Assessment of the Statistical Impedance Field Method for the Analysis of the RTN Amplitude in Nanoscale MOS Devices

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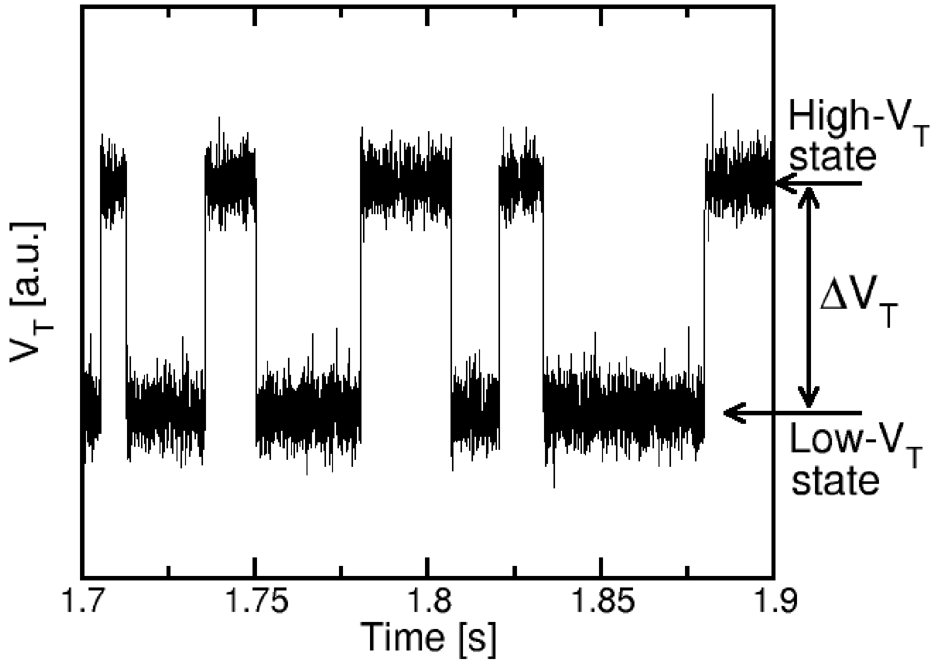
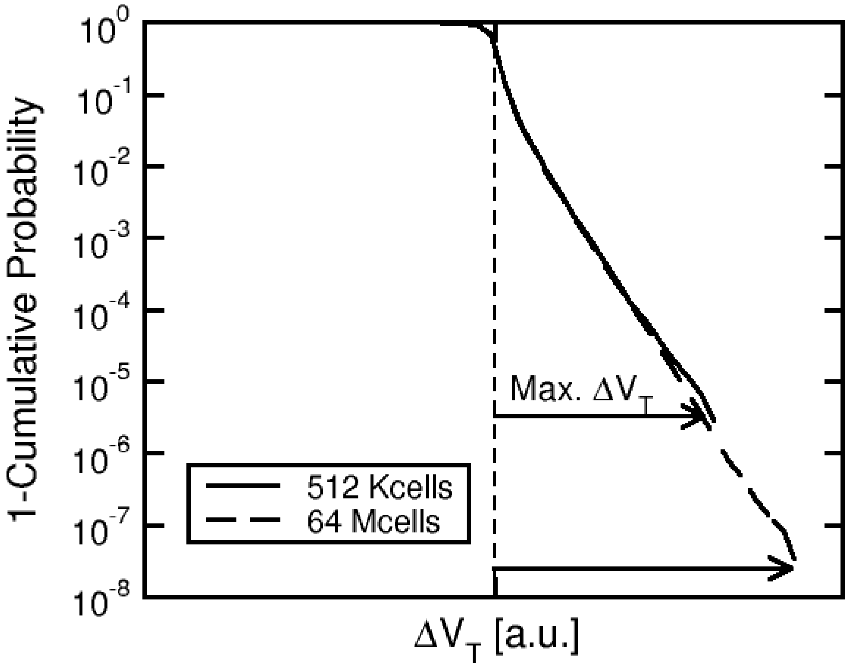
Outline

- Introduction
- Statistical Impedance Field Method (sIFM) for the analysis of the amplitude of RTN fluctuations
- Comparison between sIFM and conventional MC results
- Conclusions

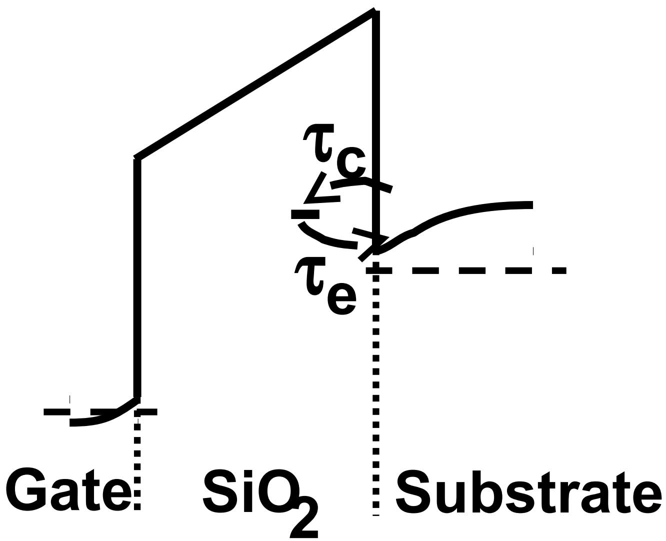
Random Telegraph Noise

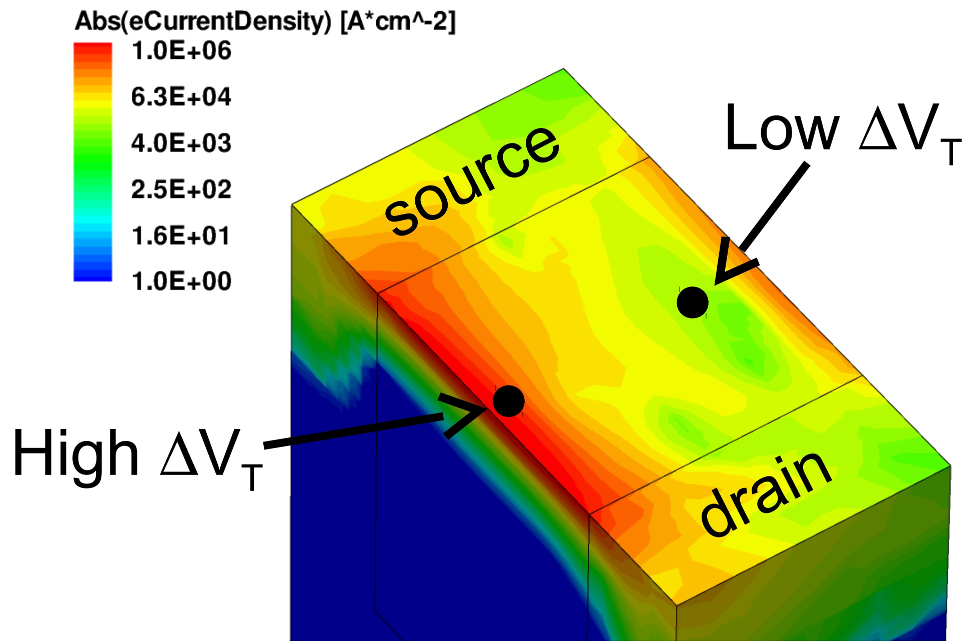




- RTN is a fluctuation of device V_T (or I_D) between two definite levels
- Technology scaling has been increasing the amplitude of RTN fluctuations giving rise to a wider statistical distribution

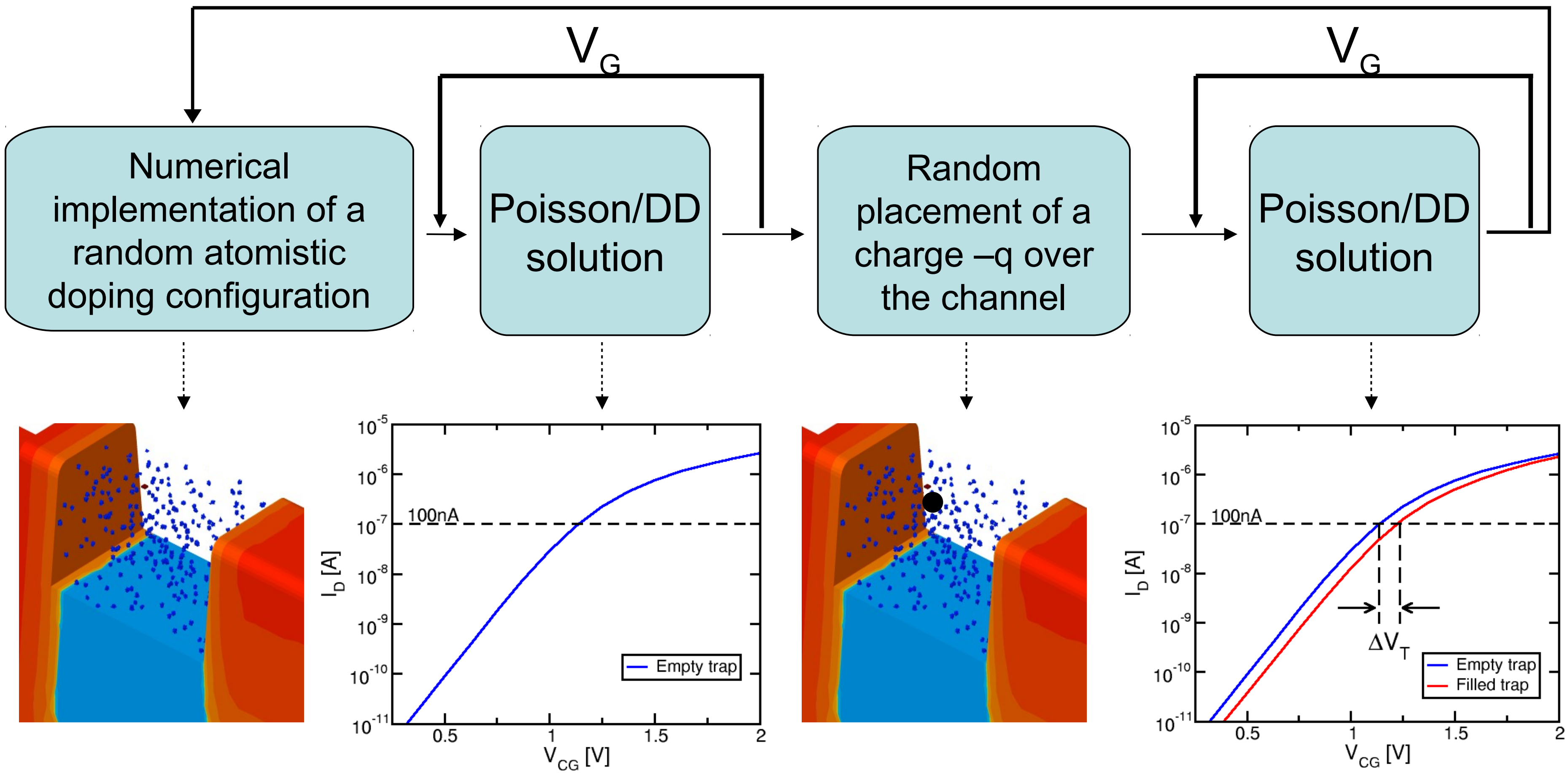
Statistical RTN effect





- The fluctuation is due to a carrier capture/emission mechanism at the SiO_2/Si interface
- The RTN amplitude is the result of trap capability to stop the percolative path
- RTN now represents a major reliability issue

Conventional RTN MC scheme



- The computational burden is proportional to the number of samples

Statistical Impedance Field Method

- *Motivation*: reducing the computational loads
- *Hypothesis*: treating the variability sources as a small perturbation of Poisson/DD solution
- *Approximation*: linear approximation of Poisson/DD equations around a reference condition
- *Thesis*: treating the effects of variability sources through the Green Functions approach

Statistical Impedance Field Method

- *Literature*: neutral V_T statistics

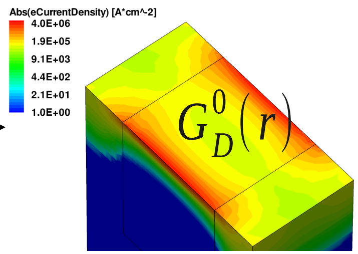
$$\delta I_k = \int G_D^0(r)\,\delta N_k(r)\,d^3 r$$

$$\delta N_k(r) = N_k(r) - N_{cont}(r)$$

- *This work*: neutral V_T statistics + RTN amplitude, using
  - **sIFM-doping**: *atomistic doping* as perturbation of the continuous doping case (with neutral and charged trap)
  - **sIFM-trap**: *trapped charge* as perturbation of the atomistic doping

1- The sIFM-doping scheme

Continuous doping device



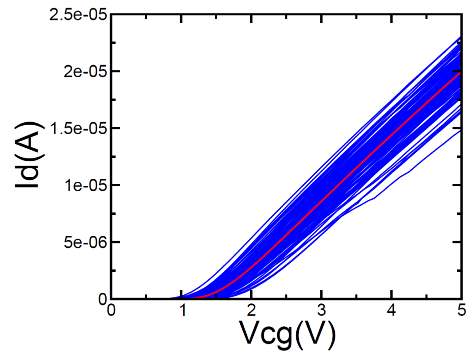
Iter. over doping cases

Calculation of δI for the k-th doping configuration:

$$\delta I_k = \int G_D^0(r)\,\delta N_k(r)\,d^3r$$

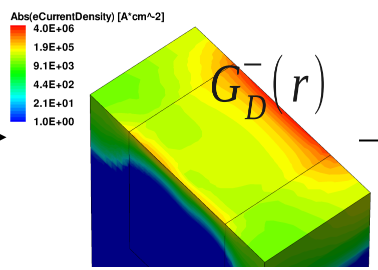
$$\delta N_k(r) = N_k(r) - N_{cont}(r)$$

Iter. over bias points



Random placement of a charge –q at the channel surface

Iter. over trap positions



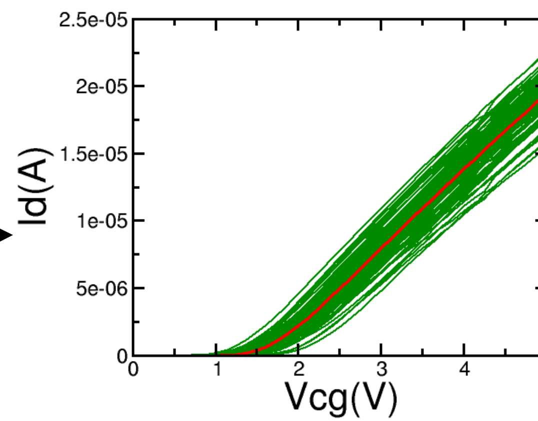
Iter. over doping cases

Calculation of δI for the k-th doping configuration:

$$\delta I_k = \int G_D^-(r)\,\delta N_k(r)\,d^3r$$

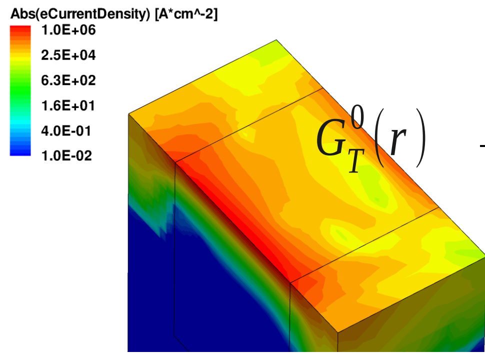
$$\delta N_k(r) = N_k(r) - N_{cont}(r)$$

Iter. over bias points



2- The sIFM-trap scheme

Random configuration of atomistic doping



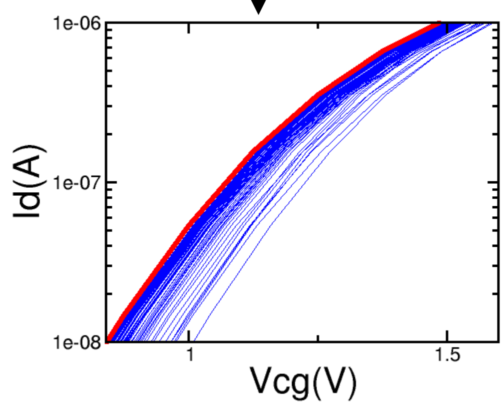
Iter. over trap positions

Calculation of δI for the i-th trap:

$$\delta I_i = qG_T^0(r_i)$$

Iter. over bias points

Iter. over doping cases



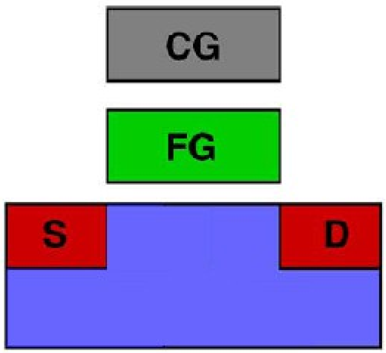
Computational load comparison

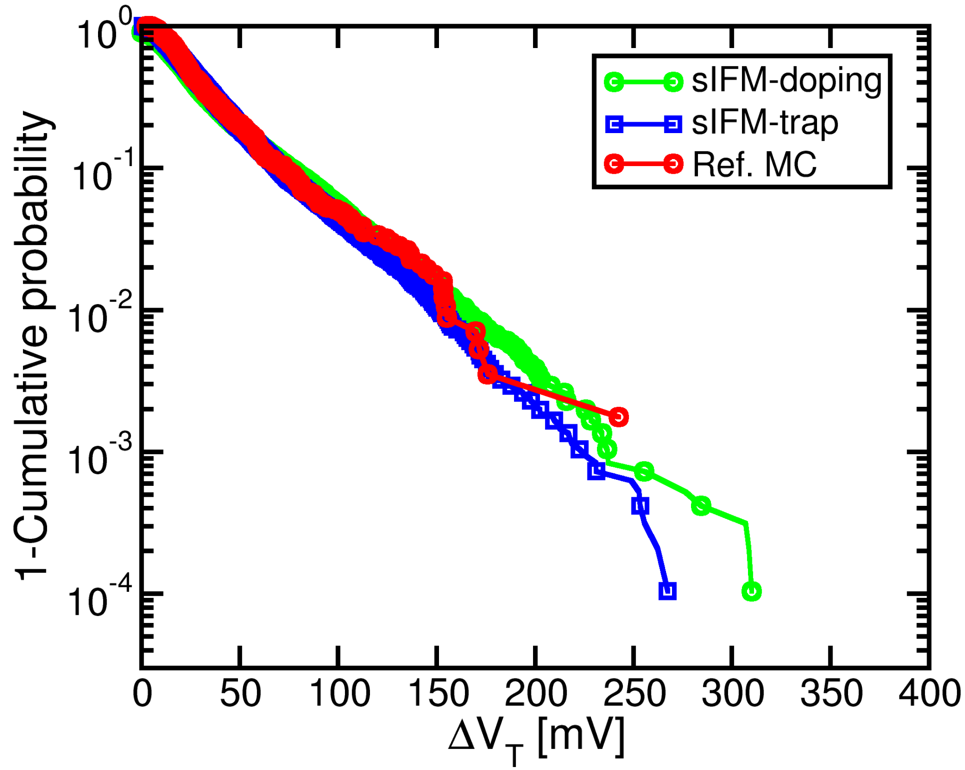
- Given:
  - N_{dop} atomistic doping configurations
  - N_{trap} trap positions per cell
- Any simulation set gives a statistical ensamble of **N_{dop} x N_{trap}** elements

Reference MC	sIFM-doping	sIFM-trap
↓	↓	↓
N_{dop}x(N_{trap}+1) Poisson/DD solutions	(N_{trap}+1) Poisson/DD solutions	(N_{dop}) Poisson/DD solutions

Statistical dispersion of ΔV_T

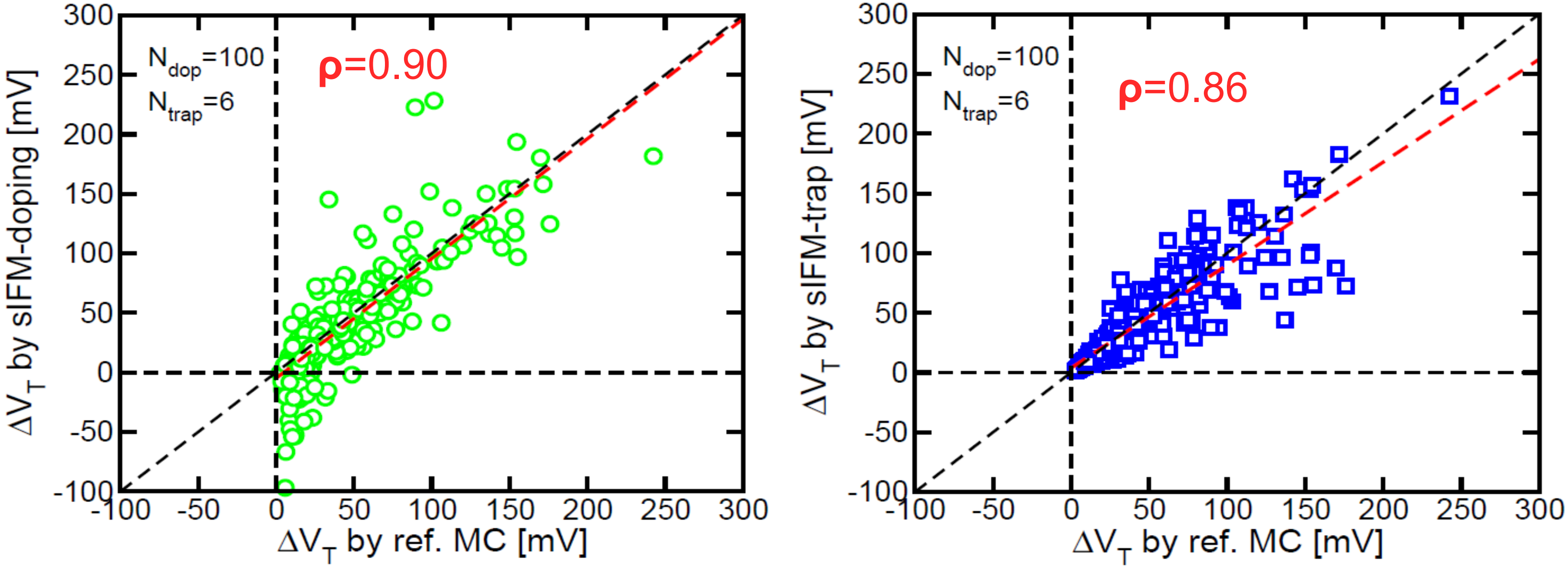
W=L=32nm
t_{ox}=8nm
$N_a=2\times10^{18}cm^{-3}$





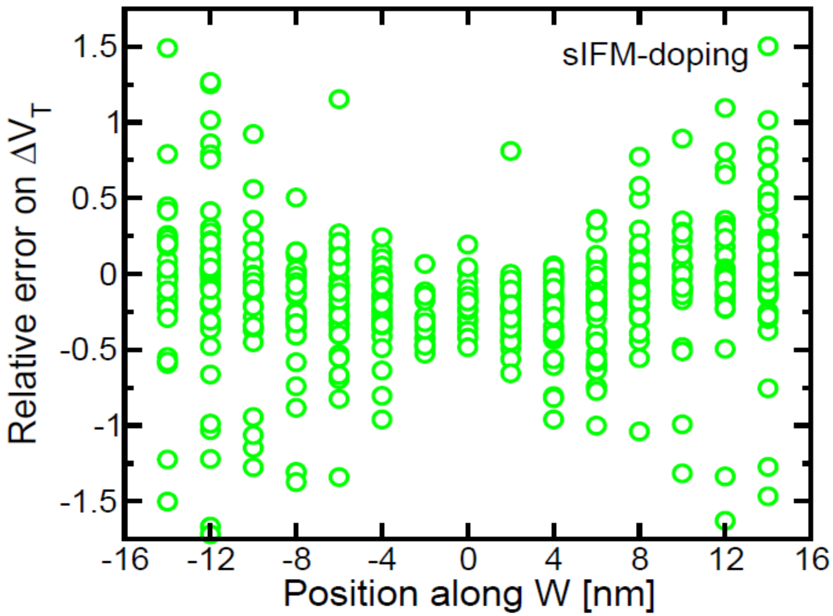
- Both of the sIFM schemes are able to reproduce the reference MC statistics
- Reduced computational burdens allow to explore lower probability ranges

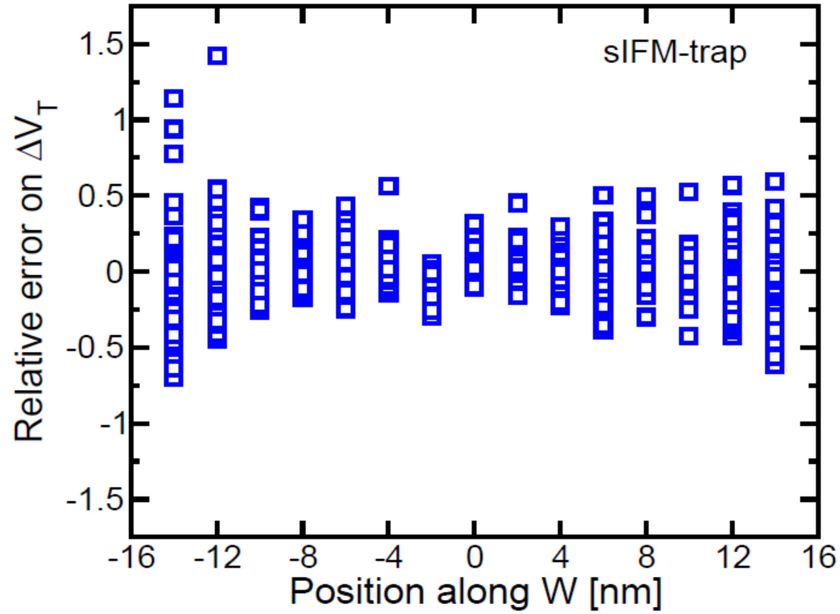
A more in-depth analysis



- A point by point comparison between MC and sIFM methods shows a non-negligible discrepancy in the results
- Unphysical negative ΔV_T may occur using sIFM-doping method
- Correlation values are calculated omitting unphysical points

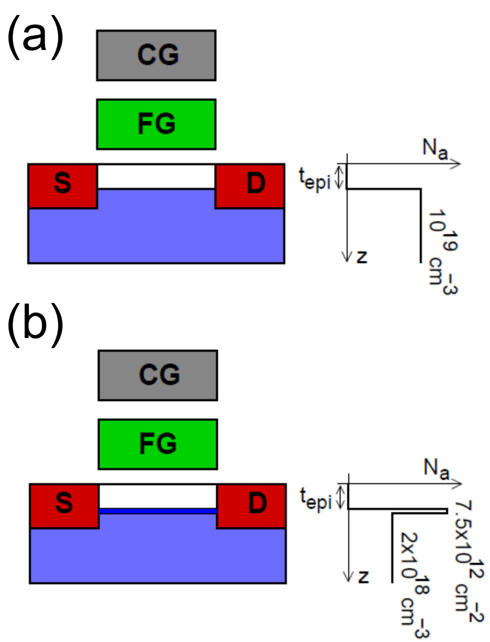
Role of trap position

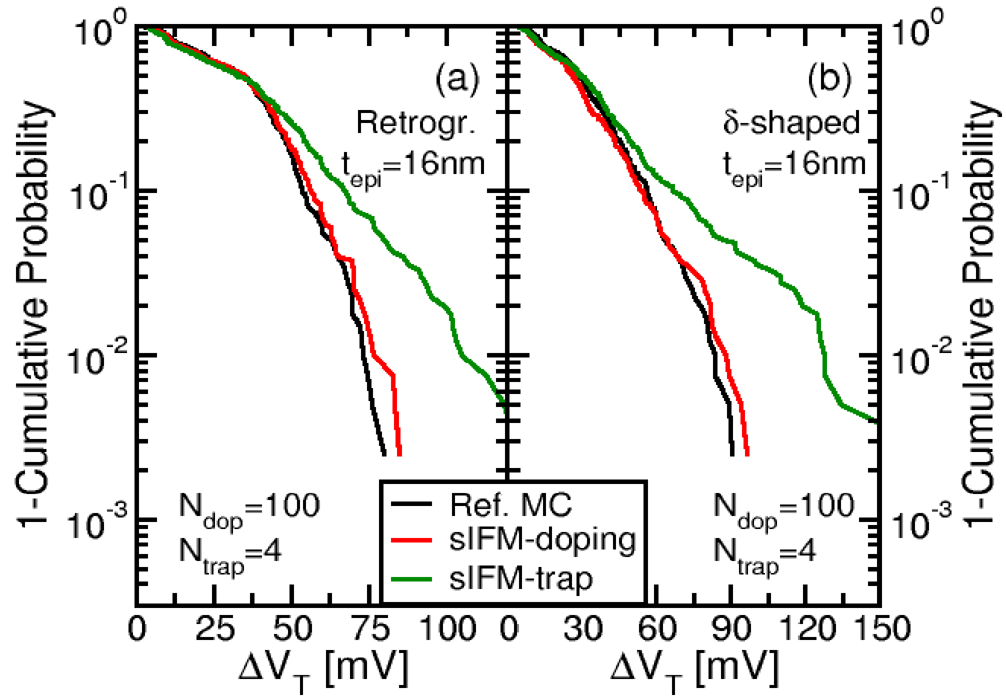




- Largest errors using sIFM schemes occur when the RTN trap is placed close to cell edges
- Dispersion is symmetric over the average value
- ΔV_T estimation errors compensate each other in a statistical analysis

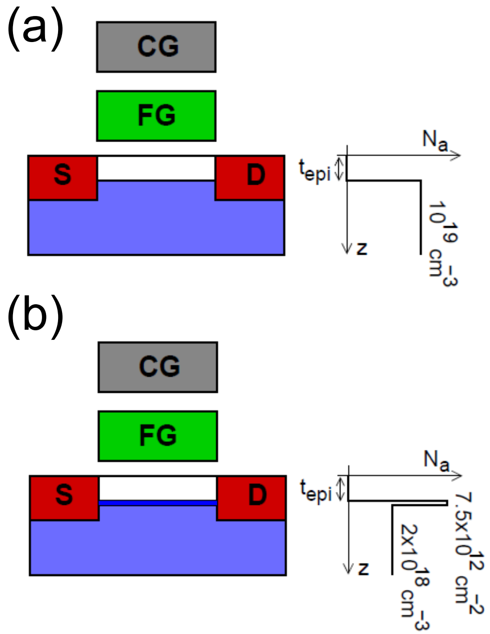
Vertically non-uniform dopings

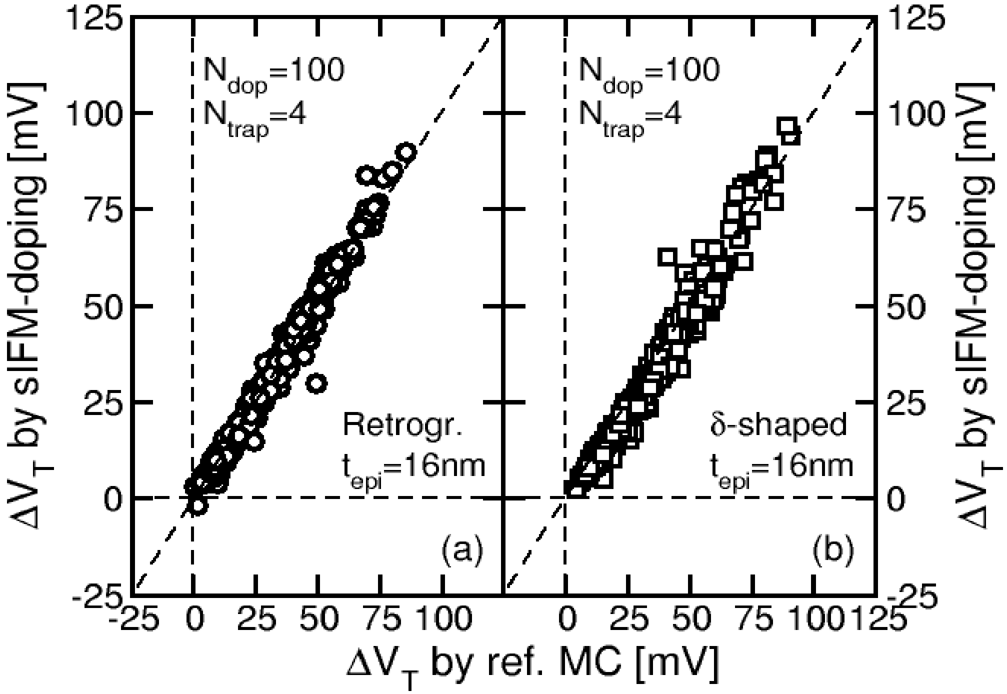




- In some cases sIFM schemes maybe inaccurate also for ΔV_T statistics
  - The sIFM-trap is not very inaccurate
  - The sIFM-doping is very good

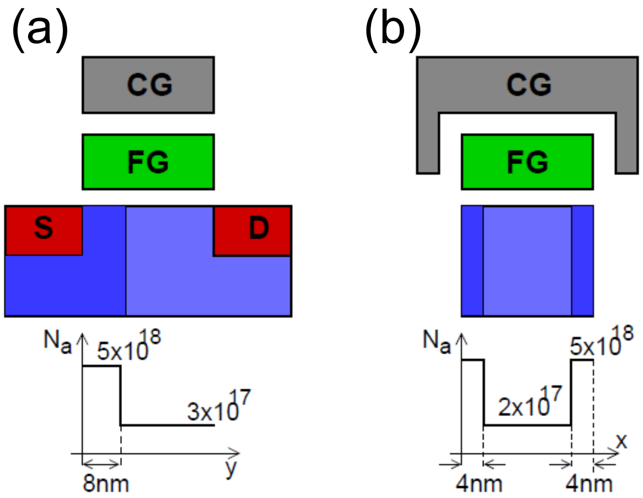
Vertically non-uniform dopings

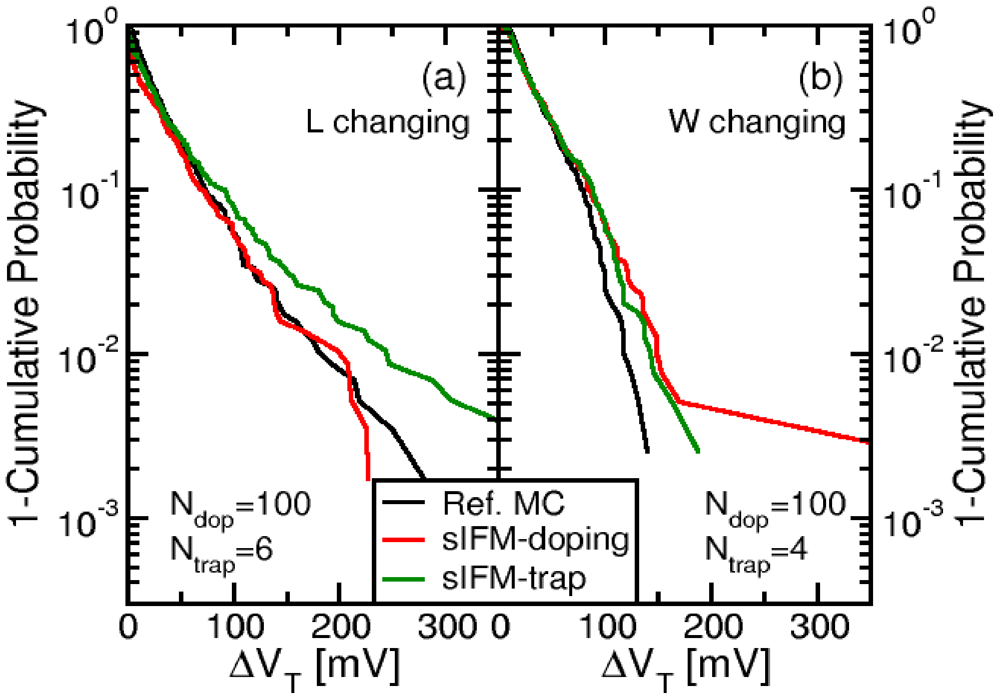




- Dopants are far from the channel surface
- sIFM-doping scheme is accurate also looking at the single MC samples

Laterally non-uniform dopings





- Changing the doping profile along W methods are equivalent
- A change in the doping profile along L modifies percolation paths
- sIFM-doping better describes these last effects

Conclusions

- The sIFM methods are a good compromise between accuracy and computational burdens allowing to explore lower probability ranges
- sIFM methods are able to reproduce with a good accuracy statistical quantities
- Performing a point by point comparison between sIFM results and MC reference, a non-negligible discrepancy occurs
- In case of nonuniform doping profiles the accuracy of the sIFM methods should be evaluated case by case

Thank you for your attention

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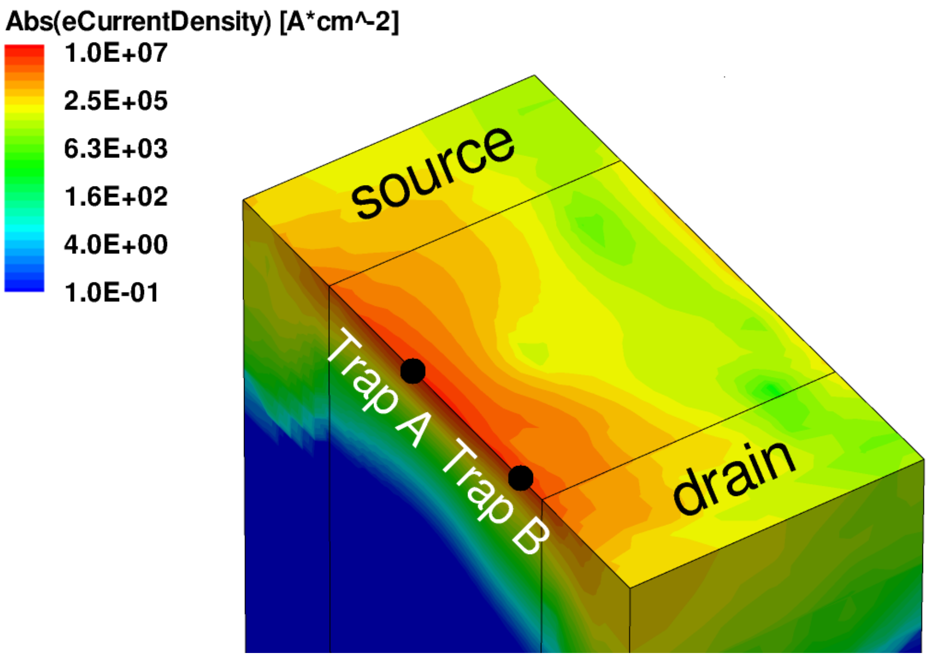
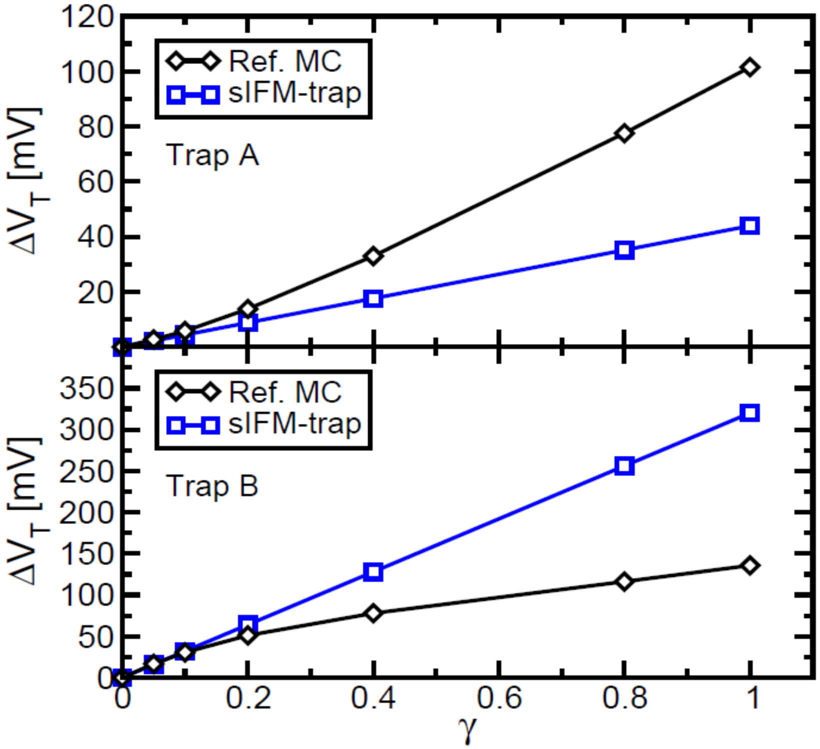
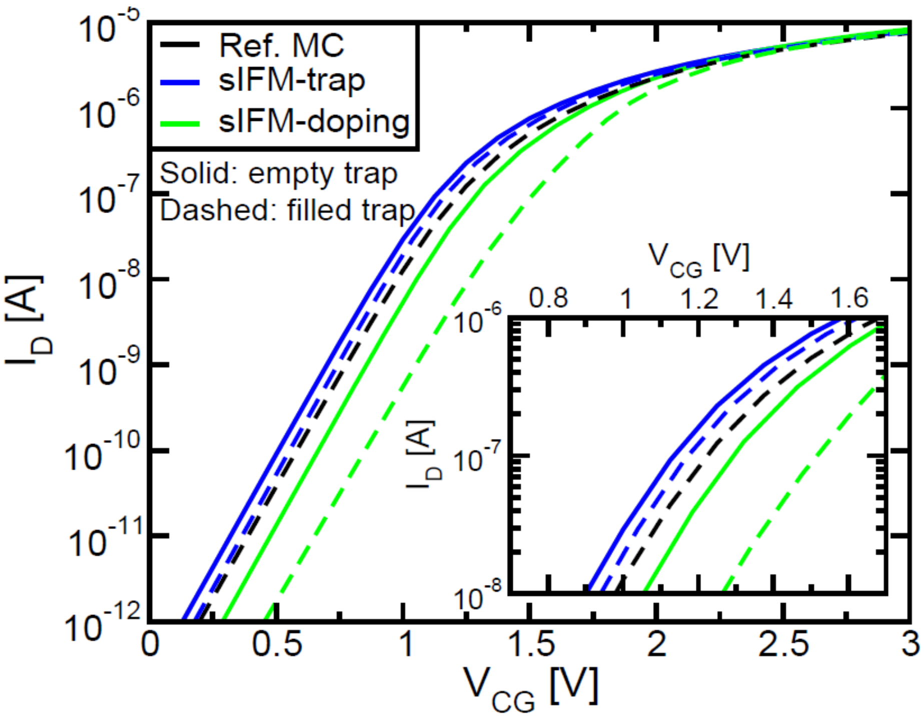
Effects of linearization





- Inaccuracies of the sIFM schemes come from the linear approximations involved in the method

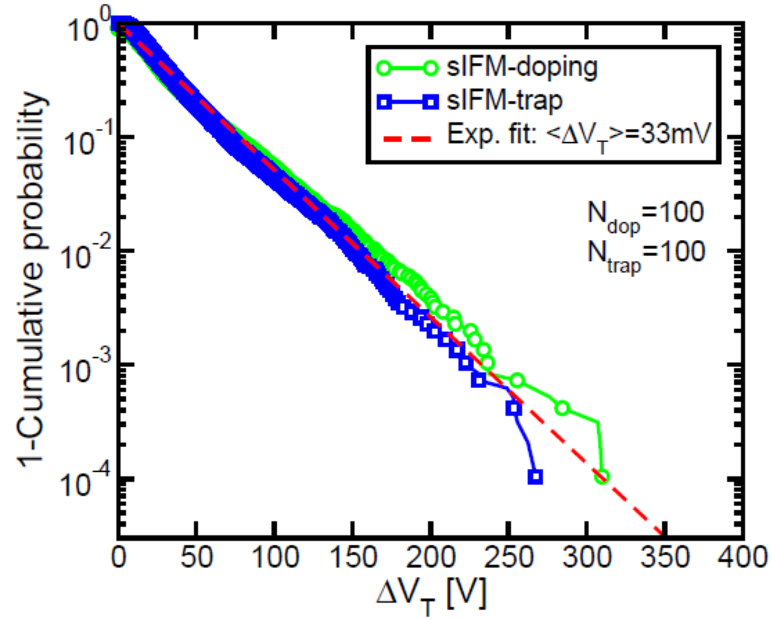
I_D-V_G of the highest sIFM-doping ΔV_T



- The sIFM methods fail to reproduce filled trap I_D-V_G
- The sIFM-doping method also fails to reproduce neutral I_D-V_G curve
- Atomistic doping cannot be considered as a small perturbation

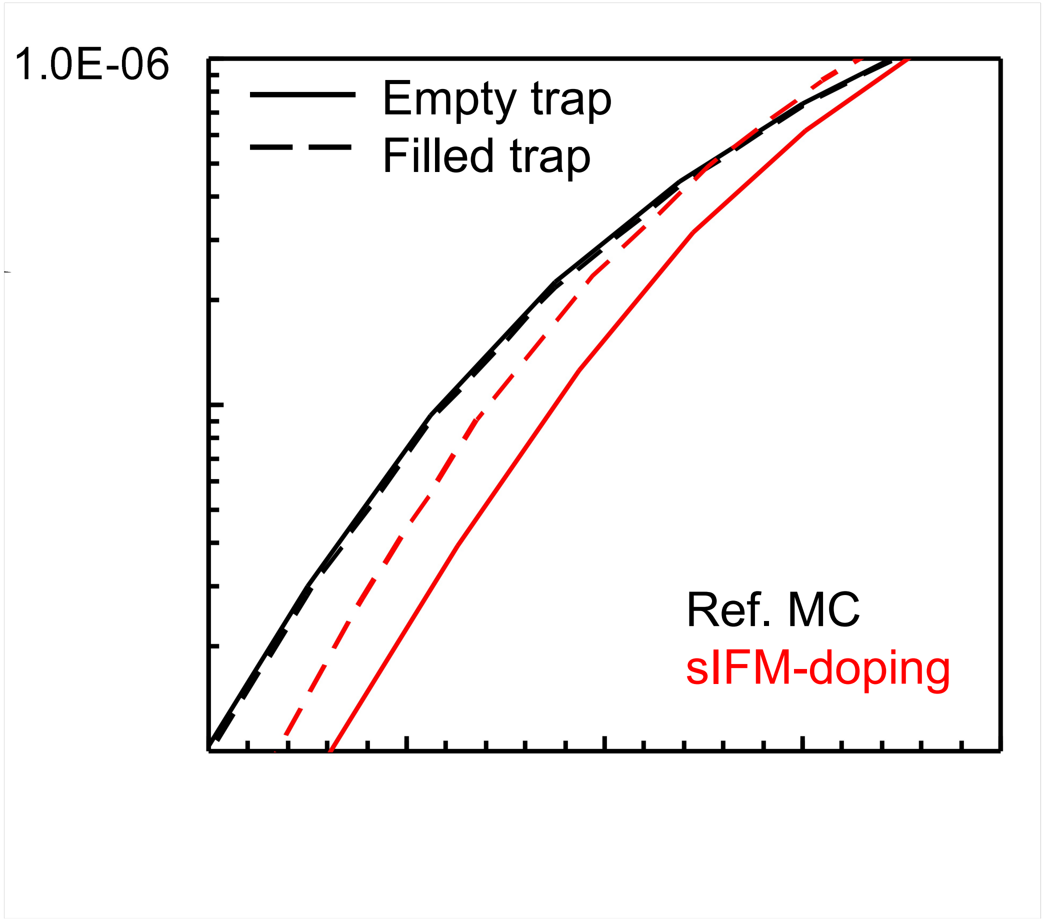
Remarks on ΔV_T dispersion

- Thanks to lower computational burdens sIFM methods are useful to extend statistics to lower probability ranges



- sIFM-trap:
  - is computationally faster
  - shows a better agreement with MC reference
  - does not introduce errors in neutral I_D-V_G calculation

Results: RTN, Uniform doping



ΔVt_MC	6,4 mV
ΔVt_sIFMdop	-66,7 mV