On CMOS Circuit Reliability

from The MOSFETs and the Input Vectors

Valeriu Beiu and Walid Ibrahim

Sven Geier '06

Structure of the presentation

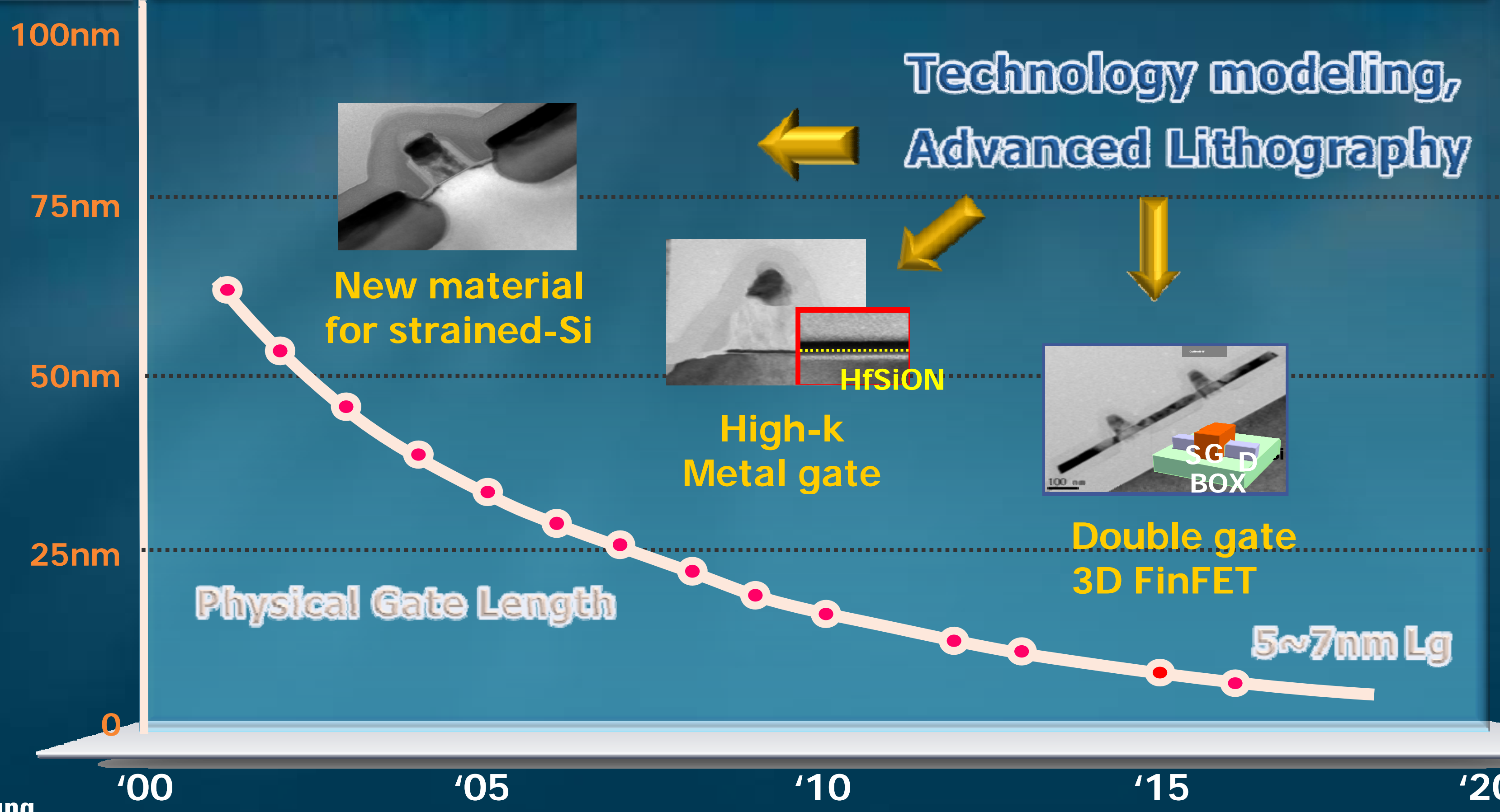
- Classical view
- Ubiquitous … variations
  - Thermal
  - Leakage
  - Vdd
  - Fabrication …
- Detailed (atomistic) view
- Vth variations
- Gate-level simulations
- Conclusions

Classical view

- Nano-scale requires new materials and device structures
- New EDA solutions are needed for technology modeling and advanced lithography

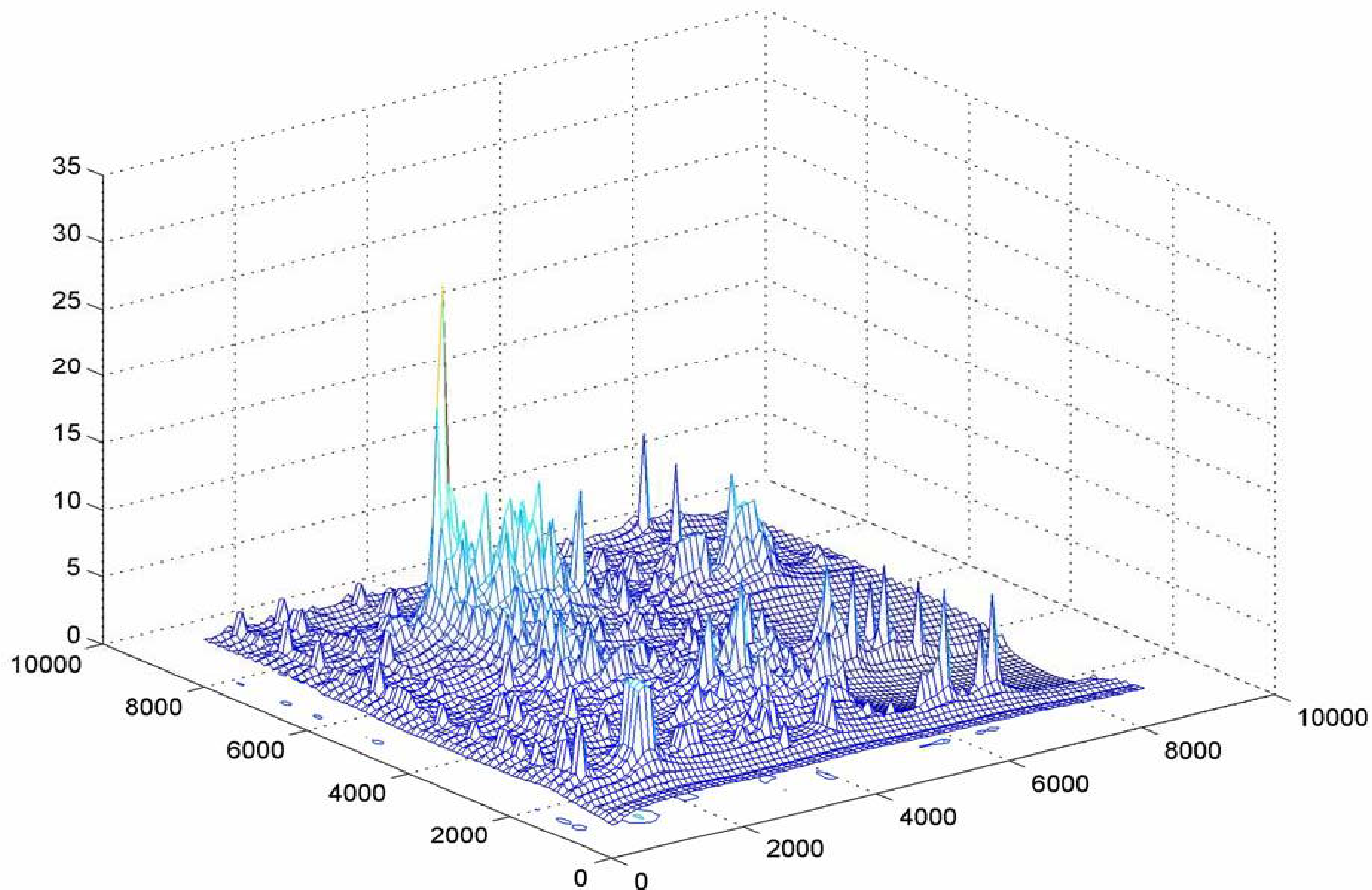
DRAM ½ pitch	90	65	45	32	22

Logic Generation	130	90	65	45	32	22	16

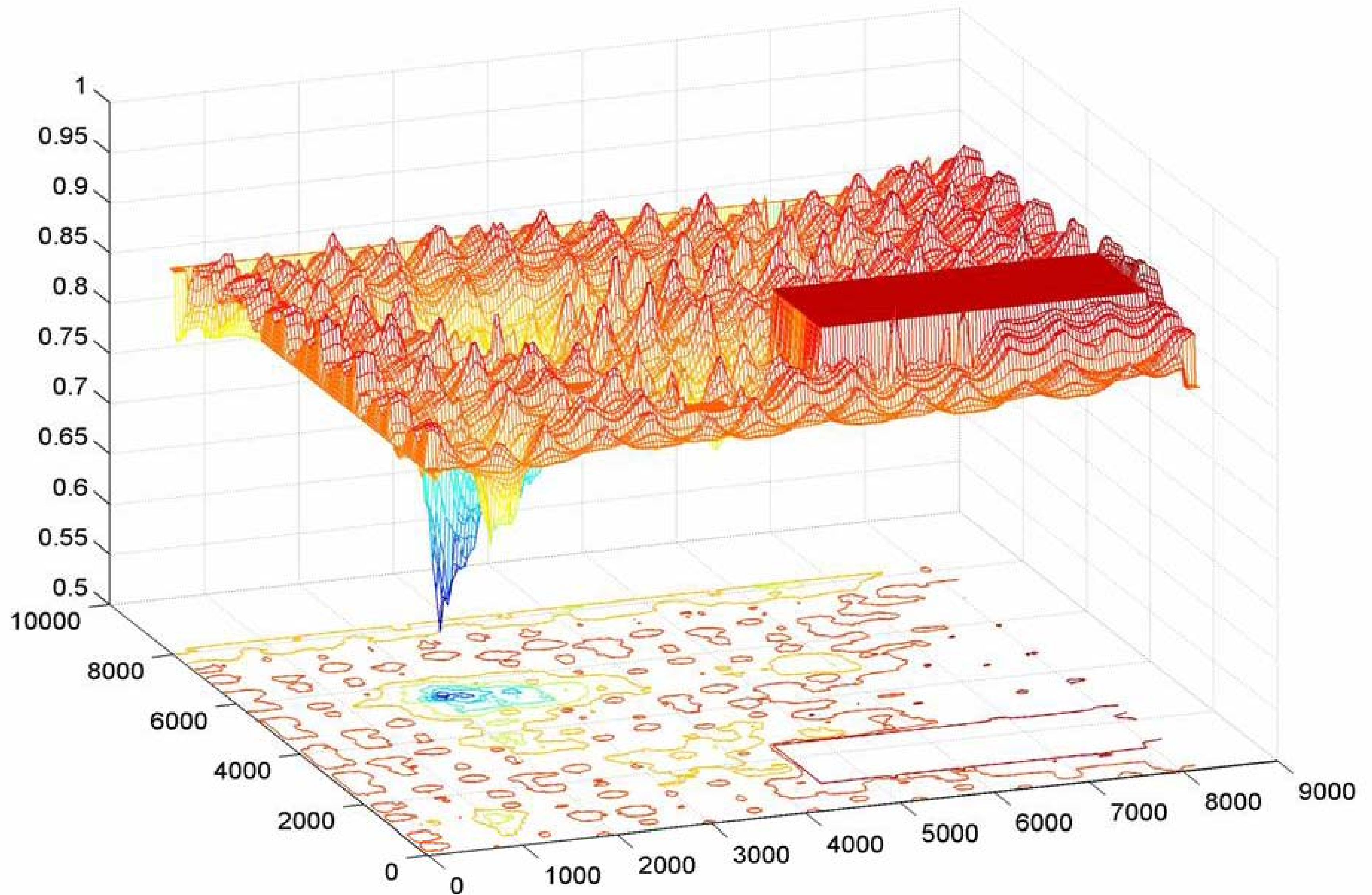


From Samsung

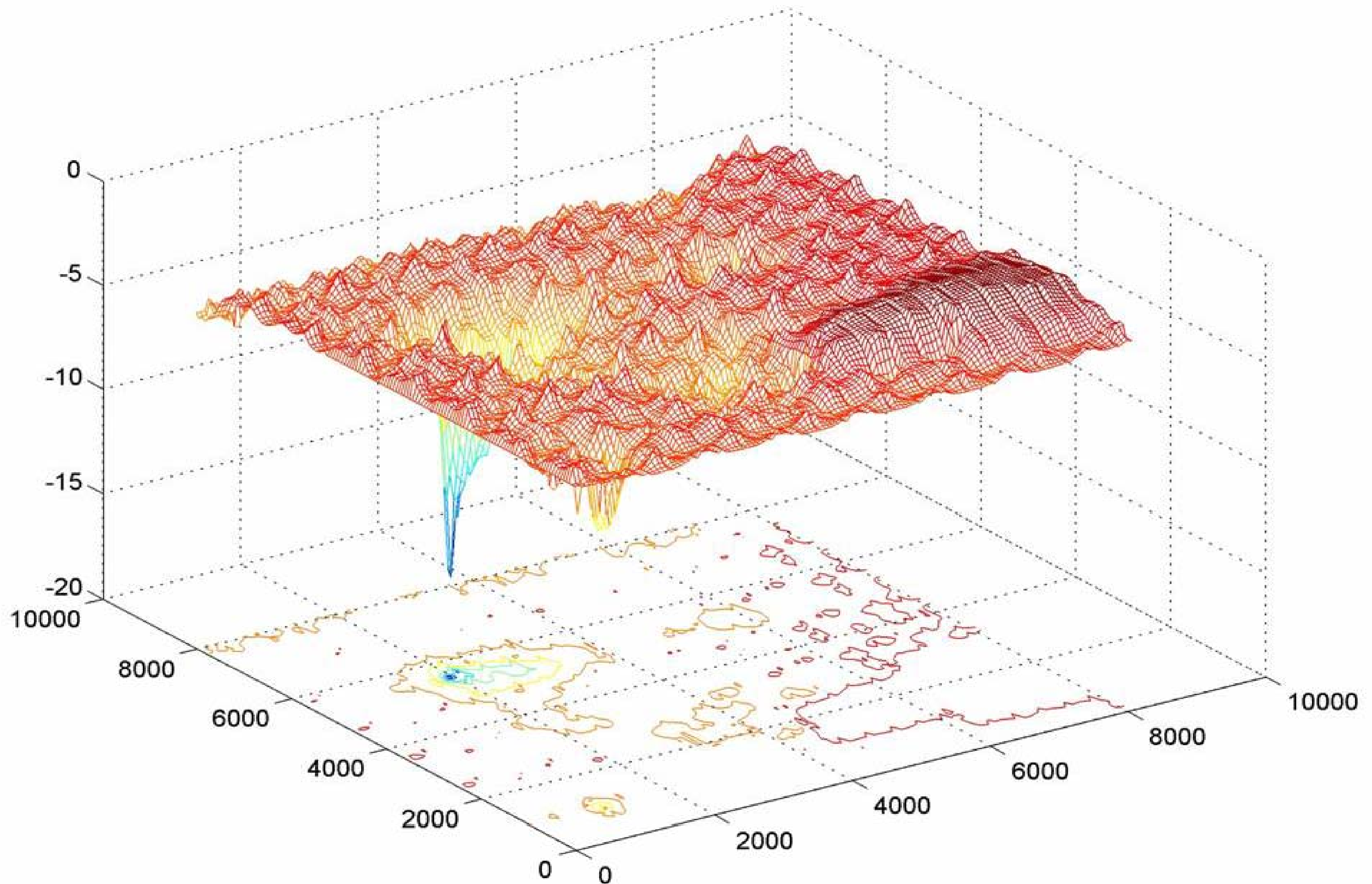
Variations ... thermal



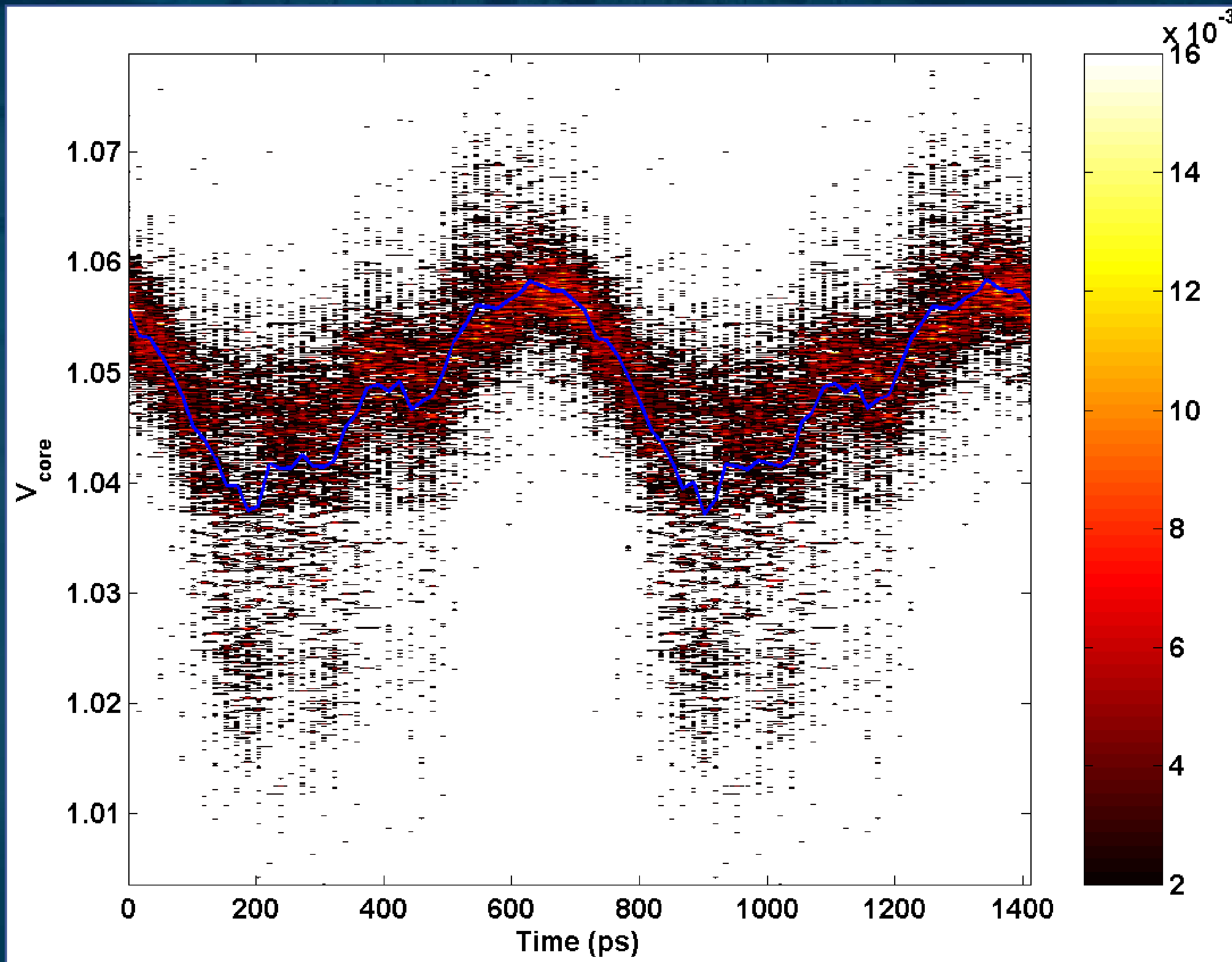
Variations ... leakage



Variations … Vdd

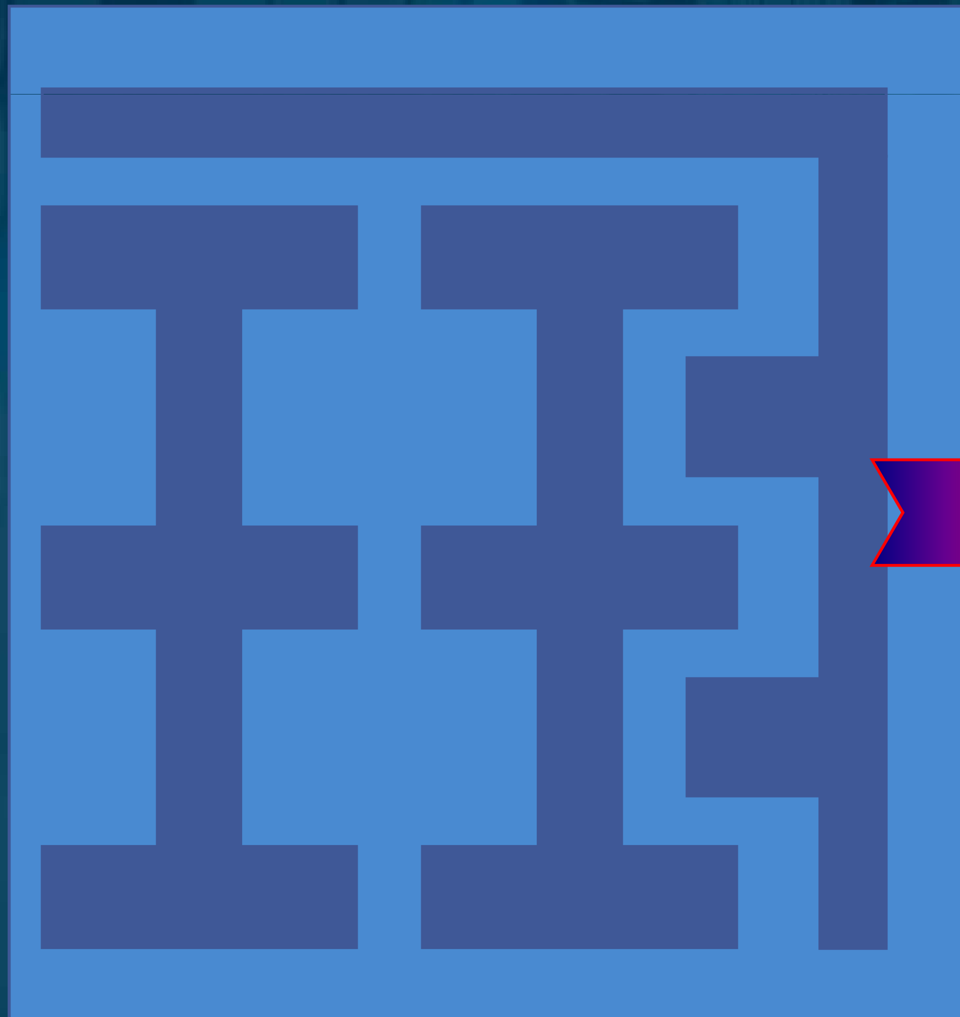


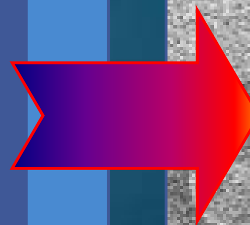
Vdd noise (Itanium, 90nm)

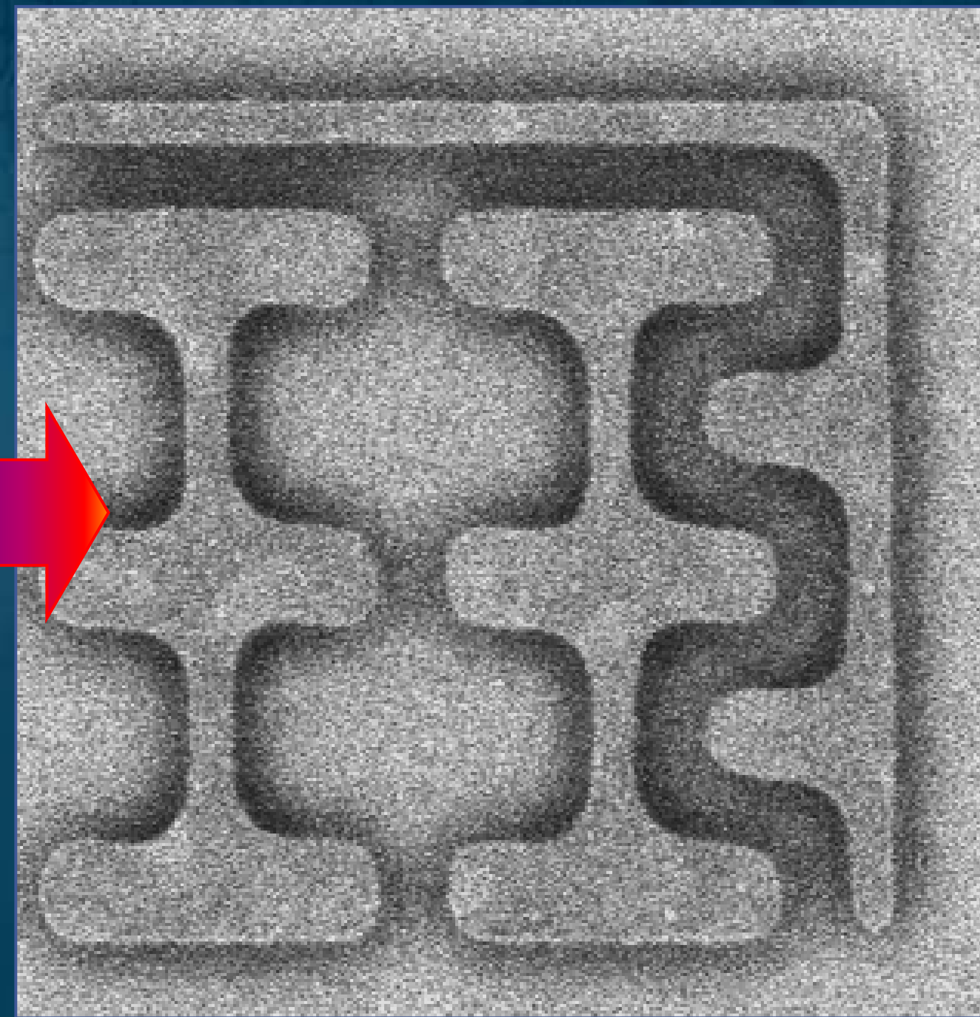


S. Naffziger, B. Stackhouse, T. Grutkowski, D. Josephson, J. Desai, E. Alon, and M. Horowitz
The Implementation of a 2-Core, Multi-Threaded Itanium Family Processor, *J. Solid-State Circ.*, Jan. 2006

Variations … when fabricating

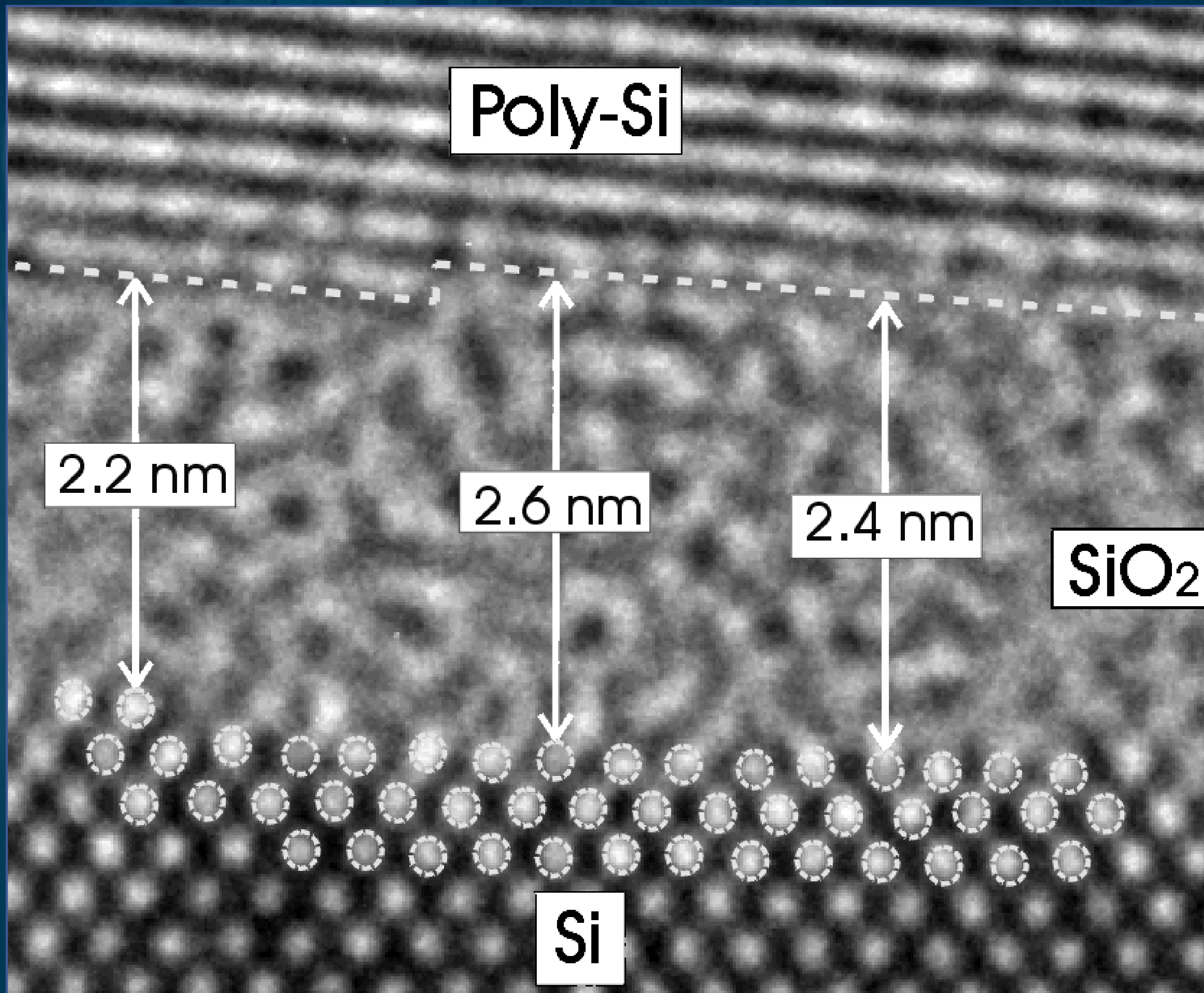




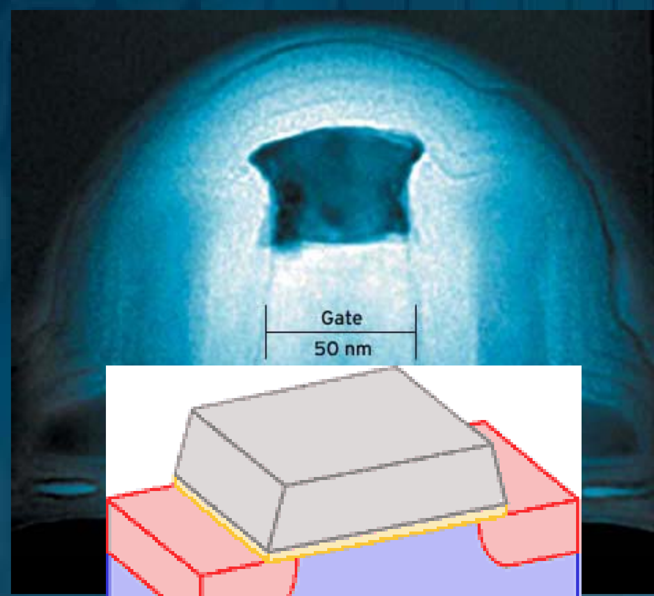


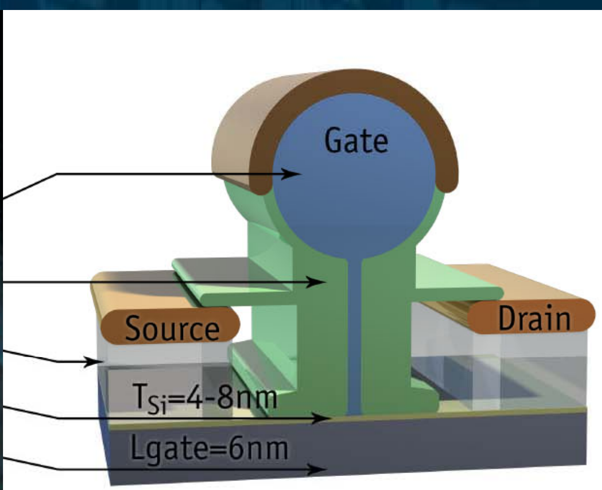
S. Nassif, DAC'03

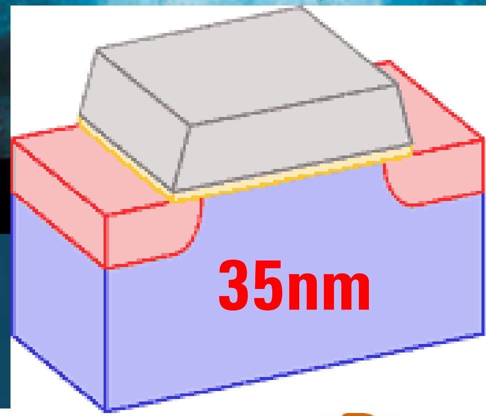
Variations ... misplacing atoms

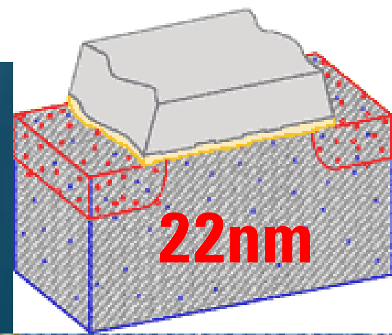


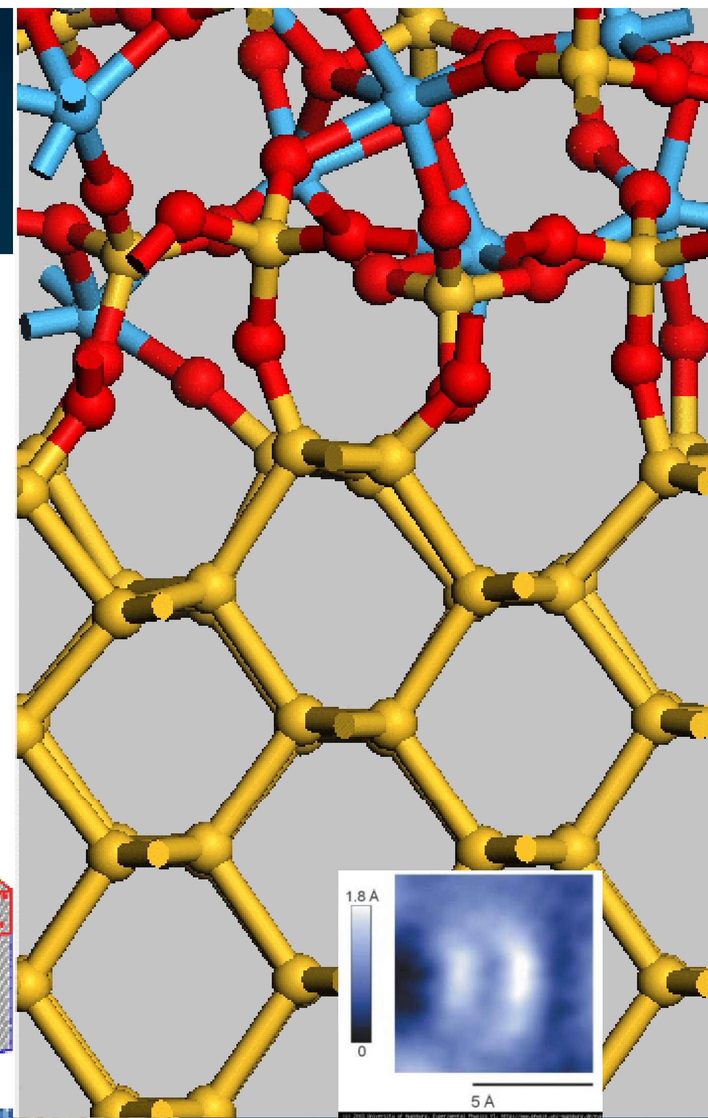
Detailed view (atomistic)

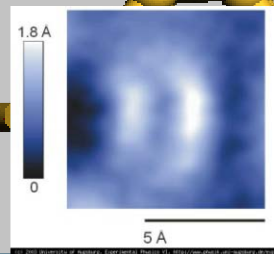


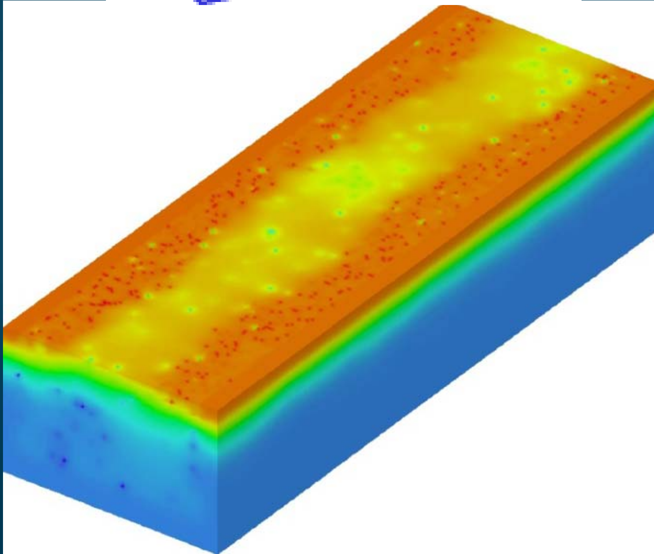


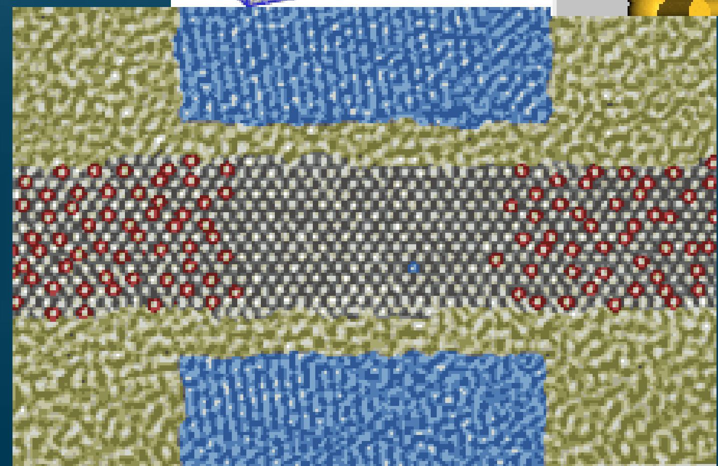


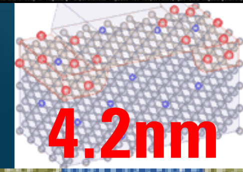


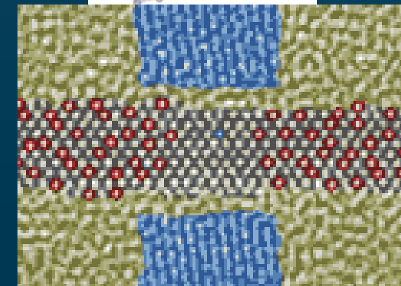




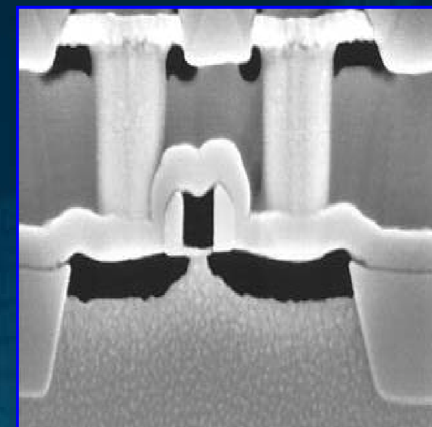








Counting e^- ...



Vdd = 0.8 V
t = 0.00 ps

E. Pop: Movie of an 18nm ultra-thin body SOI, MONET & Medici (energy in eV on the right bar)

Vth variations

- Keyes 1975
- Hagigava et al. 1982
- Wong & Taur 1993
- Mizuno et al. 1994
- Wong et al. 1998
- Asenov 1998

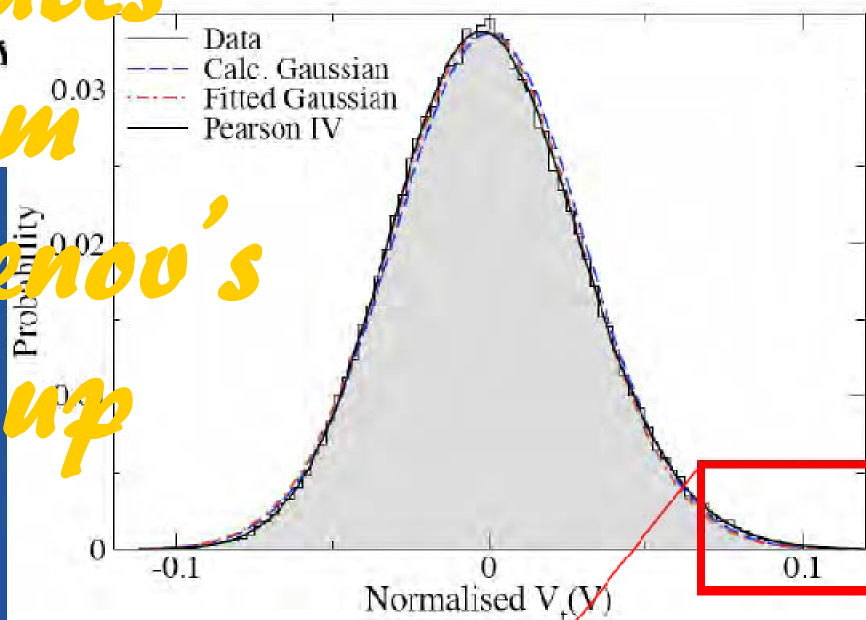
- Random dopants, oxide thickness variations, line edge roughness, polysilicon granularity, interface roughness, high-*k* morphology
- $\sigma = t_{ox} N_A^{0.45} / (L_{eff} W_{eff})^{1/2}$

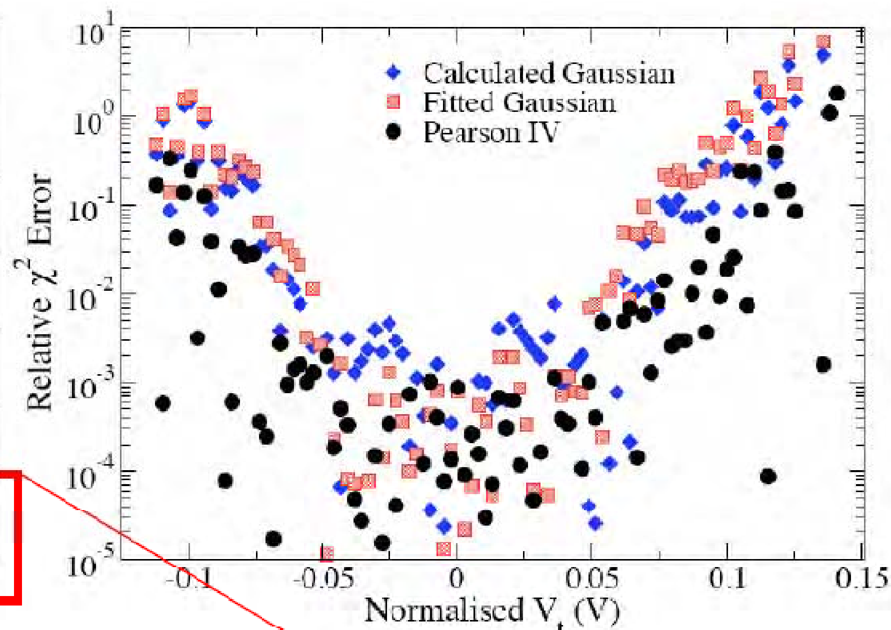
The true shape of the distribution

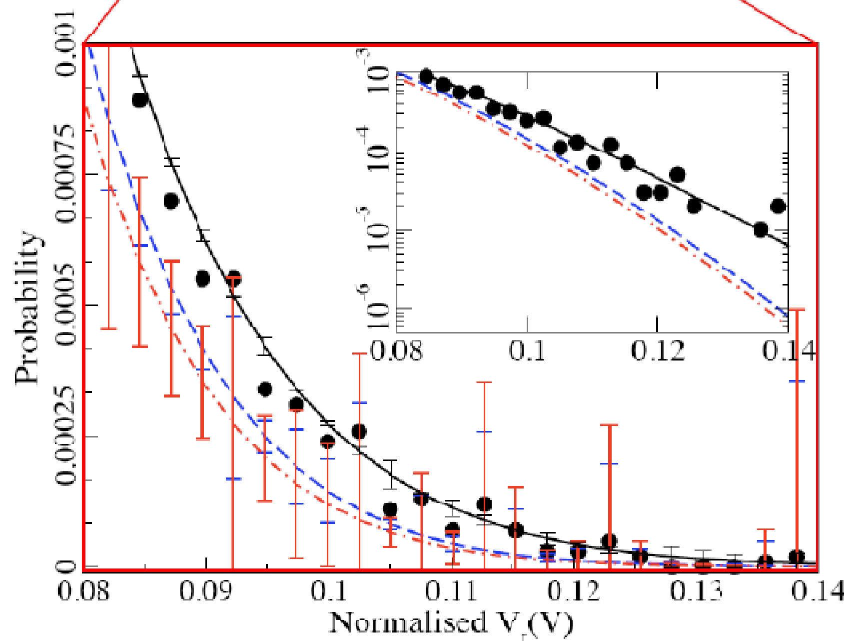
Based on the simulation of 100000 transistors

Latest results from Asenov's group

UNIVERSITY of GLASGOW



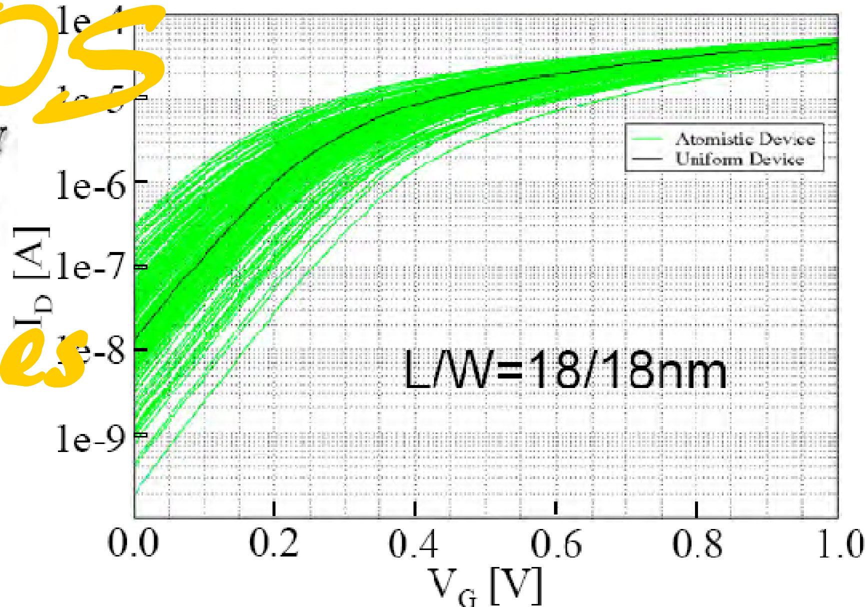


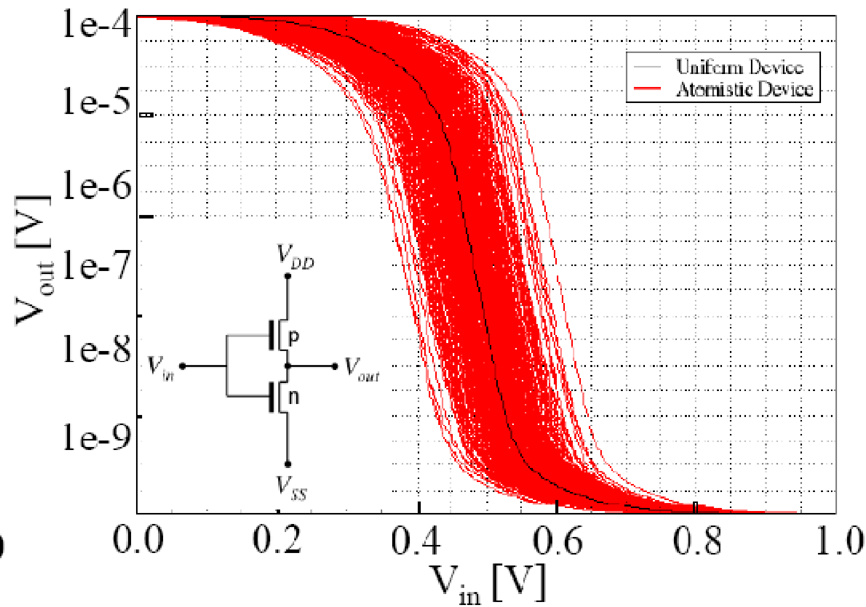


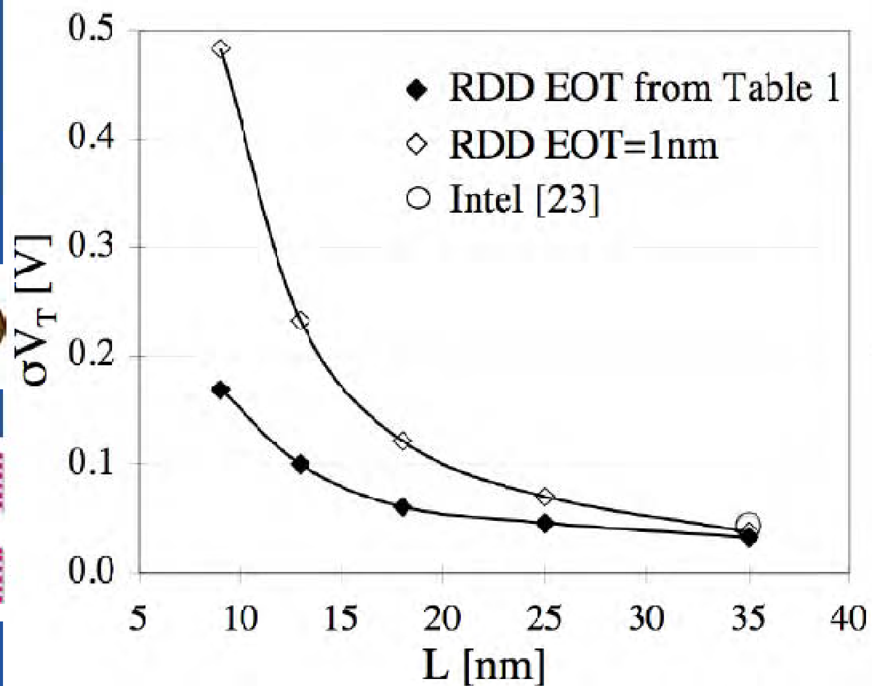
From MOS to gates

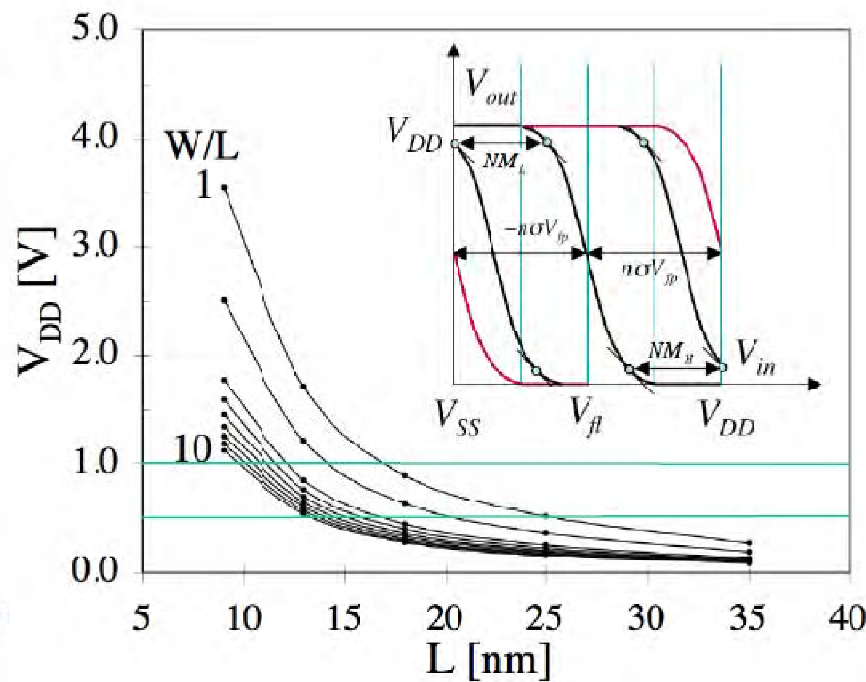
UNIVERSITY of GLASGOW

Hard logic faults

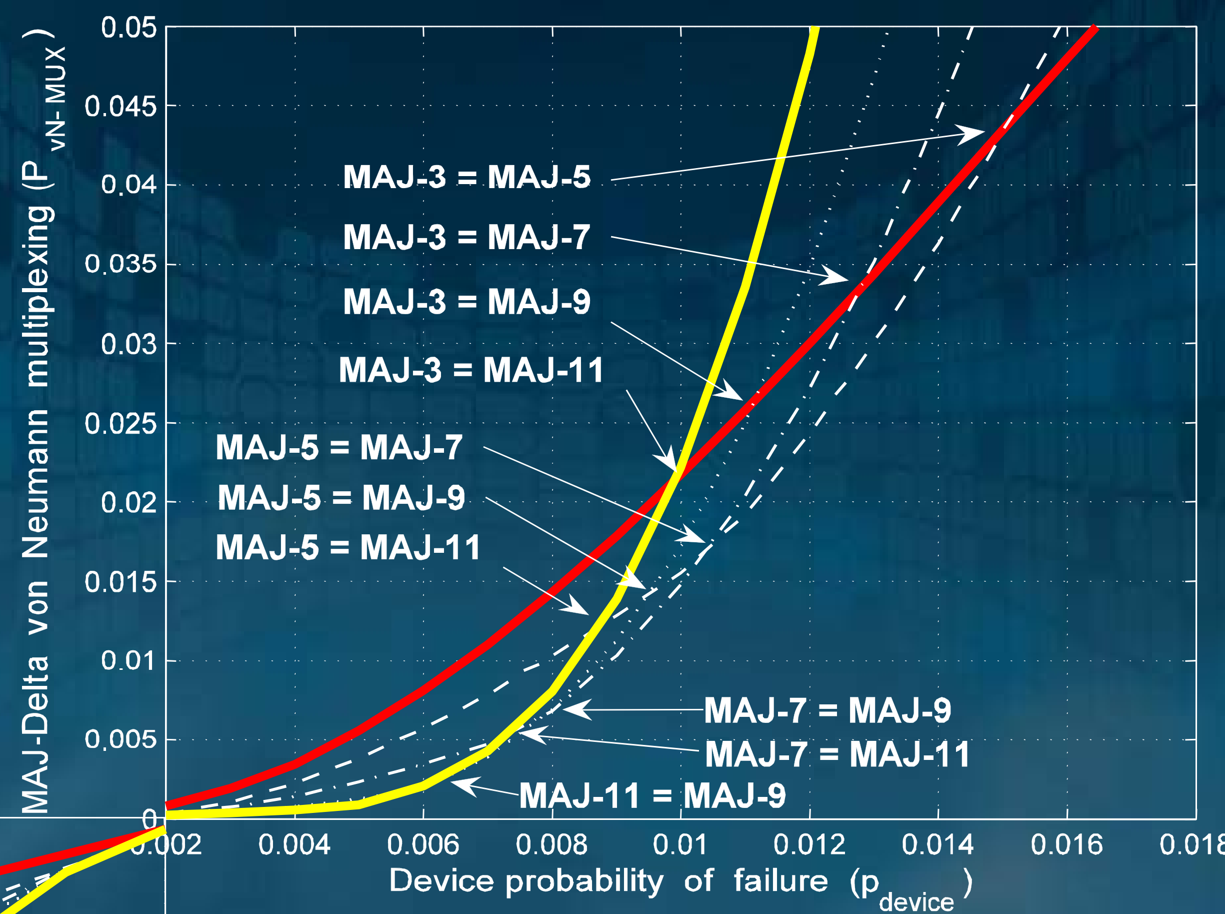


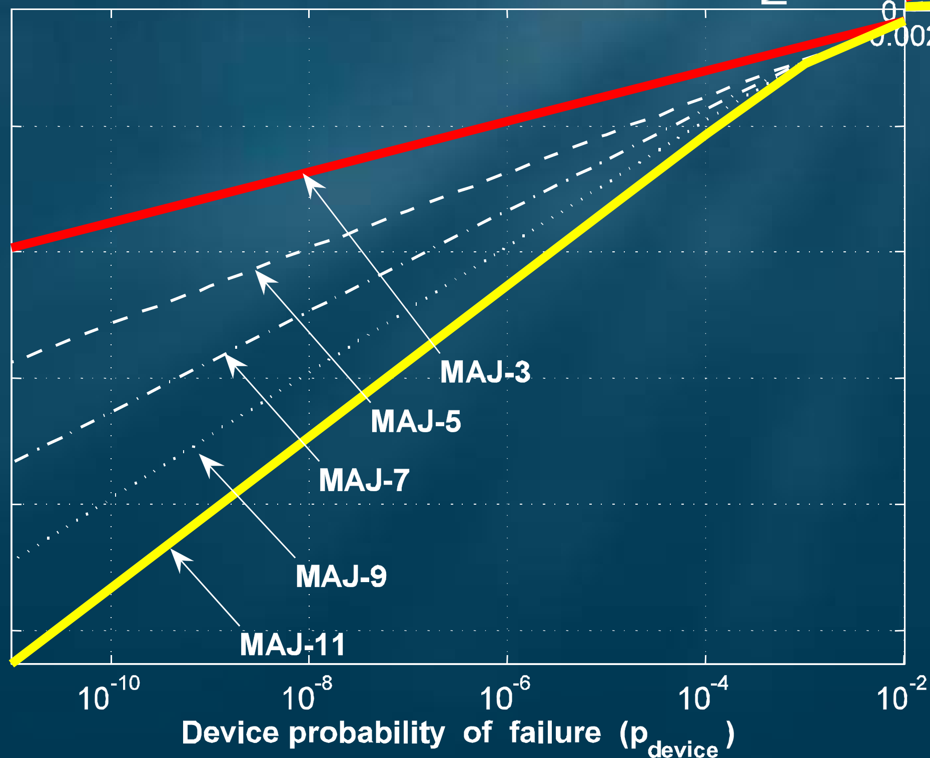






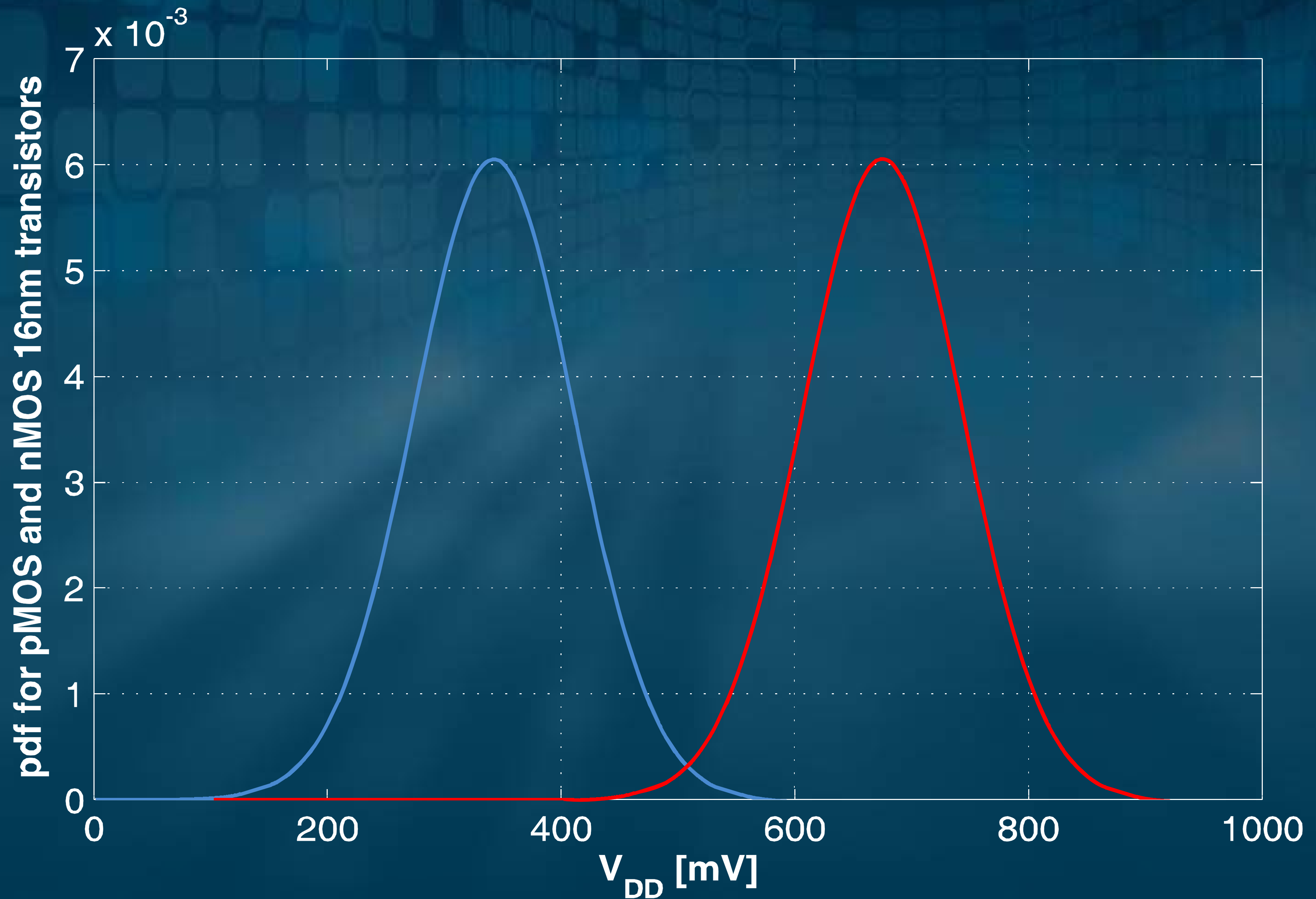
Devices get into the picture



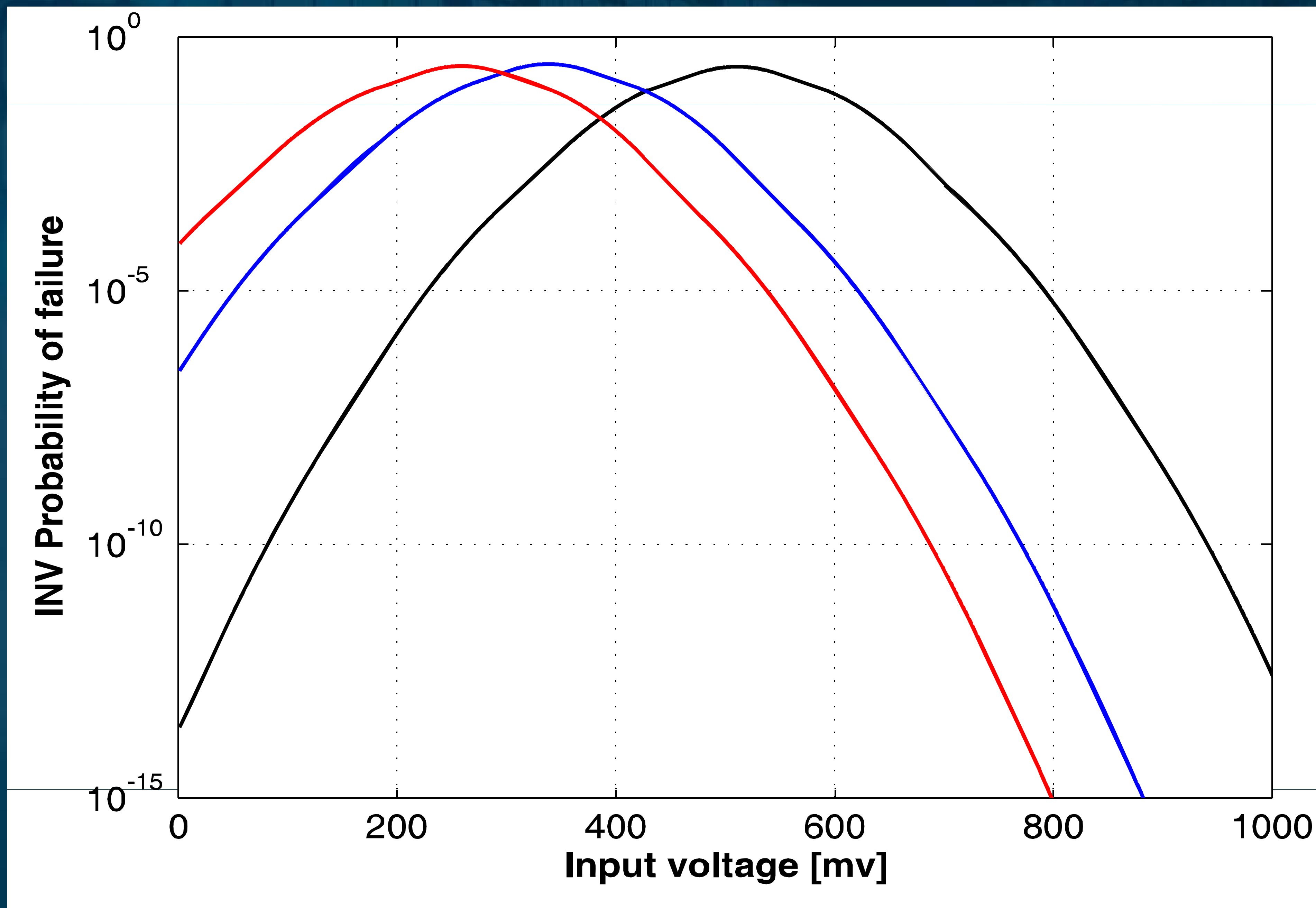


V. Beiu *et al.*, *IWANN'07*, 2007

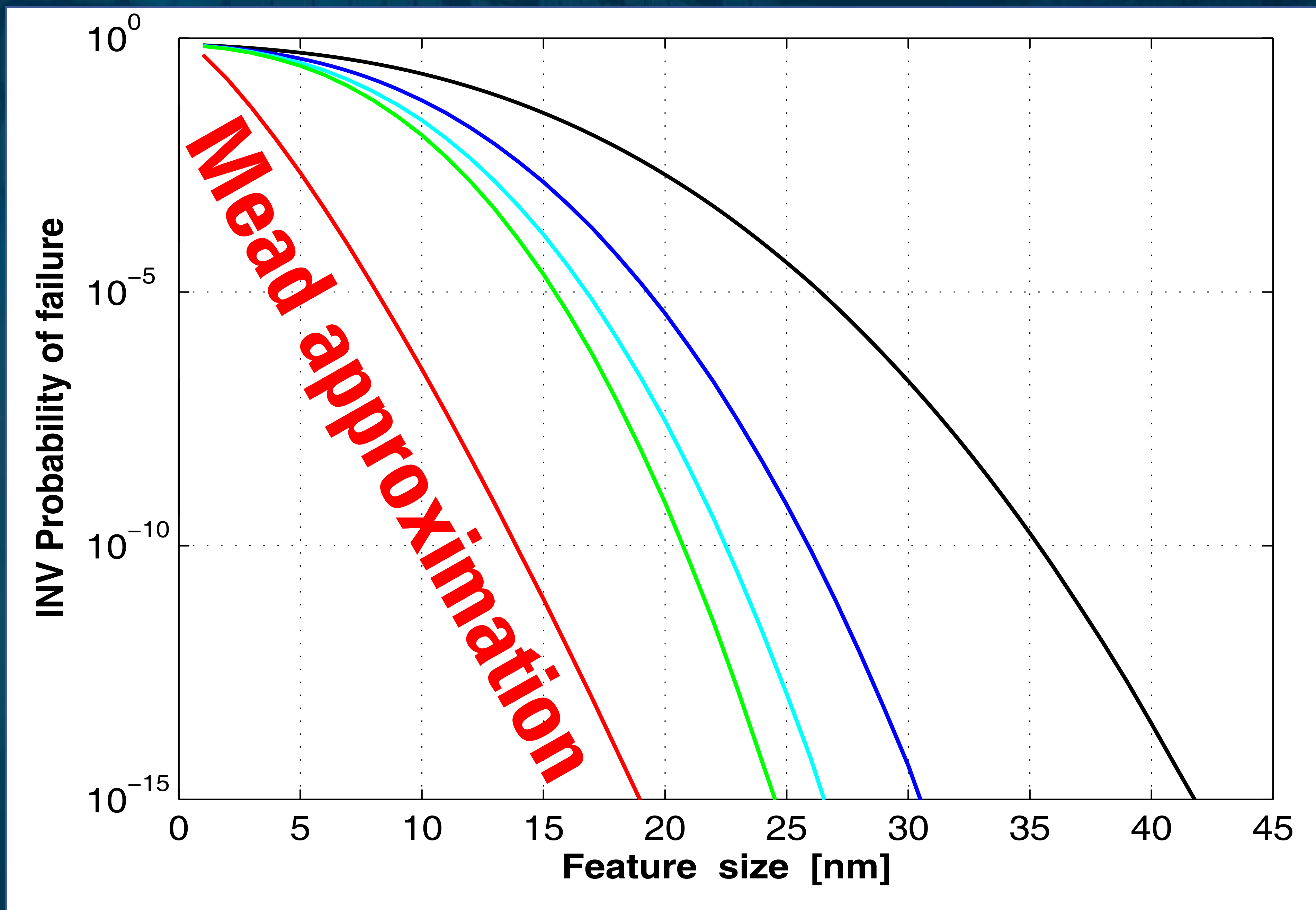
Probability density functions



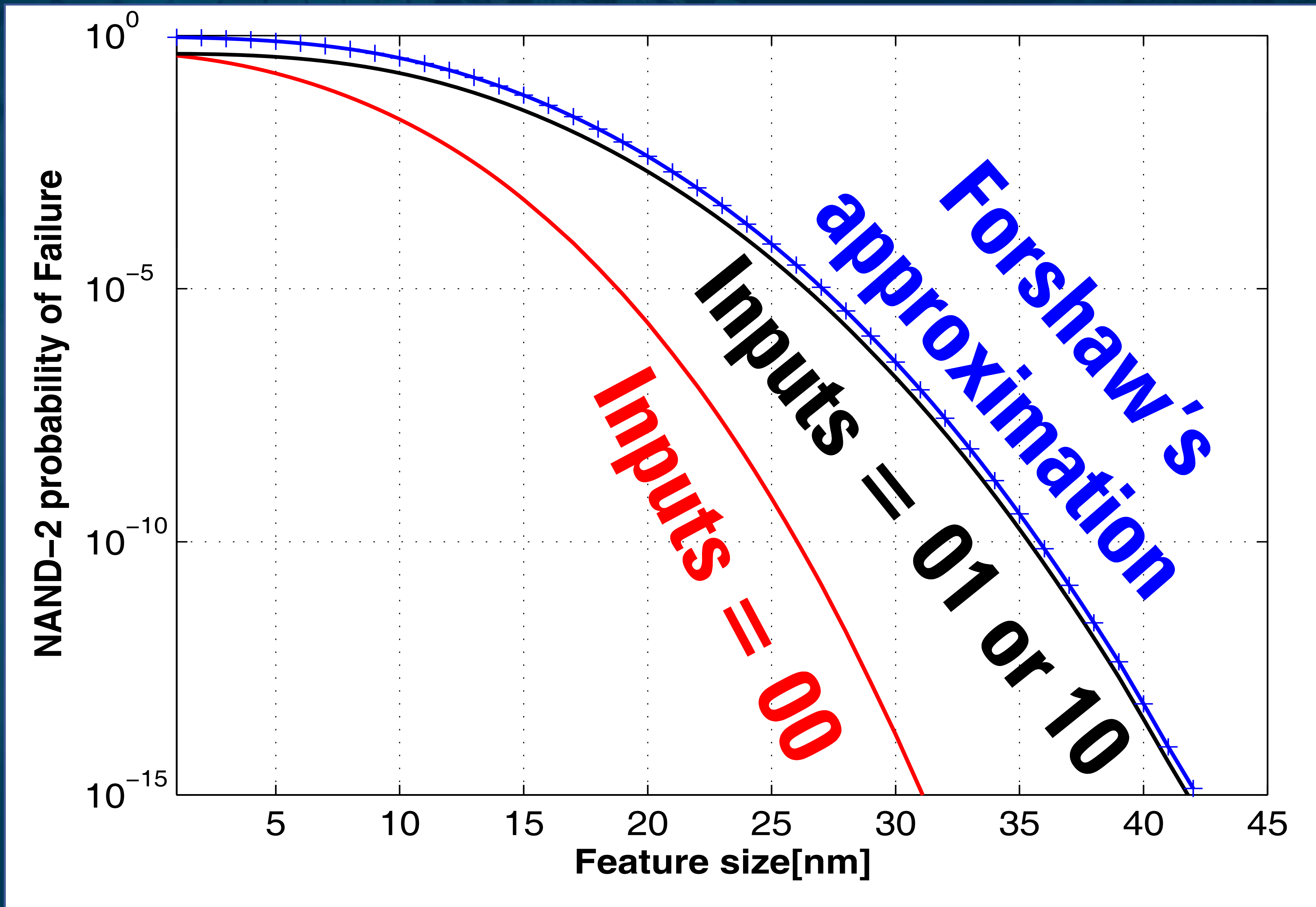
nMOS ... Vth at Vdd/2, /3, /4



Inverter (noise at Vdd/3, /4, /5 ...)



NAND-2



NAND-2 ... 3D view

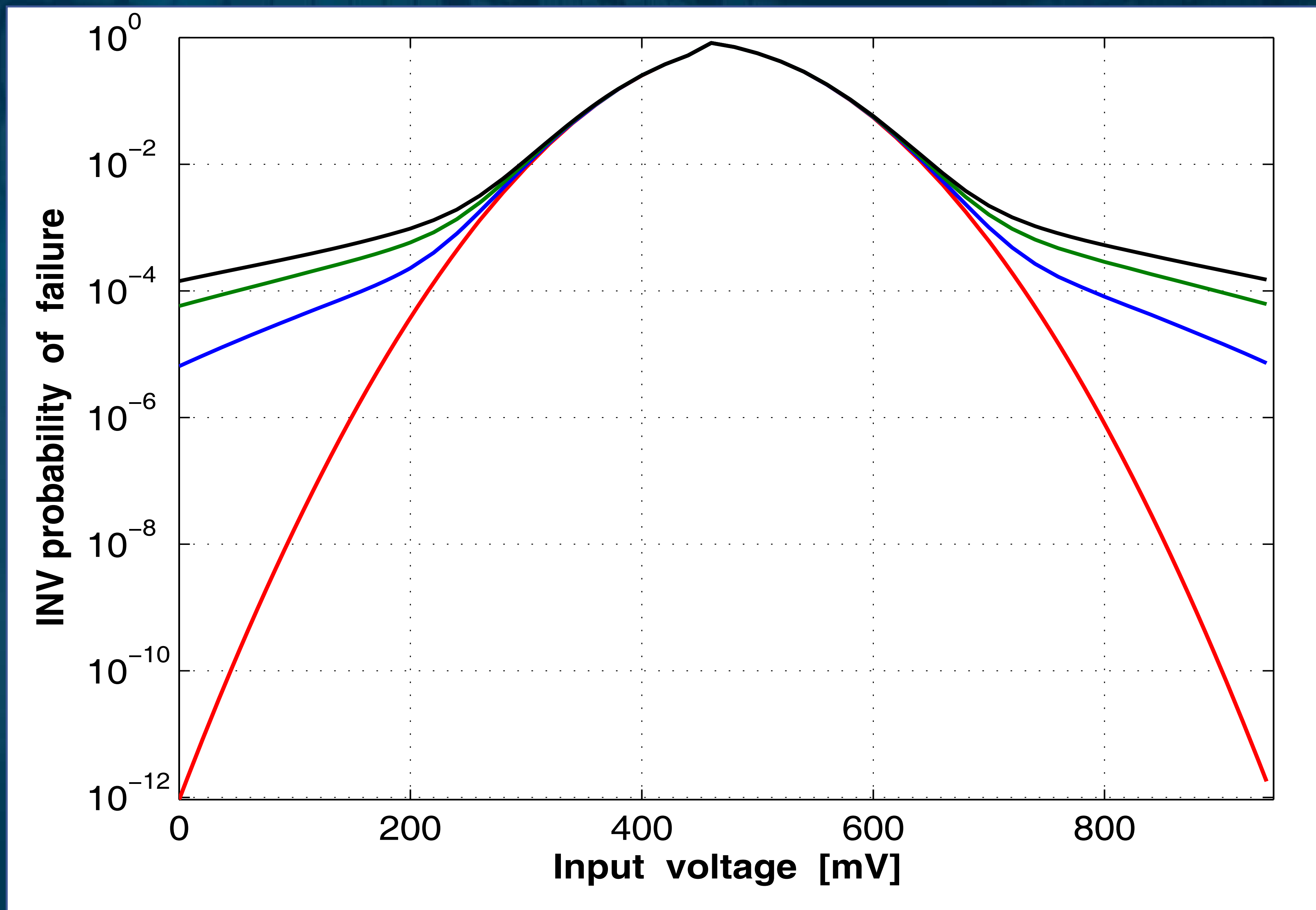
NAND–2 probability of failure

1
1E–5
1E–10
1E–15
1E–20
1E–25

Input–2 [mV]
0
500
1000

Input–1 [mV]
800
600
400
200
0

Inverter … 2, 1.99, 1.98. 1.97



Inverter 3D (at 1.97)

NAND–2 probability of failure
1
1E–2
1E–4
1E–6
1E–8
1E–10
1E–12
Input–1 [mV]
800
600
400
200
0
Input–2 [mV]
800
600
400
200
0

NAND–2 probability of failure
1
1E–5
1E–10
1E–15
1E–20
1E–25
Input–2 [mV]
0
500
1000
Input–1 [mV]
800
600
400
200
0

THANK YOU