Silicon Nano-transistors and Silicon Nanotechnology for High-Performance Logic Applications

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Content

• Transistor scaling and Moore’s law
• Silicon nano-transistors and new device architecture
• Examples of Silicon nano-technology
• Theoretical scaling limit for Si device
• Summary
Moore’s Law Continues…

- Transistor # doubling every 2 years toward the 1 billion transistor microprocessor

Heading toward 1 billion transistors in 2007

>220M transistors integrated into devices produced today
Transistor physical gate length will reach ~15nm before end of this decade, and ~10nm early next decade.
Silicon Nanotechnology has already been in production.
Production Transistors Smaller Than Virus

Si transistor in the 90nm logic technology node: currently in production

Influenza virus
Source: CDC
Experimental 15nm Si Transistor

- Well-controlled short channel characteristics

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Experimental 10nm Si MOS Transistor

- 10nm transistor still behaves like a transistor!

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Nano-device Architecture

Total Drive Current = $I_d$ per nanotube/nanowire x no. of tubes/wires
Nanotechnology Example: Crafting Thin Films with Atomic Layer Deposition (ALD)

ALD: Today’s nanotechnology for self-assembly by atomic layer
A Simple Theoretical Model to Predict Si Device Scaling Limit

- **Shannon-von Neumann-Landauer**
  - Min \( E_b = KT \ln 2 = 0.017 \text{eV} \) (300K)

- **Heisenberg Uncertainty Principles**
  \[ \Delta x \Delta p \geq \hbar \]
  \[ \Delta E \Delta t \geq \hbar \]
  \[ x_{\min} = \frac{\hbar}{\Delta p} = \frac{\hbar}{\sqrt{2m_e E_b}} = \frac{\hbar}{\sqrt{2m_e kT \ln 2}} = 1.5 \text{nm} \]
  \[ t_{\min} = \frac{\hbar}{\Delta E} = \frac{\hbar}{kT \ln 2} = 0.04 \text{ps} \]

- **Minimum theoretical size and switching time is 1.5nm and 0.04ps**

Binary switch in its Simplest form
• Theoretical limit falls on experimental trend
• Scaled silicon devices are operating like ideal switch (silicon devices close to ideal)

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• Theoretical limit falls on experimental trend
• Silicon device is close to ideal switch
Key Bullets

• Silicon nano-transistors & Silicon nanotechnology will enable Moore’s Law to continue through 2015

• Electrical properties of Silicon nano-transistors approaching those of an ideal switch

• Need to identify the most promising options for >2015
  – Many on-going research programs existing
  – Must utilize Silicon technology’s foundation
  – Semiconductor industry, academia and government need to form close collaboration

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