Mitigation of Intrinsic Vt Variation using Oxygen Inserted (OI) Silicon Channel

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Outline

• Variation Mitigation Techniques
  – 3D Techniques
    • Alternate doping scheme
    • Effective width increase
  – Planar Techniques
    • Super steep retrograde doping profile
• $V_T$ Variation Improvement with Oxygen Inserted (OI) Channel
• Mobility Enhancement with Oxygen Inserted (OI) Channel
• Future Outlook
Vt fluctuation is considered a fundamental technology scaling roadmap.

Punch-through Stopper (PTS) Implant

- Punch-through Stop (PTS) implants are required to suppress sub-fin leakage in sub-22nm FinFETs.
- Lower channel doping to improve carrier transport.

Effective Gate Width

3D Factor = \frac{\text{Total width of FinFET}}{\text{Planar width used}} = \frac{2 \times H_{\text{FIN}} + T_{\text{FIN}}}{\text{Fin Pitch}}

Part of Tri-gate appeal is improved electrostatics
Other part is \textit{folded width}
Reversal of Intrinsic Variation Trend

Variation $\propto \frac{A_{VT}}{\sqrt{W \cdot L}}$

S. Natarajan (Intel), IEDM 2014

Tri-gate was primarily intended for electrostatics.
It uses 3D factor to scale effective width to mitigate variation
and reduce standard cell footprint.

Greg Yeric (ARM), IEDM 2015

95% of design engineer’s time

Slowest (SS) 3σ
Typical (TT)
Fastest (FF) 3σ
Oxygen Incorporated (OI) Channel by Atomera for Improved Intrinsic Vt Variation
OI Silicon Channel for TED Blocking

• Transient enhanced diffusion (TED) causes Boron/Phosphorus to diffuse upward toward surface during annealing
• OI layer blocks TED and allows targeting of lower surface concentration to improve RDF-induced $V_T$ variation.

PTS Optimization with OI silicon

- Punch through stopper (PST) dopant profile optimization using OI silicon:
  - S/D profile (SD1: baseline)
  - PST profile (PST2: OI Si)
FinFET $A_{vt}$ : RDF only

- Considering only RDF fluctuation, OI Si FinFET shows 30% improvement in $\sigma_{V,\text{Th-RDF}}$ and $A_{vt}$ (RDF) over baseline FinFET.

![Graph showing improvement in $\sigma_{V,\text{Th-RDF}}$ and $A_{vt}$ over baseline FinFET.](image)

- $A_{vt1} = 0.69 \text{ mV-µm}$
- $A_{vt2} = 0.50 \text{ mV-µm}$
- $A_{vt3} = 0.48 \text{ mV-µm}$
Oxygen Insertion creates pseudo-energy barrier in Si MOSFET channel that:

1. Splits Δ-2 valley sub-band levels, further lowering transport effective mass.
2. Results in electron mobility improvement over a control Silicon MOSFET

Mobility Improvement with OI Channel with Poly Si-SiON

- 25% electron mobility improvement ($n_s = 8 \times 10^{12} \text{ cm}^{-2}$) is observed with OI channel and SiON/Poly gate stack.
- Is this OI-induced mobility enhancement retained with HfO$_2$/TiN gate stack?

High-k / metal gate FETs with OI Si channel

<table>
<thead>
<tr>
<th>Substrate</th>
<th>$SS_{LIN}$ (mV/dec)</th>
<th>$V_{T,LIN}$ (mV)</th>
<th>$I_{D,LIN}$ ($\mu$A/µm) $V_G-V_T=1V$</th>
<th>$I_{D,SAT}$ ($\mu$A/µm) $V_G-V_T=1V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>OI Channel</td>
<td>186</td>
<td>854</td>
<td>1.94</td>
<td>5.05</td>
</tr>
<tr>
<td>Control</td>
<td>112</td>
<td>962</td>
<td>1.69</td>
<td>4.38</td>
</tr>
</tbody>
</table>

- OI channel FET shows 15% higher $I_{D,LIN}$ and $I_{D,SAT}$ over Control FET at matched overdrive.
Output Characteristics

- At fixed $V_G - V_T$, OI channel shows 15% higher $I_{D,SAT}$ than Control Si.
At matched $N_{\text{INV}} = 5 \times 10^{12} \text{ cm}^{-2}$, OI channel device shows 15% higher transconductance and electron mobility over Control Si.
• OI Channel shows 5.6% lower $N_{INV}$ at fixed $V_G - V_T$. 
Future Outlook

- Oxygen Inserted (OI) Silicon channel provides a CMOS-compatible method to simultaneously reduce $V_T$ variation and improve transistor drive currents.

- 30% improvement in $V_t$ variation potentially with OI channel in FinFET configuration

- In both SiON/Poly-Si and HfO$_2$/TiN gate stack, Oxygen Inserted (OI) Silicon channel provides 15% low field electron mobility enhancement.

- Future work to focus on BTI benefit of OI channel in high-k/metal gate planar FETs
Thank You

• NASA is ahead of the curve bringing edge intelligence to the

NDnano
BACK-UP
Mean electron mobility is 14% higher in OI Channel FETs than Control Si FETs.

Indicative that mobility gain is expected with OI layer with scaled HK/MG stack.