Multiple-Step Electron Charging in Si Quantum-Dot Floating Gate nMOSFETs

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Our Previous Works

Kohno et al. SSDM (1997)

Ikeda et al. JJAP (2003)

Fabrication of Si-QDs Floating Gate nMOSFETs

Si Quantum Dot
- Coulomb Blockade
- Quantum Confinement

Multivalued Memory
**ID-VG Characteristics for n-MOSFET with Si-QDs Floating Gate**

- Discharging: $V_G = -4V$, $V_D = 50mV$
- $L/W = 0.8\mu m/10\mu m$, $V_D = 50mV$

**GATE VOLTAGE (V)**

<table>
<thead>
<tr>
<th>$1/s\text{-SWEEP RATE (s/mV)}$</th>
<th>Charging Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^-14</td>
<td>1.0V</td>
</tr>
<tr>
<td>10^-12</td>
<td>0.8V</td>
</tr>
<tr>
<td>10^-10</td>
<td>0.6V</td>
</tr>
<tr>
<td>10^-8</td>
<td>0.4V</td>
</tr>
<tr>
<td>10^-6</td>
<td>0.2V</td>
</tr>
<tr>
<td>10^-4</td>
<td>0.0V</td>
</tr>
</tbody>
</table>

**Transient Drain Current by Electron Charging to Si-QDs Floating Gate**

- Multiple-step e-Injection
- Incubation or suppression period for further e-Injection

**Transient Drain Current by Electron Charging to Si-QDs Floating Gate**

- Redistribution of Electrons
- Metastable State

**Sweep Rate Dependence of ID-VG Characteristics**

Charging voltages increase with sweep rate
Exponential relationship between charging voltage and charging time

**Transient Drain Current by Electron Charging to Si-QDs Floating Gate**

- 1st Injection
- 2nd Injection
- 3rd Injection

**Transient Drain Current by Electron Charging to Si-QDs Floating Gate**

- 1st State (metastable)
- 2nd State (metastable)
- 3rd State

**Transient Drain Current by Electron Charging to Si-QDs Floating Gate**

- Redistribution of Electrons
- Metastable State
Transient Drain Current by Electron Charging to Si-QDs Floating Gate

Redistribution of electrons in QDs floating gate is proceeding during metastable state weakly confined condition.

Electron injection is slow down and metastable states are prolonged with decreasing temperature.

Temperature Dependence of $I_D-V_G$ & $I_D-t$ Characteristics

Model for Electron Charging in Si-QDs Floating Gate

Arrehnius Plots of Injection & Metastable Time

Quantization & Charging Energy
Summary

- The multiple-step electron charging to a Si-QDs floating gate in the MOSFETs has been studied in the temperature range of 200-350K.
- The metastable states in electron charging at the constant gate bias are attributable to the redistribution of electrons in the Si-QDs floating gate.
- The Coulomb interaction among the neighboring charged dots may play an important role in regulation of the electron injections to the Si-QDs floating gate, which leads the generation of intermediate charged states.
- In intermediate charged states the redistribution of electrons in the floating gate proceeds without increasing charges by electron tunneling between the different energy states in the neighboring dot.