Past and Future of Mirco/Nano-Electronics

Nov 9, 2009

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

Einstein Visit

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

	Undergraduate	Graduate	Master's	Doctoral	Teaching Staff	Student/Instructor	Staff
Tokyo Inst.	5,000	5,000	3,500	1,500	1,200	8.3	550
Per Year	1,200		1,800	500			

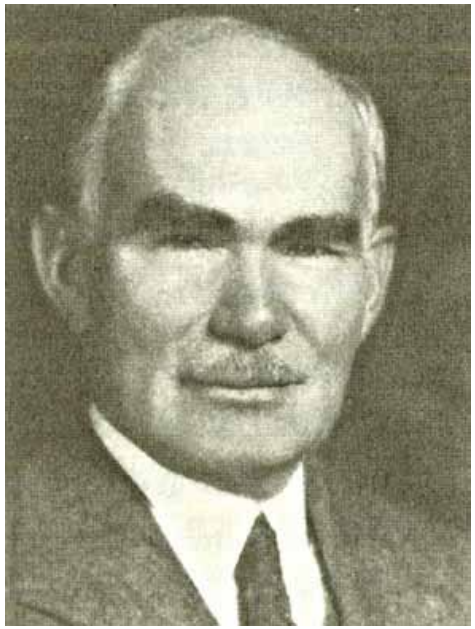
- There were many inventions in the 20th century:

  Airplane, Nuclear Power generation, Computer,

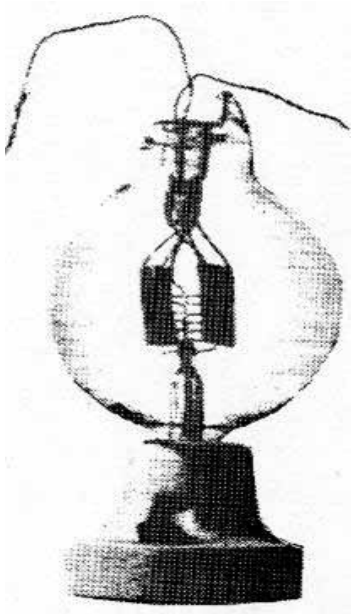
  Space aircraft, etc
- However, everything has to be controlled by electronics
- Electronics

  Most important invention in the 20th century
- What is Electronics: To use electrons,

  Electronic Circuits

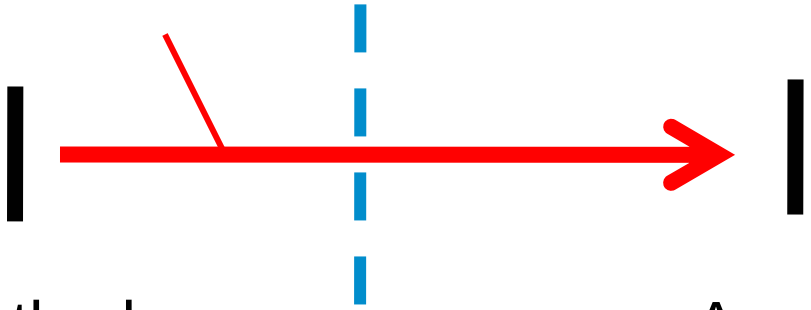


Lee De Forest



Electronic Circuits started by the invention of vacuum tube (Triode) in 1906

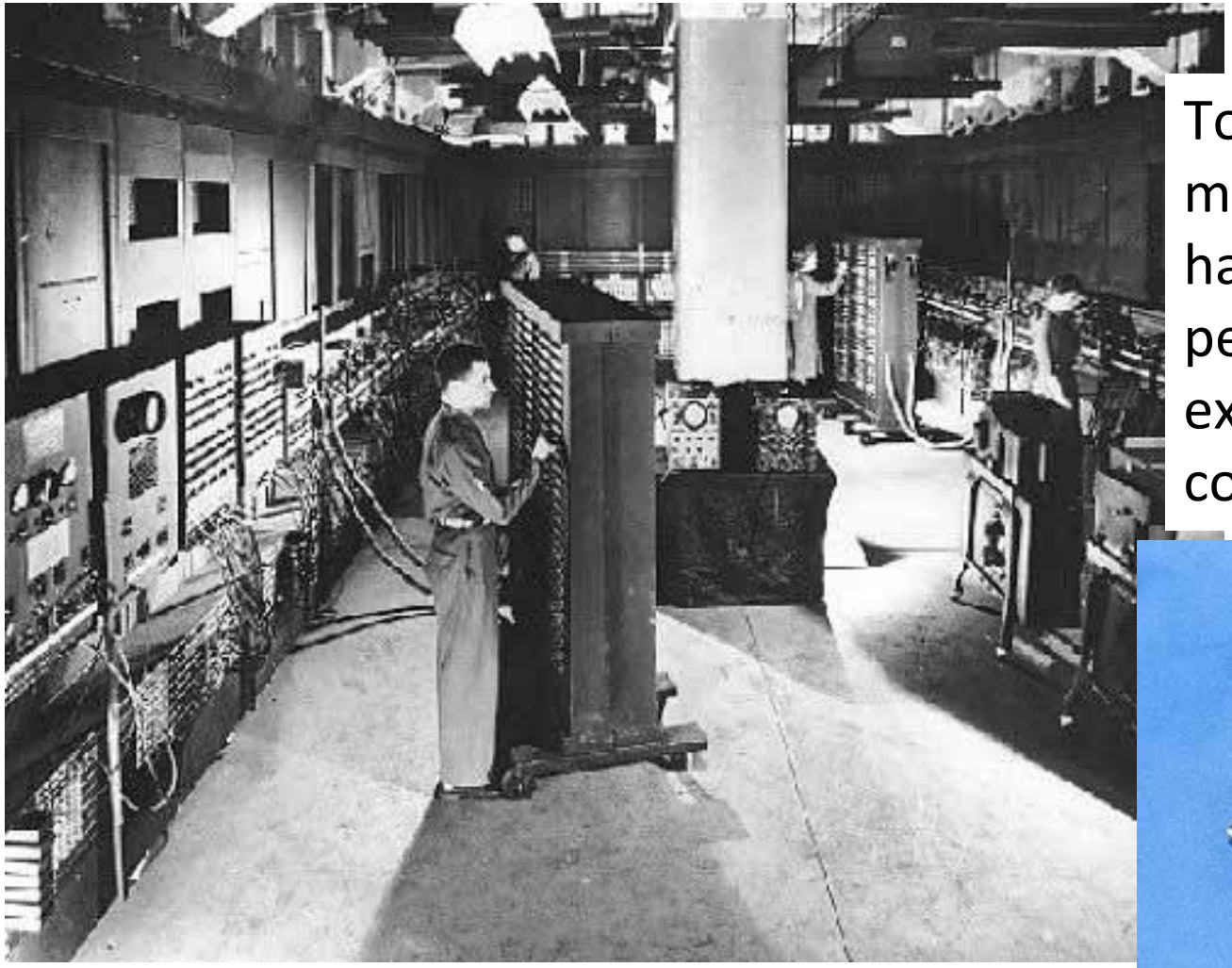
Thermal electrons from cathode controlled by grid bias



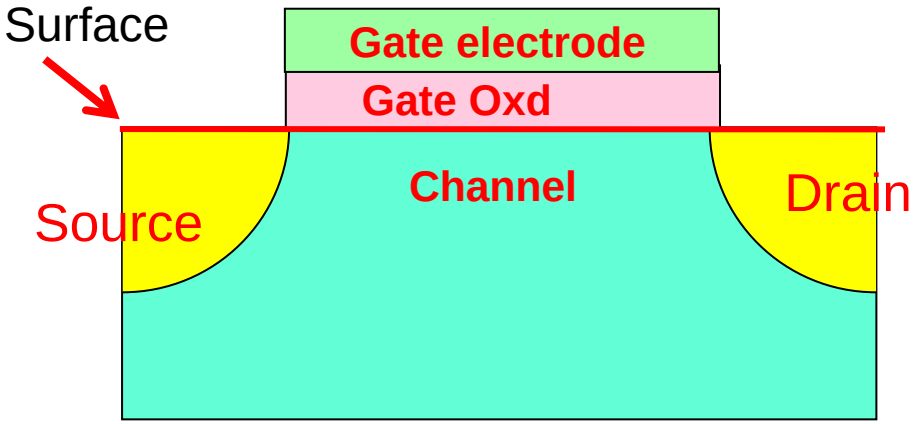
Same mechanism as that of transistor

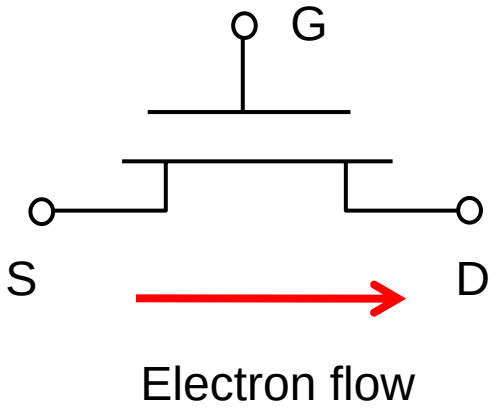
First Computer Eniac: made of huge number of vacuum tubes 1946
Big size, huge power, short life time filament

→ dreamed of replacing vacuum tube with solid-state device



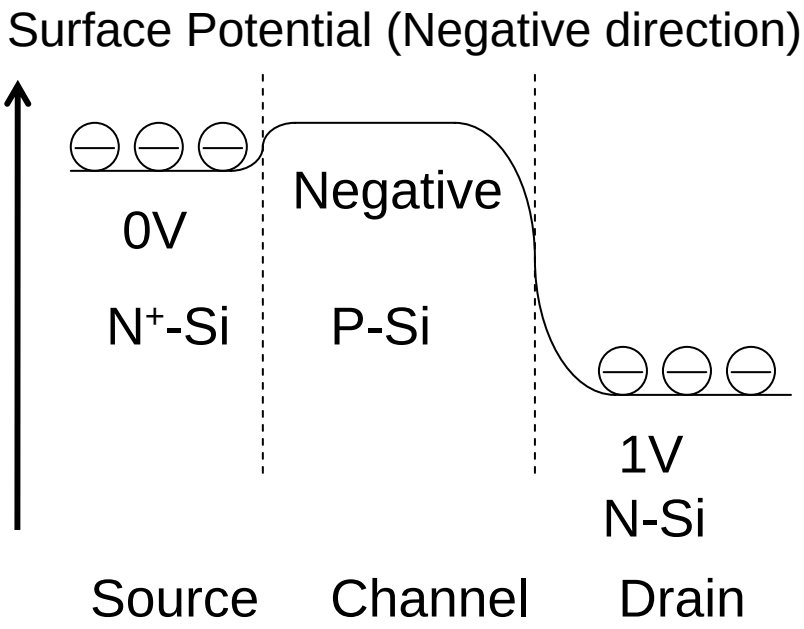
Today's pocket PC made of semiconductor has much higher performance with extremely low power consumption

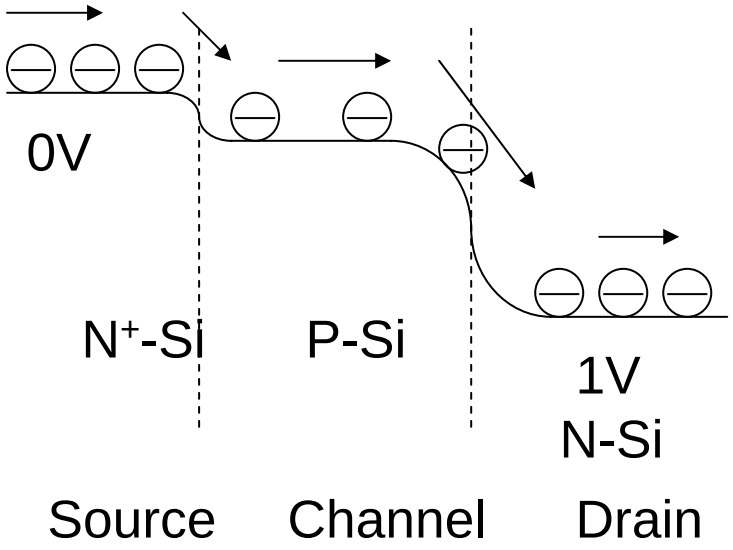




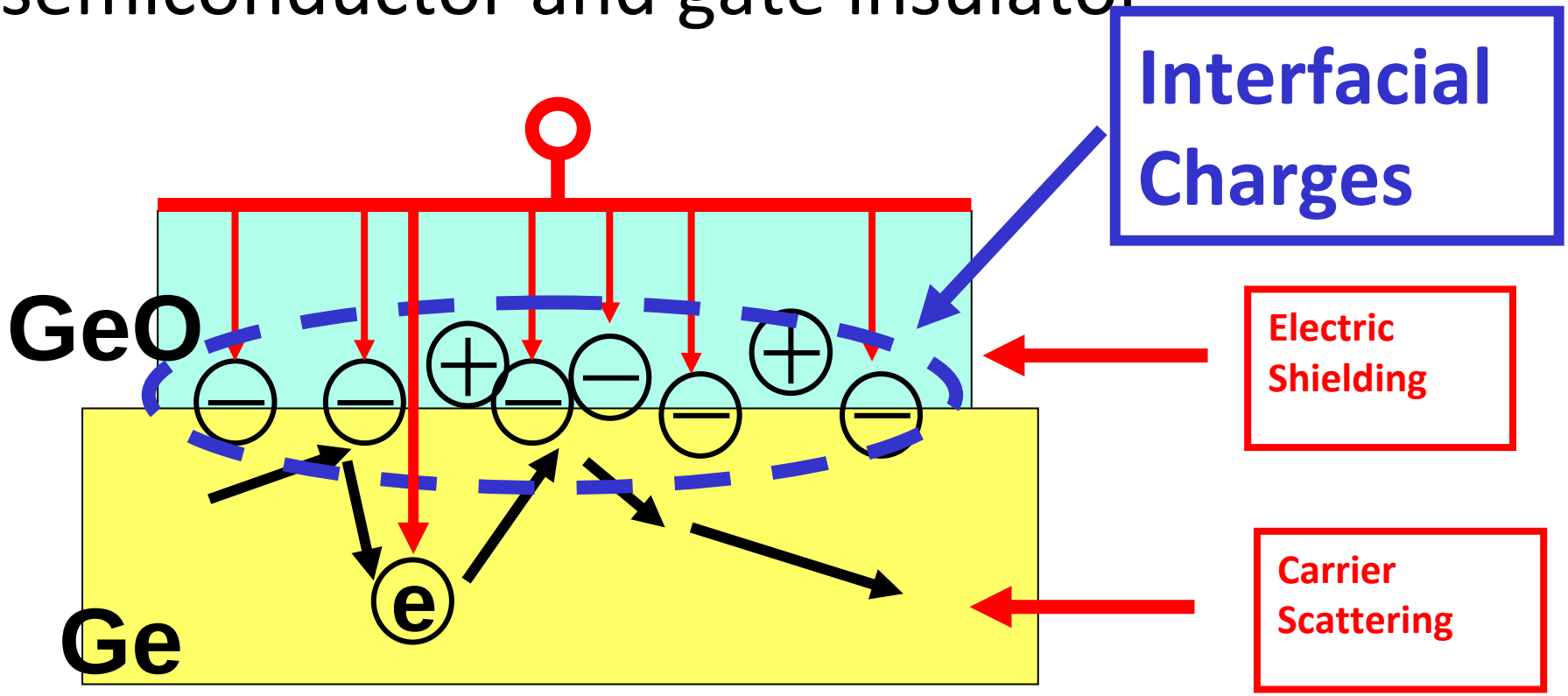
0 bias for gate

Positive bias for gate





Very bad interface property between the semiconductor and gate insulator

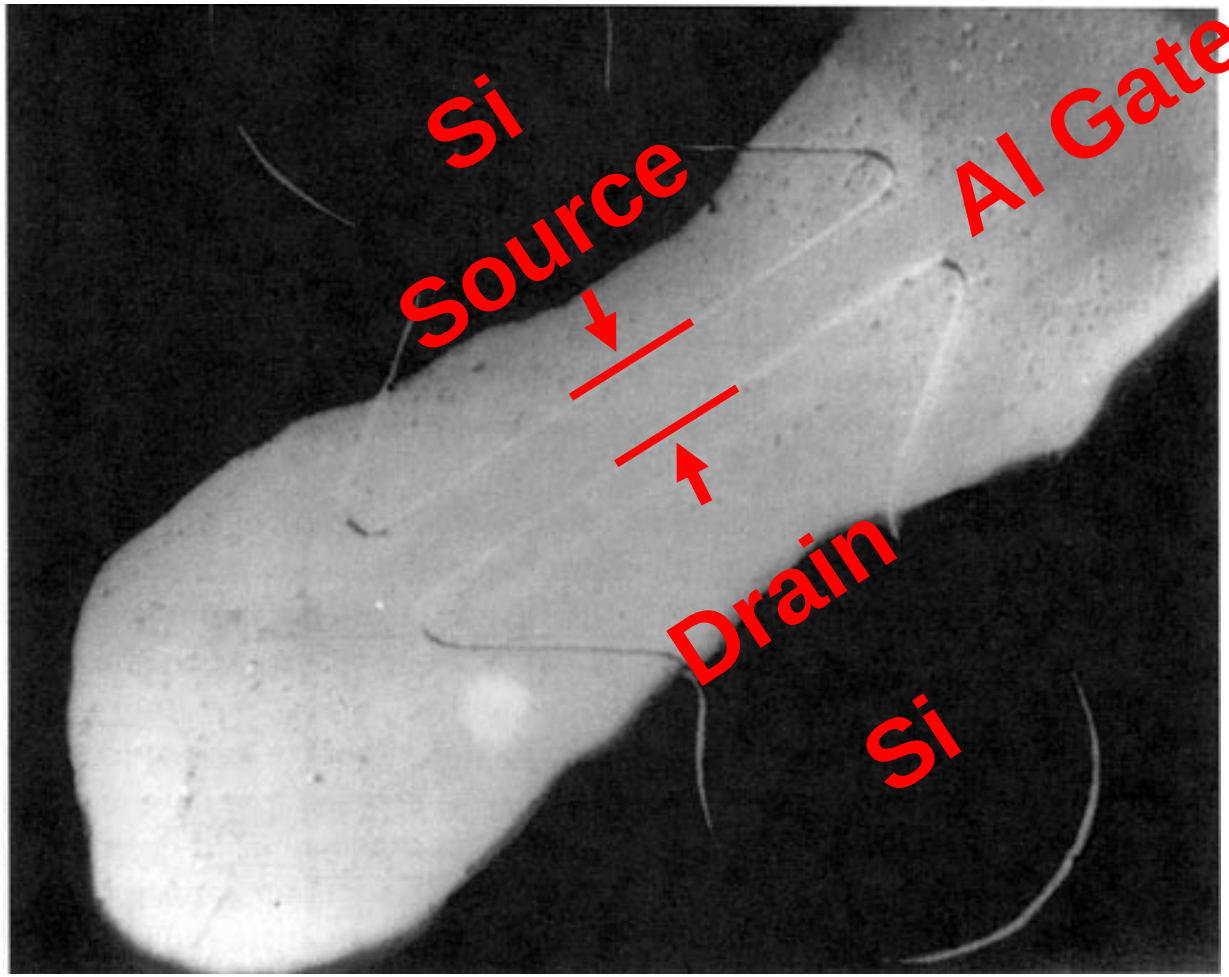


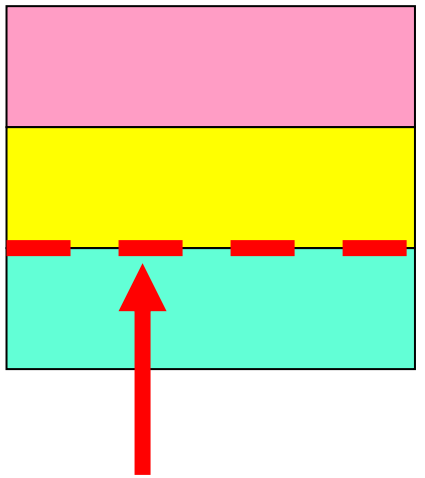
Drain Current was several orders of magnitude smaller than expected

Even Shockley!

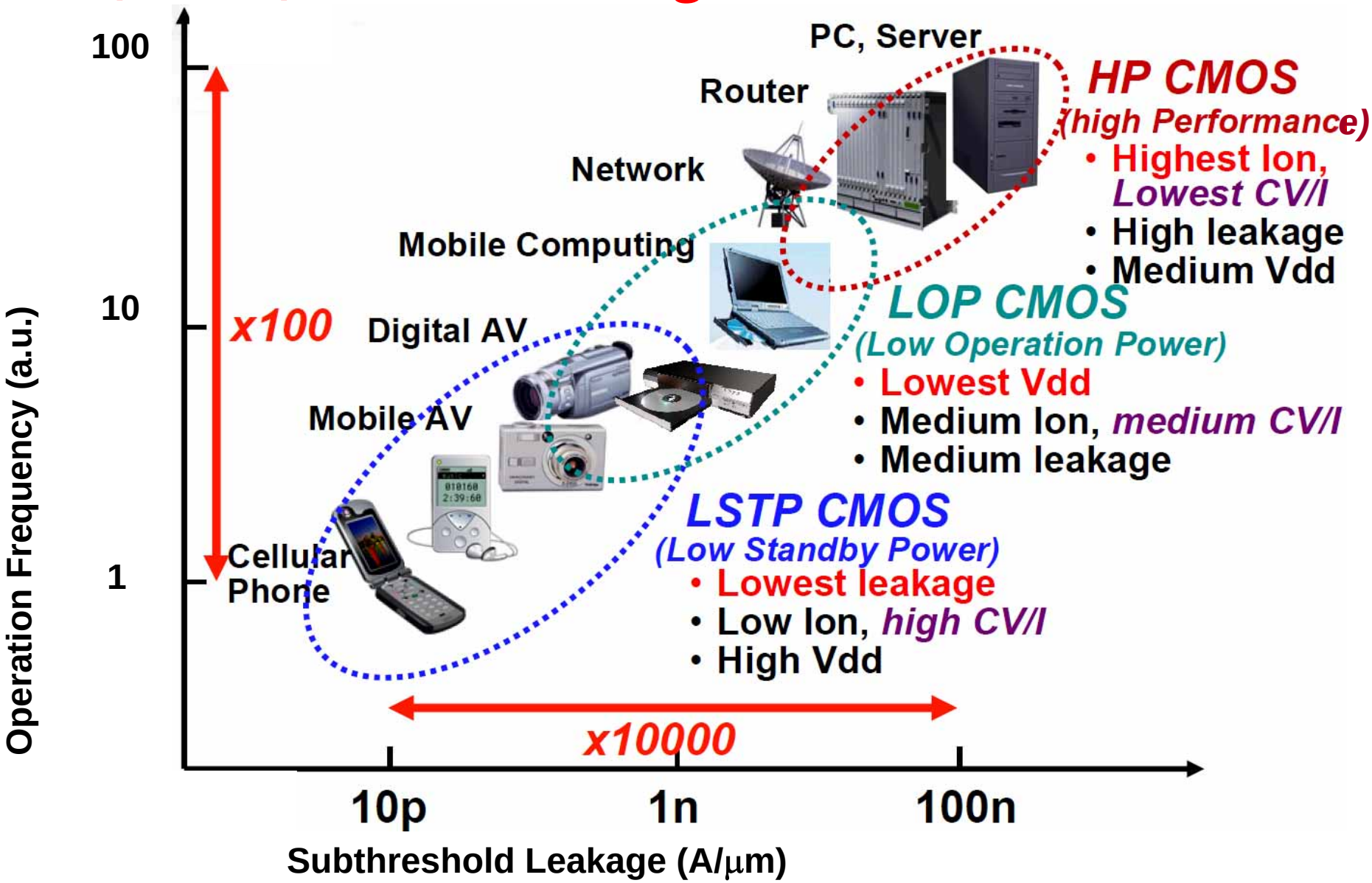
1960: First MOSFET
by D. Kahng and M. Atalla

Top View





HP, LOP, LSTP for Logic CMOS



Source: 2007 ITRS Winter Public Conf.

MOS LSI experienced continuous progress for many years

	Name of Integrated Circuits	Number of Transistors
1960s	IC (Integrated Circuits)	~ 10
1970s	LSI (Large Scale Integrated Circuit)	~1,000
1980s	VLSI (Very Large Scale IC)	~10,000
1990s	ULSI (Ultra Large Scale IC)	~1,000,000
2000s	?LSI (? Large Scale IC)	~1000,000,000

Downsizing of the components has been the driving force for circuit evolution

1900	1950	1960	1970	2000
Vacuum Tube	Transistor	IC	LSI	ULSI
10 cm	cm	mm	10 μm	100 nm
10^{-1}m	10^{-2}m	10^{-3}m	10^{-5}m	10^{-7}m

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**

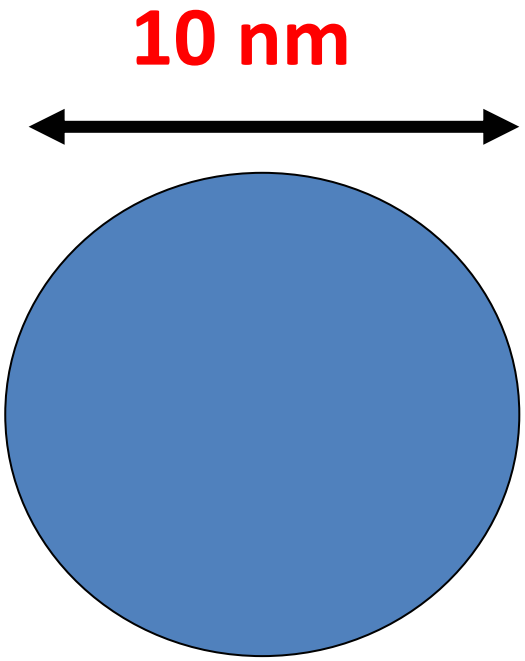
Downsizing contribute to the performance increase in double ways

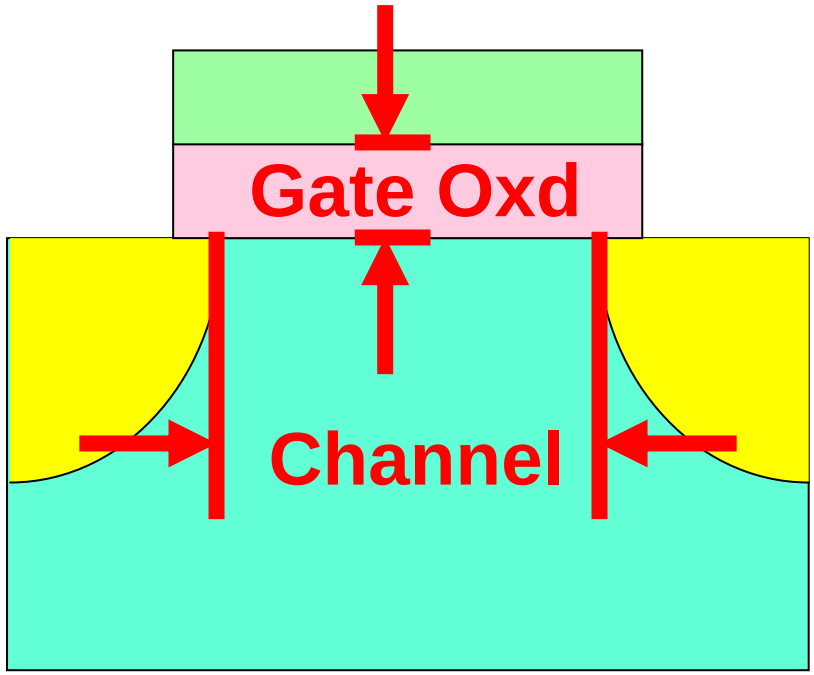
Thus, downsizing of Si devices is the most important and critical issue.

Downsizing limit?

Channel length?

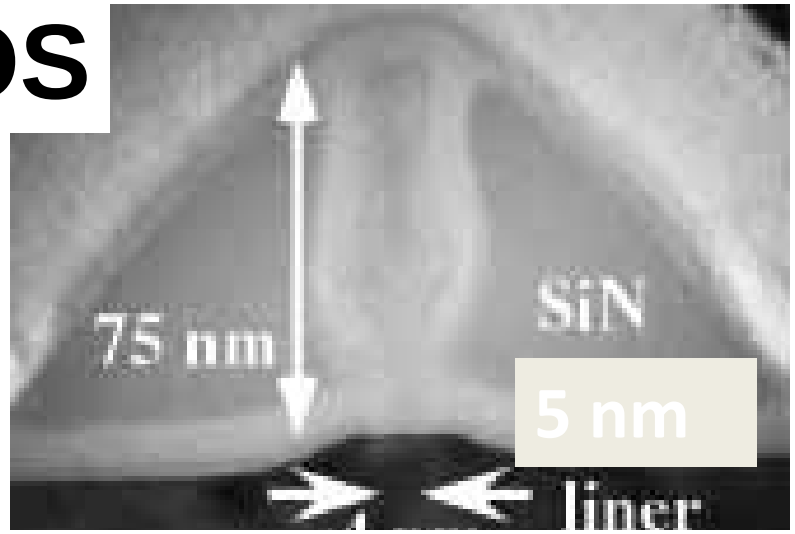
Electron wave length



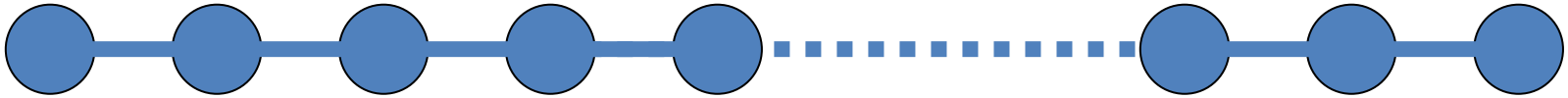


5 nm gate length CMOS

Is a Real Nano Device!!

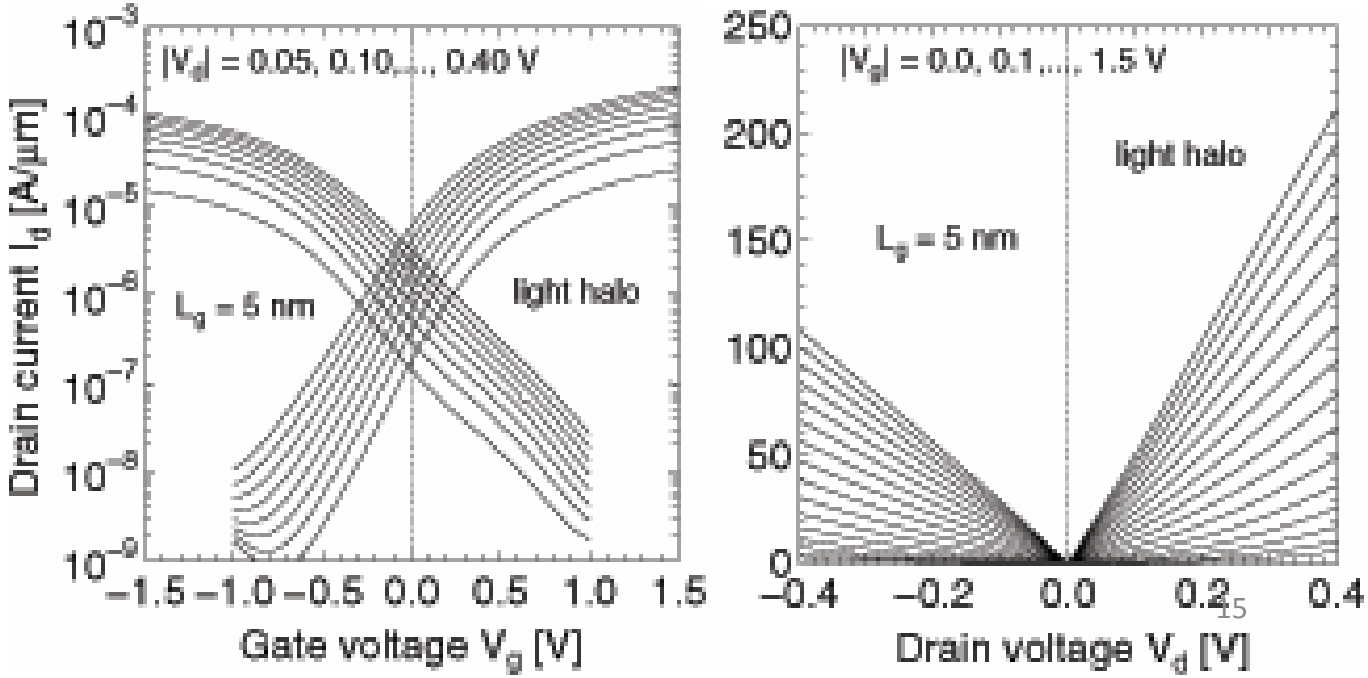


Length of 18 Si atoms



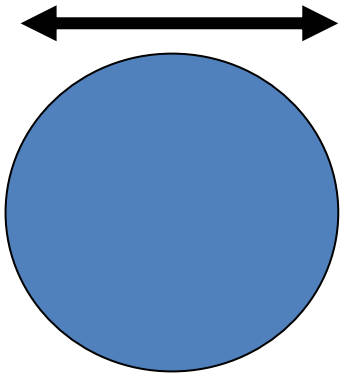
H. Wakabayashi
et.al, NEC

IEDM, 2003



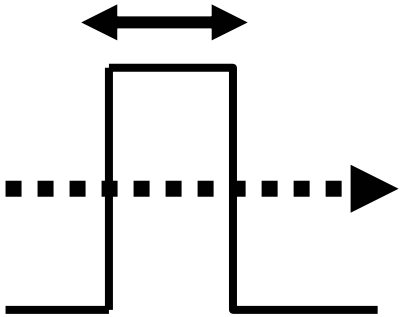
Electron wave length

10 nm



Tunneling distance

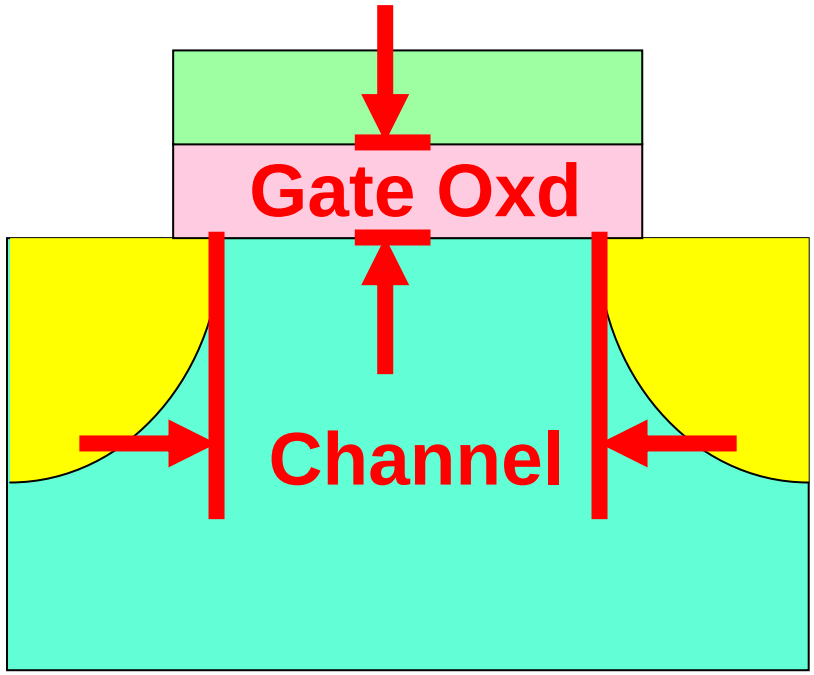
3 nm



Downsizing limit!

Channel length

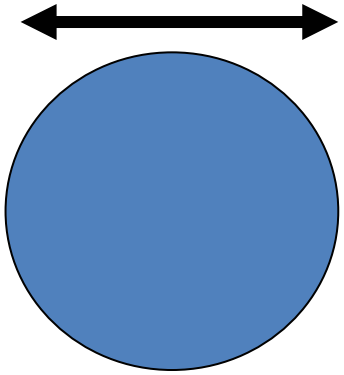
Gate oxide thickness



Prediction now!

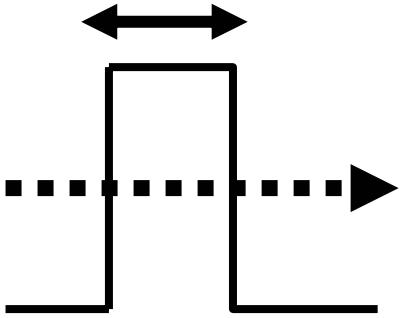
Electron wave length

10 nm



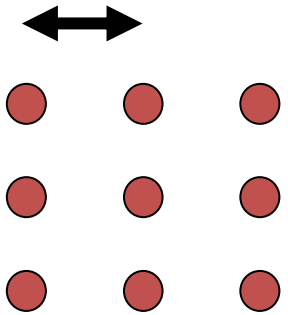
Tunneling distance

3 nm



Atom distance

0.3 nm



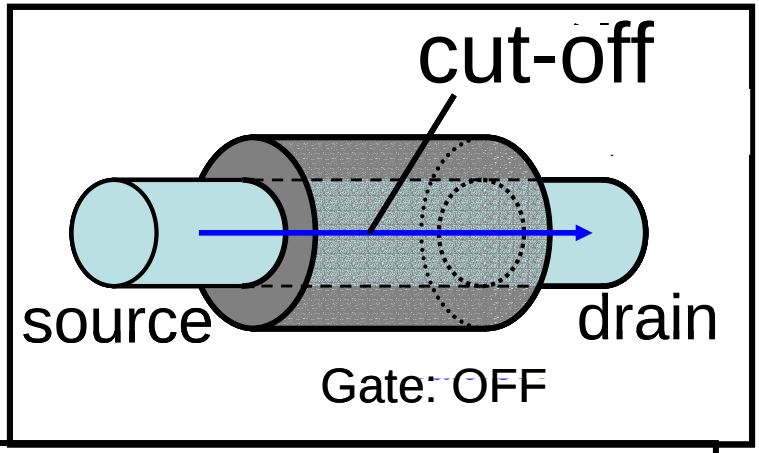
MOSFET operation

Lg = 2 ~ 1.5 nm?

Below this,
no one knows future!

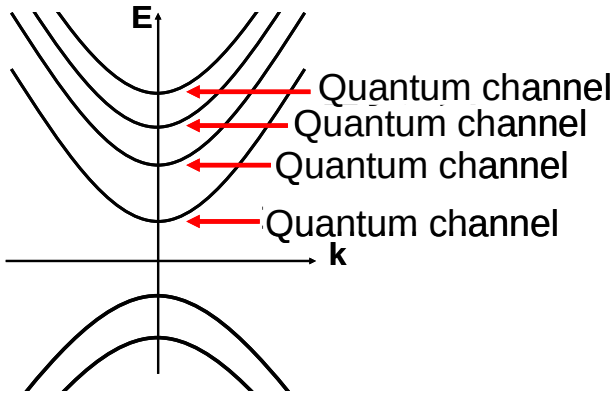
Si nanowire FET as a strong candidate after CMOS limitation

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

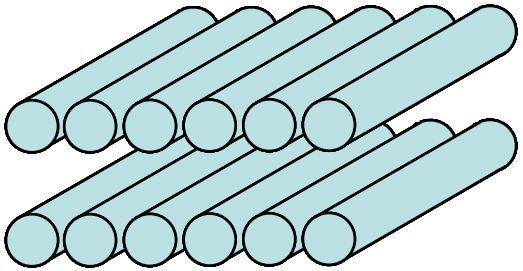


1D ballistic conduction

Multi quantum Channel



High integration of wires



by the courtesy of Professor H. Iwai