Green's function based simulation of trap-induced device variability

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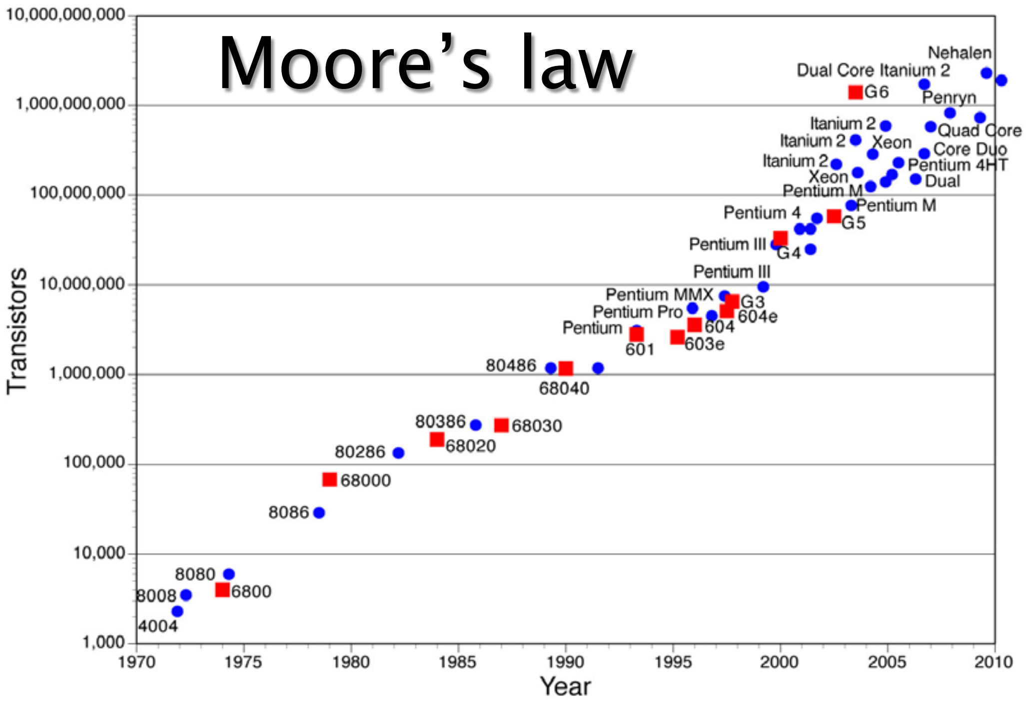
OUTLINE

- MOS Variability
  - Random Telegraph Noise (single trap)
    - also in conjunction with Random Doping Fluctuation (RDF)
- Green's function *vs.* incremental approach
- Case study
  - 32 nm MOS for FLASH applications
  - Varying trap position
- Green's function approach Validation
  - static case
- Variability analysis

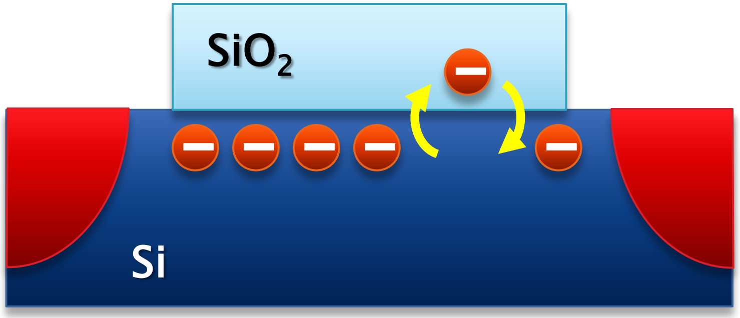
Device scaling


Moore's law

Variability issues

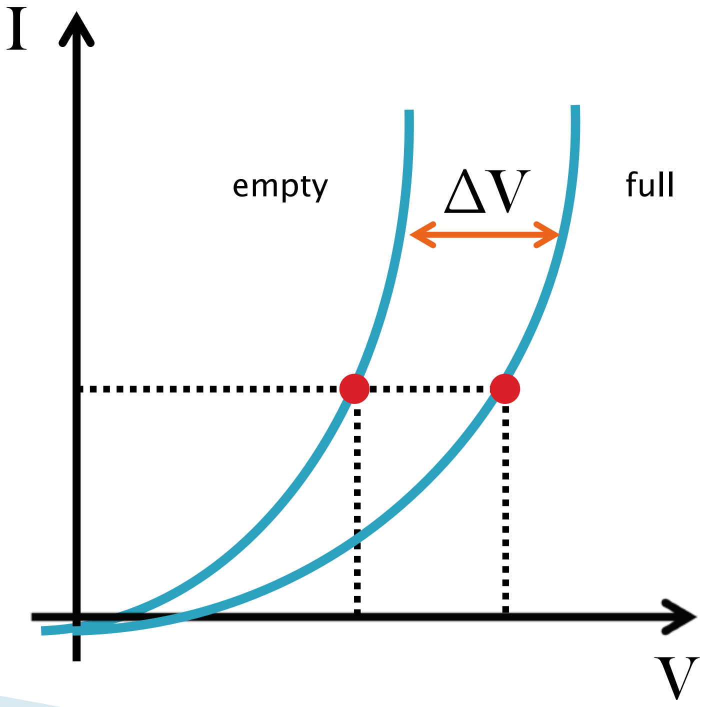
- RTN (Random Telegraph Noise)
- RDF (Random Dopant Fluctuation)

Variability: Random Telegraph Noise



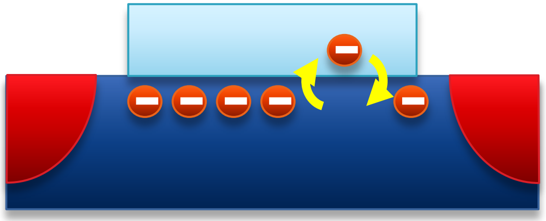
Capture/Emission of single electrons by oxide/interface traps

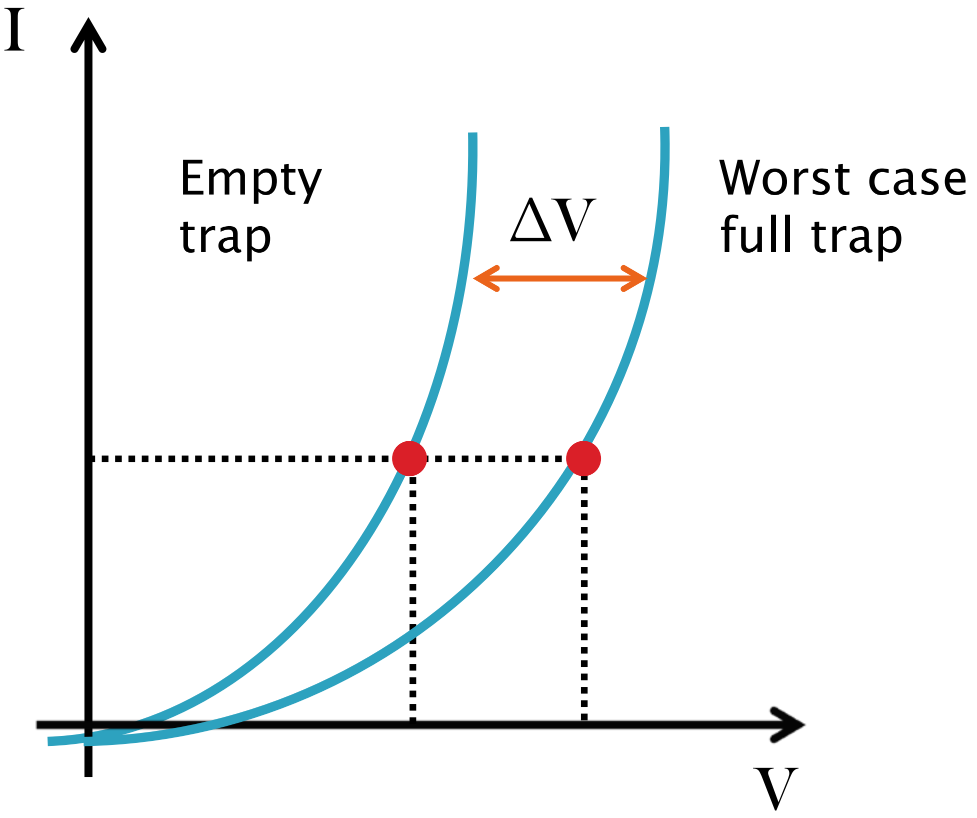
Due to reduced device dimensions, fluctuations in the device terminal properties become important



Single Trap Analysis

- Worst case difference of the drain current with full–empty trap

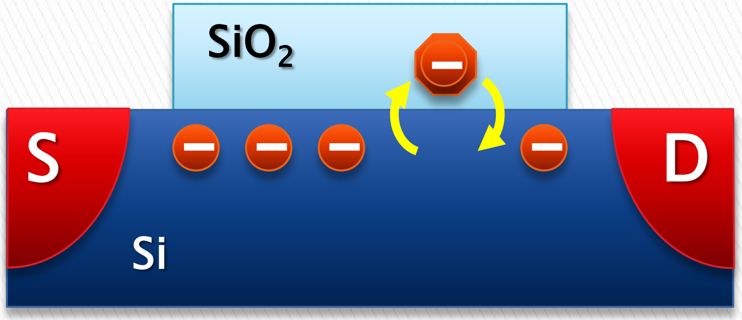




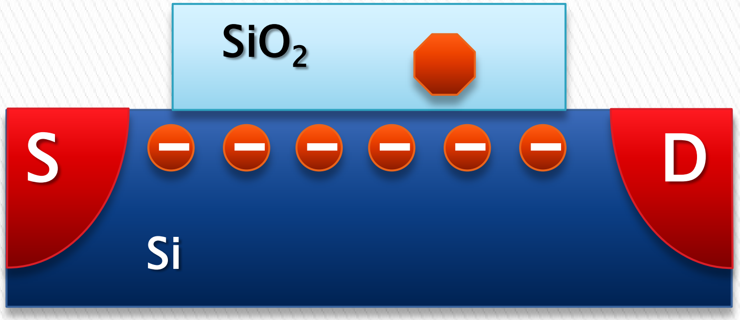
How to evaluate Single Trap Effect?

- **Incremental**
  - Simulations at the possible traps positions
  - Time consuming
  - High computing resources

Full trap:



Empty trap:



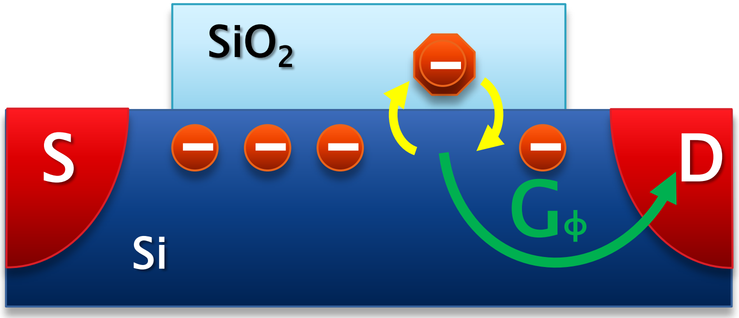
$$\Delta I_{D,inc}(x) = I_{D,full}(x) \quad - I_{D,empty}(x)$$

How to evaluate Single Trap Effect?

- **Green's function**
  - Well established tool for variability analisys e.g. RDF Synopsis model
  - One simulation to evaluate the Green's function
  - Single trap effect amounts to a small variation of charge -> linear response through Poisson equation Green's function

Evaluate Green's function
(computation time ~ SS analysis at 0 f.)

Full trap effect:



Convolution integral for single trap reduces to 1 product

$$\Delta I_{D,ifm}(x) = q_{trap} \times G_{\varphi}(x)$$

Simulation setup for RTN

- Advanced MOS 32nm [1]
  - European MODERN Project
  - Bando Alta Formazione – Regione Piemonte

- Traps positions
  - Si/SiO_2 interface
  - Si channel
  - SiO_2
- No traps dynamics

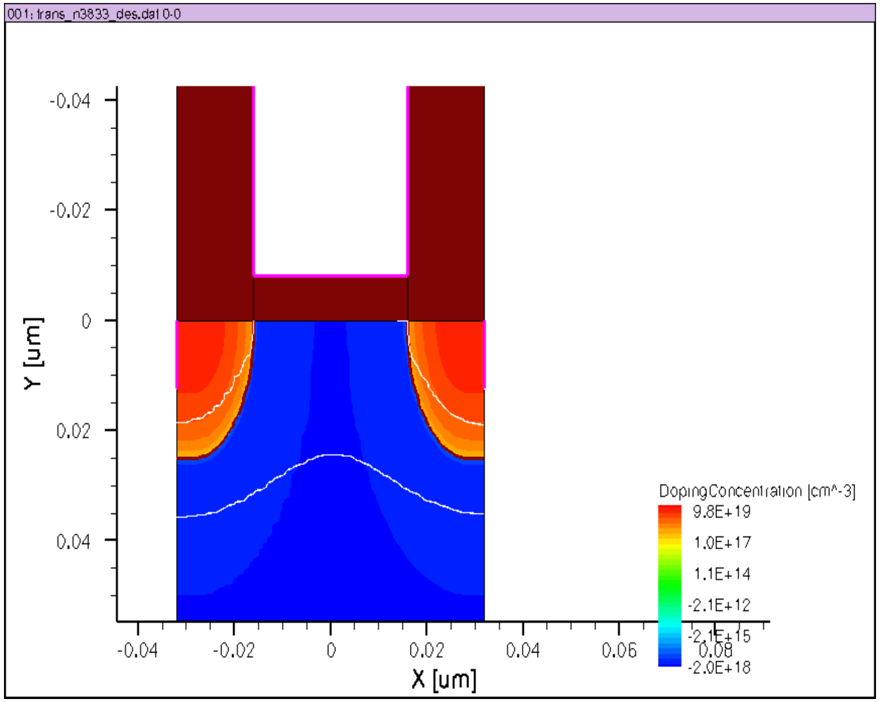


Figure 1: 2D cross-section of the 32 nm MOSFET device obtained by eliminating the floating gate from the template non-volatile memory device used in MODERN

Model Validation : RTN

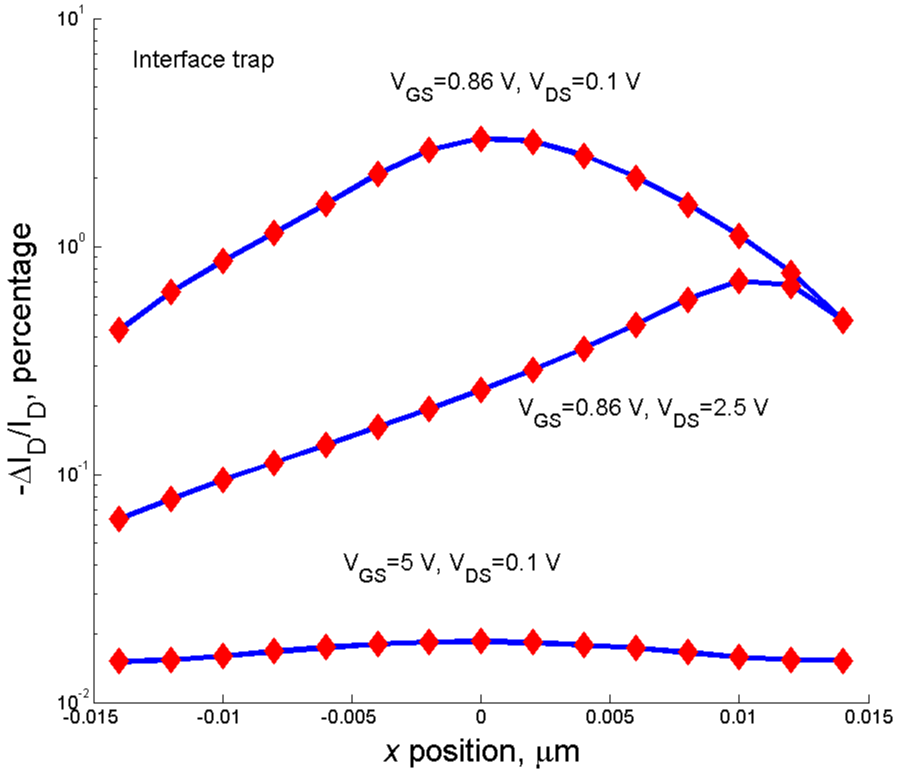


Figure 2: Comparison between the incremental (symbols) and Green’s function (line) estimation of (minus) the relative drain current variation $\Delta I_D/I_D$. Trap placed at the interface between SiO_2 and Si.

Threshold voltage variability found from drain current 1e-7 A/mm exploiting Y21 SS parameter at zero freq.

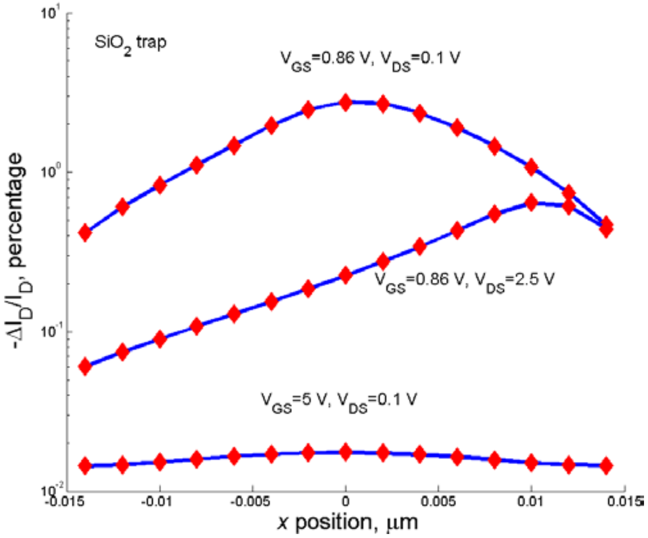
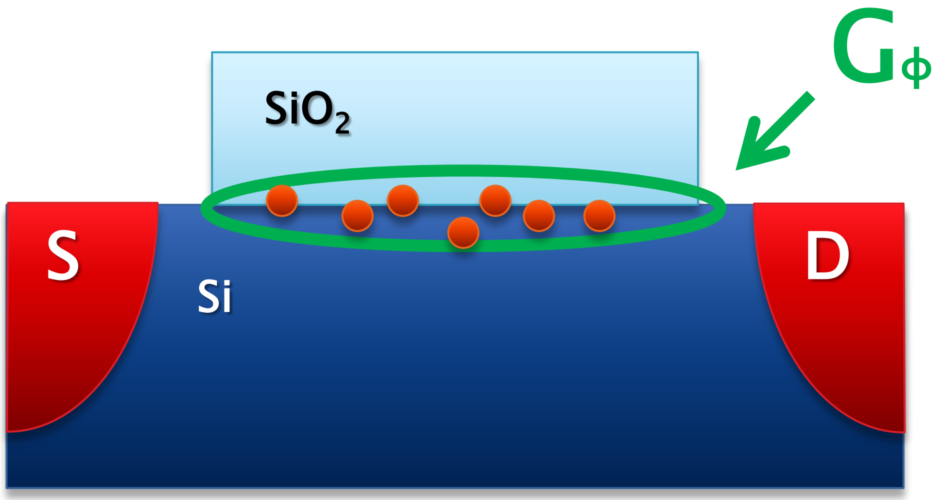


Figure 3: Comparison between the incremental (symbols) and Green’s function (line) estimation of (minus) the relative drain current variation $\Delta I_D/I_D$. Trap placed near the interface at the SiO_2 side.

Variability RTN

- Randomize traps position at Si–SiO_2 interface
  - Uniform distribution
  - Evaluate Green's function at the interface



Variability: RDF (Synopsys implem)

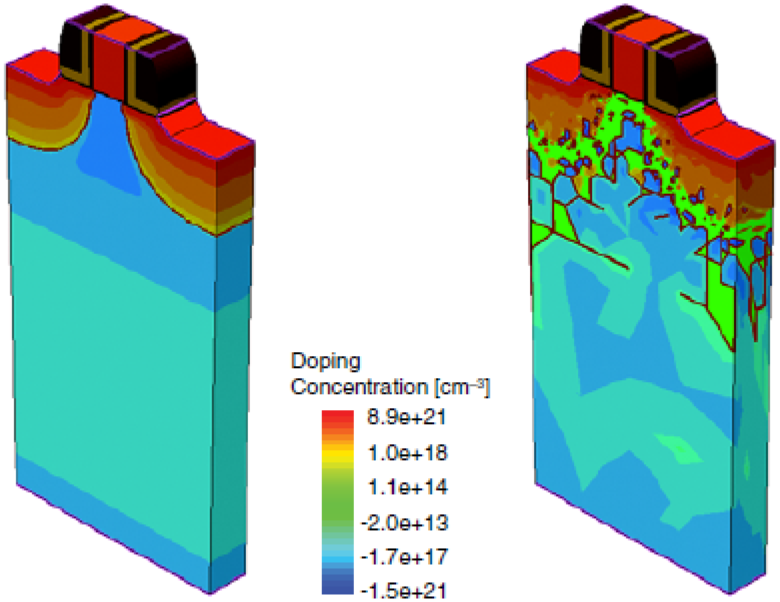


Figure 4: Synopsis NMOS structure with (left) continuum doping and (right) randomized doping profile

Device fabbricated in large numbers

Differences in the number and exact placement of dopant atoms

Induced fluctuations (noise-like) at the device terminal

Green’s functions statistical RTN+RDF analysis

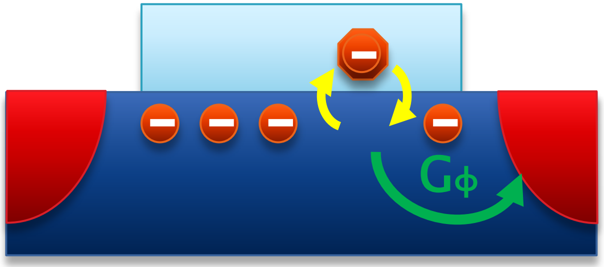
Ongoing work

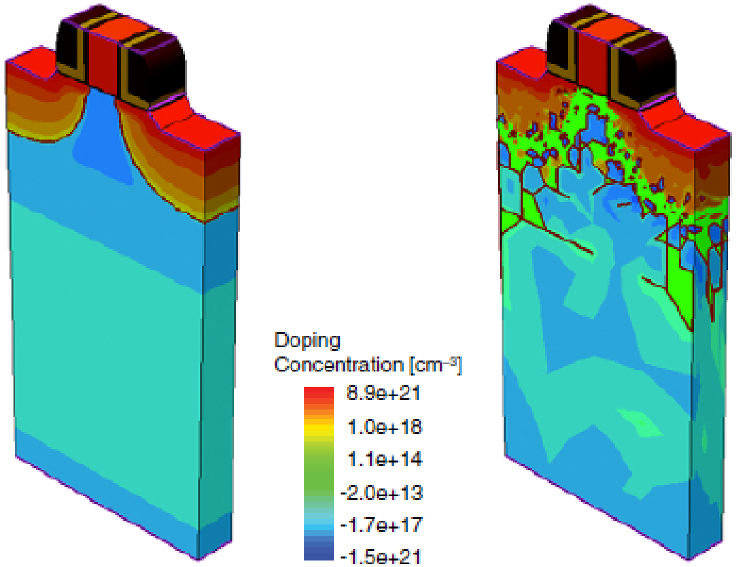
Green’s function statistical RTN

+

Linearity Uncorrelated

Synopsis demonstrated statistical RDF





Variability analysis: RTN

- Extraction of the slope λ [mV/dec] of the statistical distribution of the single trap RTN (1000 random position on Si/SiO2 interface)

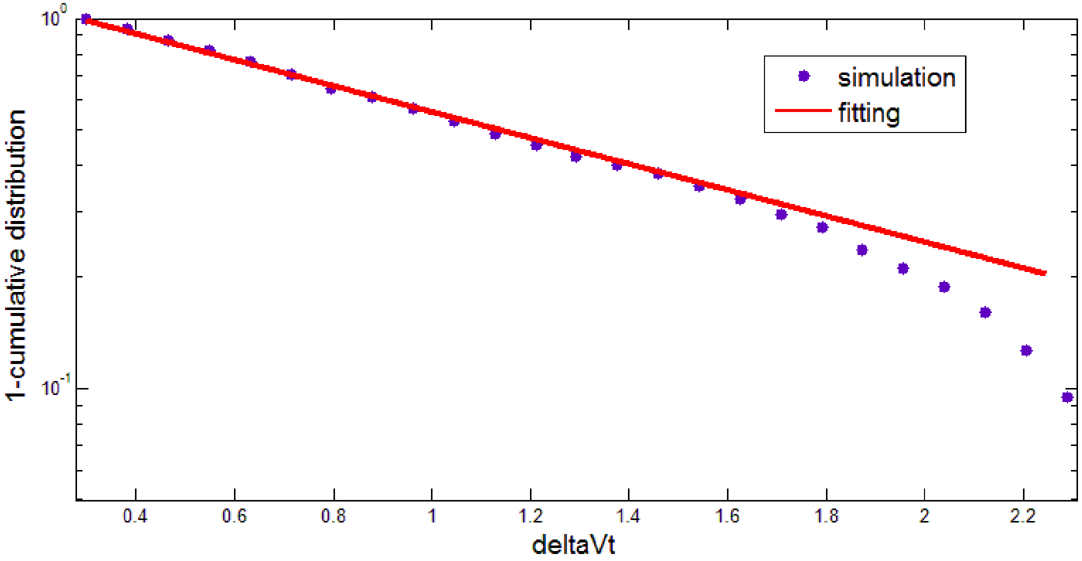
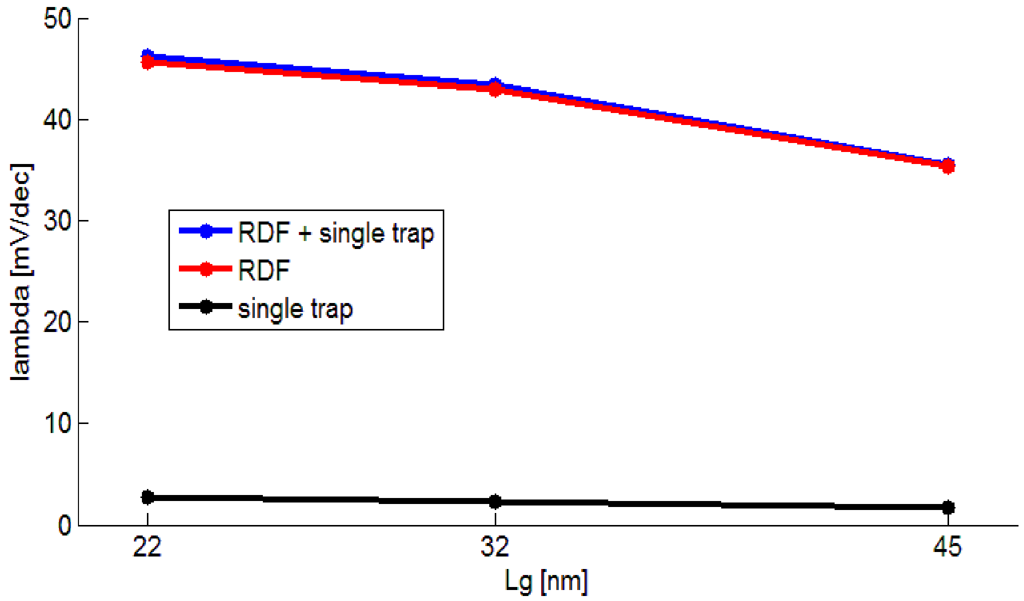


Figure 5 Statistical distribution of the RTN on the threshold voltage

MonteCarlo:
1000 simulations
Green:
1 simulation
+1000 convolutions

Variability analysis : RTN + RDF

- Dependence of λ [mV/dec] on Gate length considering both the RTN and RDF



MonteCarlo:
3000 simulations
Green :
3 simulations
+3000 convolution

Figure 6 Statistical distribution of the RTN on the threshold voltage

Further work

- Validation of the Green’s function approach on a MOS 3D template
- Study of other 3D structures

Thanks fot the attention

- Riccardo Tisseur