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

Original

Availability:
This version is available at: 11583/2497863 since:

Publisher:
Associazione gruppo italiano di elettronica

Published
DOI:

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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
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
Moore’s law

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

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

Capture/Emission of single electrons by oxide/interface traps

\[ \text{SiO}_2 \]

\[ \text{Si} \]

\[ \Delta V \]

\[ \empty \text{ full} \]
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

\[
\Delta I_{D,inc}(x) = I_{D,full}(x) - I_{D,empty}(x)
\]
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 → linear response through Poisson equation Green’s function

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

Full trap effect:

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

Convolution integral for single trap reduces to 1 product
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

Threshold voltage variability found from drain current $1 \times 10^{-7}$ A/mm exploiting Y21 SS parameter at zero freq.

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.

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–SiO₂ interface
  - Uniform distribution
  - Evaluate Green’s function at the interface
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

Doping Concentration [cm⁻²]

-8.9e+21
-1.0e+18
1.1e+14
-2.0e+13
-1.7e+17
-1.5e+21
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)

MonteCarlo:
1000 simulations
Green:
1 simulation
+1000 convolutions

Figure 5 Statistical distribution of the RTN on the threshold voltage
Variability analysis: RTN + RDF

- Dependence of $\lambda$ [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