Past and Future of Micro/Nano-Electronics

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IEEE ESD MQ
@GOVERNMENT ENGINEERING COLLEGE Andaman & Nicobar Islands, PB, Port Blair

Hiroshi Iwai,
Tokyo Institute of Technology
Founded in 1881, Promoted to Univ. 1929
Institute Overview

Established in 1881 → 130th anniversary in 2011
3 undergraduate schools
- School of Science, School of Engineering, School of Bioscience and Biotechnology

7 graduate schools
- Science and Engineering Science, Science and Engineering Technology,
  Bioscience and Biotechnology, Interdisciplinary Graduate School of Science and Engineering,
  Information Science and Engineering, Decision Science and Technology, Innovation Management

Total Number of Students

<table>
<thead>
<tr>
<th></th>
<th>Undergraduate</th>
<th>Graduate</th>
<th>Master's</th>
<th>Doctoral</th>
<th>Teaching Staff</th>
<th>Student/Instructor</th>
<th>Staff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo Inst.</td>
<td>5,000</td>
<td>5,000</td>
<td>3,500</td>
<td>1,500</td>
<td>1,200</td>
<td>8.3</td>
<td>550</td>
</tr>
<tr>
<td>Per Year</td>
<td>1,200</td>
<td>1,800</td>
<td>500</td>
<td></td>
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</table>
• There were many inventions in the 20\textsuperscript{th} century: Airplane, Nuclear Power generation, Computer, Space aircraft, etc
• However, everything has to be controlled by electronics
• Electronics
  Most important invention in the 20\textsuperscript{th} century
• What is Electronics: To use electrons, Electronic Circuits
Electronic Circuits started by the invention of vacuum tube (Triode) in 1906

Thermal electrons from cathode controlled by grid bias

Cathode (heated) Grid Anode (Positive bias)

Same mechanism as that of transistor
First Computer Eniac: made of huge number of vacuum tubes 1946
Big size, huge power, short life time filament

→ dreamed of replacing vacuum tube with solid-state device

Today's pocket PC made of semiconductor has much higher performance with extremely low power consumption
Surface Potential (Negative direction)

0V  N⁺-Si  P-Si

1V  N-Si

Source  Channel  Drain

0 bias for gate

Positive bias for gate

Electron flow
Very bad interface property between the semiconductor and gate insulator.

Drain Current was several orders of magnitude smaller than expected.

Even Shockley!
1960: First MOSFET by D. Kahng and M. Atalla

Top View

Si

Source

Al Gate

Drain

Si

SiO$_2$

Al

Si

Si/SiO$_2$ Interface is extraordinarily good
**HP, LOP, LSTP for Logic CMOS**

- **HP CMOS (high Performance)**
  - Highest Ion, Lowest CV/I
  - High leakage
  - Medium Vdd

- **LOP CMOS (Low Operation Power)**
  - Lowest Vdd
  - Medium Ion, medium CV/I
  - Medium leakage

- **LSTP CMOS (Low Standby Power)**
  - Lowest leakage
  - Low Ion, high CV/I
  - High Vdd

Source: 2007 ITRS Winter Public Conf.
MOS LSI experienced continuous progress for many years

<table>
<thead>
<tr>
<th>Name of Integrated Circuits</th>
<th>Number of Transistors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960s IC (Integrated Circuits)</td>
<td>~ 10</td>
</tr>
<tr>
<td>1970s LSI (Large Scale Integrated Circuit)</td>
<td>~1,000</td>
</tr>
<tr>
<td>1980s VLSI (Very Large Scale IC)</td>
<td>~10,000</td>
</tr>
<tr>
<td>1990s ULSI (Ultra Large Scale IC)</td>
<td>~1,000,000</td>
</tr>
<tr>
<td>2000s ?LSI (? Large Scale IC)</td>
<td>~1,000,000,000</td>
</tr>
</tbody>
</table>
In 100 years, the size reduced by one million times. There have been many devices from stone age. We have never experienced such a tremendous reduction of devices in human history.
Downsizing

1. **Reduce Capacitance**
   - Reduce switching time of MOSFETs
   - Increase clock frequency
     - Increase circuit operation speed

2. **Increase number of Transistors**
   - Parallel processing
     - Increase circuit operation speed

Downsizing contribute to the performance increase in double ways

Thus, downsizing of Si devices is the most important and critical issue.
Downsizing limit?  
Channel length?

Electron wave length

10 nm
5 nm gate length CMOS
Is a Real Nano Device!!

Length of 18 Si atoms

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H. Wakabayashi et.al, NEC

IEDM, 2003
Electron wave length
10 nm

Tunneling distance
3 nm

Channel length
Gate oxide thickness

Downsizing limit!
Prediction now!

Electron wave length 10 nm

Tunneling distance 3 nm

Atom distance 0.3 nm

MOSFET operation

Lg = 2 ~ 1.5 nm?

Below this, no one knows future!
Si nanowire FET as a strong candidate after CMOS limitation

1. Compatibility with current CMOS process
2. Good controllability of $I_{\text{OFF}}$
3. High drive current

1D ballistic conduction

Multi quantum Channel

High integration of wires

by the courtesy of Professor H. Iwai