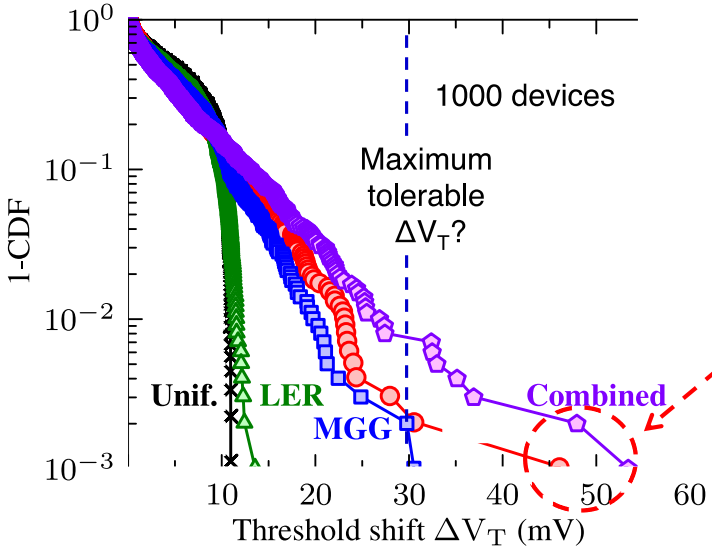
Epitaxial channel transistors – CL + back doping



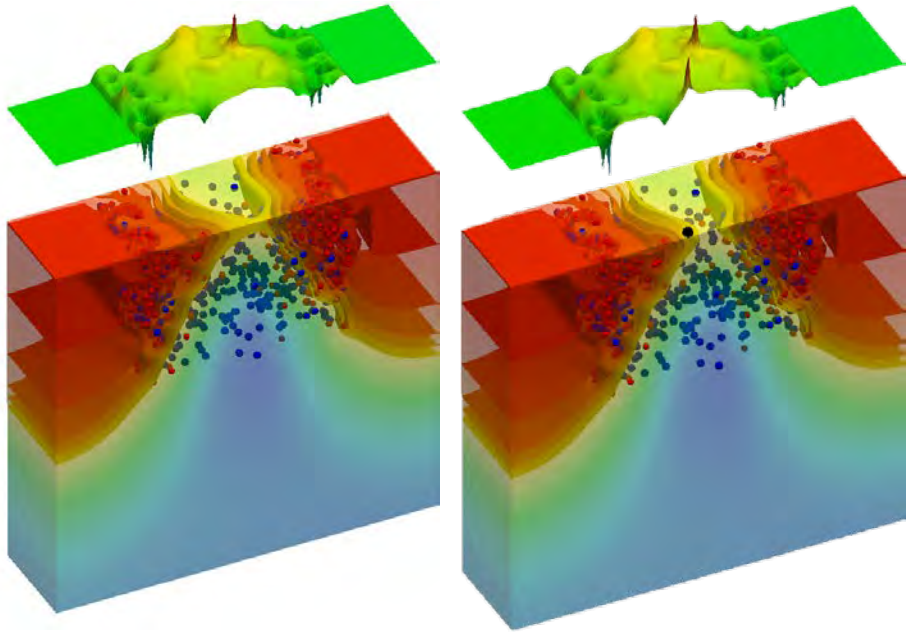
	σV_T [mV]			C_2 [mV/μm]
N_{AM}cm^{-3}]	RDD	LER	LER+RDD	LER+RDD
0	22	23	30	1.06
1×10^{19}	21	22	29	1.03
2×10^{19}	17	19	25	0.88
5×10^{19}	10	15	16	0.56

Strong interplay between statistical variability and statistical reliability

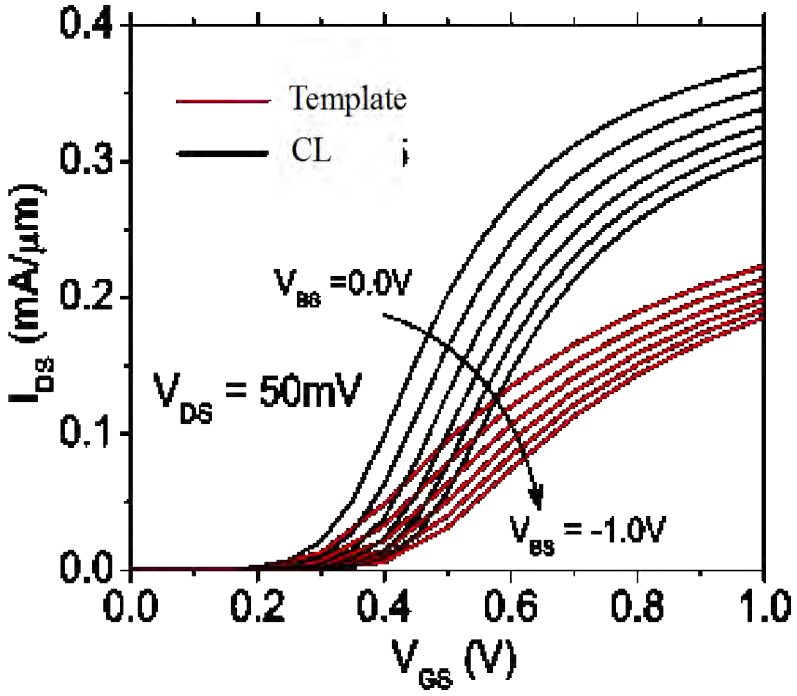


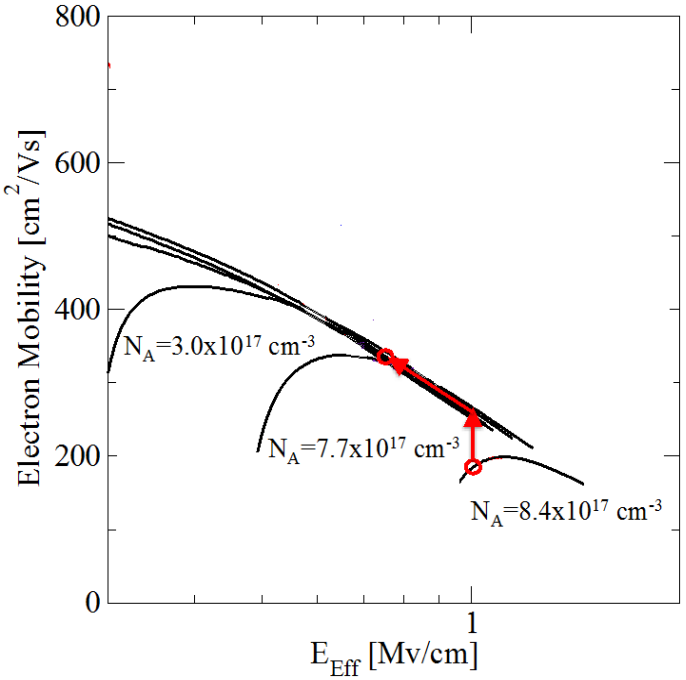


Parameter		n-MOS
L_g	[nm]	25
EOT	[nm]	0.85
X_j	[nm]	15
N_A	[E18/cm^3]	4.5
V_{dd}	[V]	1
I_{off}	[nA]	100
I_{on}	[µA]	1351
Spacer	[nm]	24



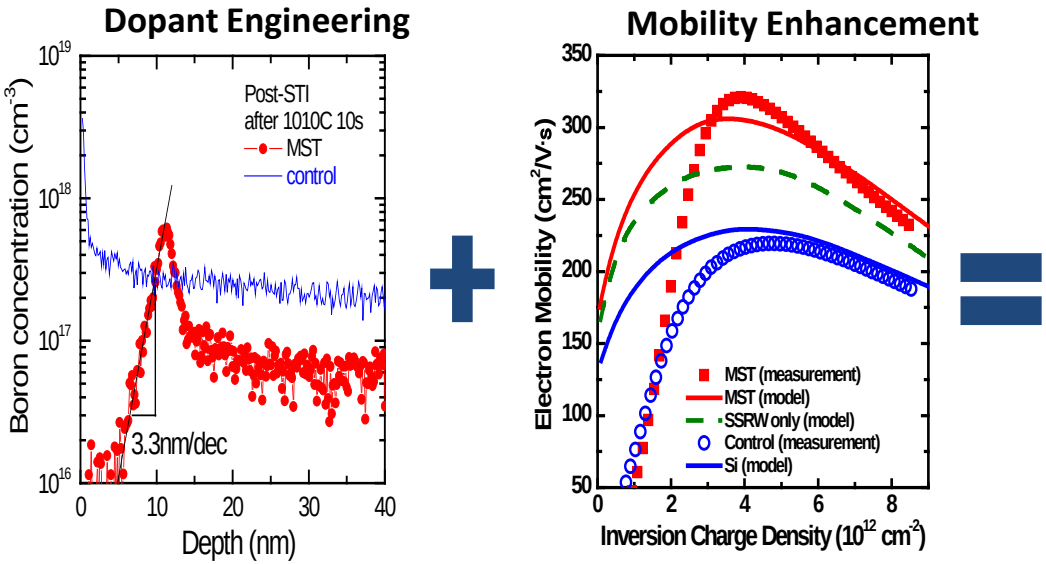
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- Variability reduced & Matching improved
- Potential 1/f Noise reduction
- TDDB & NBTI Reliability improved