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

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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

- **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

$\text{SiO}_2$

$\text{Si}$
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

\[
\Delta I_{D,\text{inc}}(x) = I_{D,\text{full}}(x) - I_{D,\text{empty}}(x)
\]
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
  
  \[ \Delta I_{D,ifm}(x) = q_{trap} \times G_\phi(x) \]

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

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.

$V_{GS} = 0.86 \text{ V}, V_{DS} = 0.1 \text{ V}$

$V_{GS} = 5 \text{ V}, V_{DS} = 0.1 \text{ V}$

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.

$V_{GS} = 0.86 \text{ V}, V_{DS} = 0.1 \text{ V}$

$V_{GS} = 0.86 \text{ V}, V_{DS} = 2.5 \text{ V}$

$V_{GS} = 6 \text{ V}, V_{DS} = 0.1 \text{ V}$

Threshold voltage variability found from drain current $1e^{-7}$ A/mm exploiting Y21 SS parameter at zero freq.
Randomize traps position at Si–SiO₂ interface
  ◦ Uniform distribution
  ◦ Evaluate Green’s function at the interface

Variability RTN
Variability: RDF (Synopsys implem)

Device fabbricated 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
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 for the attention

Riccardo Tisseur