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

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Green’s function based simulation of trap–induced device variability

Author: Ph.D student Riccardo Tisseur
Co–Author: Prof. Fabrizio Bonani
Prof. Simona Donati
Prof. Giovanni Ghione

Dipartimento di Elettronica e Telecomunicazioni
Politecnico di Torino
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)
Due to reduced device dimensions, fluctuations in the device terminal properties become important.

Capture/Emission of single electrons by oxide/interface traps
Single Trap Analysis

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

![Diagram showing I-V curves for empty and worst case full trap, with ΔV indicating the difference.]
How to evaluate Single Trap Effect?

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

\[
\Delta I_{D,inc}(x) = I_{D,full}(x) - I_{D,empty}(x)
\]
How to evaluate Single Trap Effect?

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

Evaluate Green’s function
(computation time $\sim$ SS analysis at 0 f.)

Full trap effect:

Convolution integral for single trap reduces to 1 product

$$\Delta I_{D,ifm}(x) = q_{trap} \times G_\phi(x)$$
Simulation setup for RTN

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

- Traps positions
  - Si/SiO₂ interface
  - Si channel
  - SiO₂
- 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 implementation)

Device fabricated in large numbers

Differences in the number and exact placement of dopant atoms

Induced fluctuations (noise-like) at the device terminal

Figure 4: Synopsis NMOS structure with (left) continuum doping and (right) randomized doping profile
Green’s functions statistical RTN+RDF analysis

Ongoing work

Green’s function statistical RTN

Synopsis demonstrated statistical RDF

Linearity Uncorrelated

\[ G_\Phi \]
Variability analysis: RTN

- Extraction of the slope $\lambda$ [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

Monte Carlo:
1000 simulations
Green:
1 simulation
+1000 convolutions
Variability analysis: RTN + RDF

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

Figure 6: Statistical distribution of the RTN on the threshold voltage

MonteCarlo:
3000 simulations
Green:
3 simulations
+3000 convolution
Further work

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

Riccardo Tisseur