Short Presentation and Discussion for Future of Mirco/Nano-Electronics

January 8, 2011

@SKP Engineering College,
India

Hiroshi Iwai,
Tokyo Institute of Technology

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

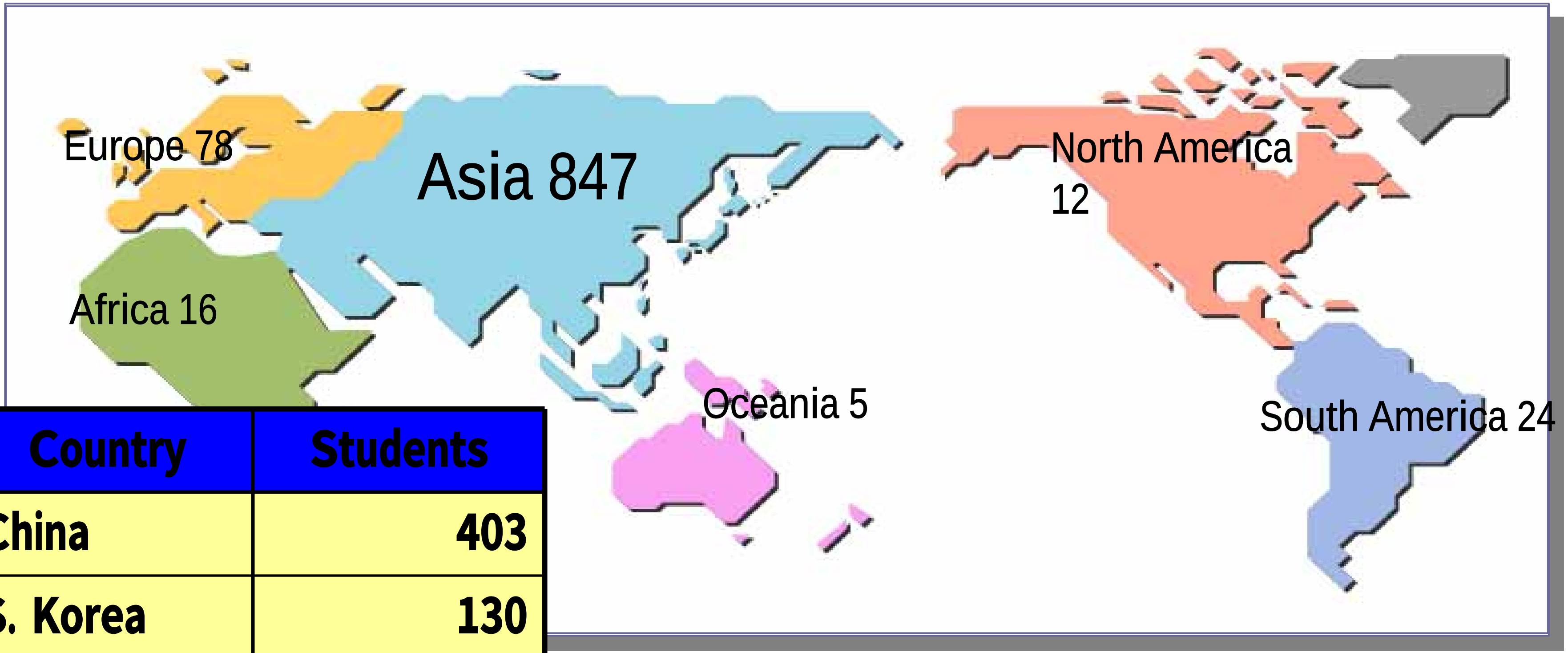
7 graduate schools

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**			

International Students



Country	Students
China	403
S. Korea	130
Indonesia	64
Thailand	55
Vietnam	60
Malaysia	28

Total 982

(As of May. 1, 2005)

東京工業大学大学院
総合理工学研究科

複合創造領域
Innovative Platform for Education and Research

先端ナノエレクトロニクス研究コアユニット研究室メンバー

Nanoelectronics Research Frontier Core Unit

（2010年10月1日現在）

物理電子システム創造専攻
教授　岩井　洋
Electronics and Applied Physics
Professor
Hiroshi Iwai

物理電子システム創造専攻
教授　筒井　一生
Electronics and Applied Physics
Professor
Kazuo Tsutsui

物理電子システム創造専攻
准教授　大見　俊一郎
Electronics and Applied Physics
Associate Professor
Shunichiro Ohmi

フロンティア研究機構
特任准教授
アヘメト　パールハット
Frontier Research Center
Associate Professor
Parhat Ahmet

教員
（10人）

Simon Min Sze
（客員教授）

服部健雄
（客員教授）

名取研二
（特任教授）

杉井信之
（連携教授）

西山彰
（連携教授）

角嶋邦之
（助教）

技術員
（1人）

[illegible]

博士研究員
（1人）

Milan Kumar Bera

博士学生
（19人）

佐々木雄一朗
（D3）

[illegible]
（D3）

川那子高暢
（D3）

佐藤創志
（D3）

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（D3）

Maimaitirexiati Maimaiti
（D3）

Abudukelimu Abudureheman
（D3）

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幸田みゆき
（D2）

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（D1）

ダリウス・ハサンザデ
（D1）

Mokhammad Sholihul Hadi
（D1）

[illegible]
（D1）

修士学生
（26人）

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（M2）

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Dou Chunmeng
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中島一裕
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Li Wei
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（M1）

学部生
（3人）

[illegible]
（B4）

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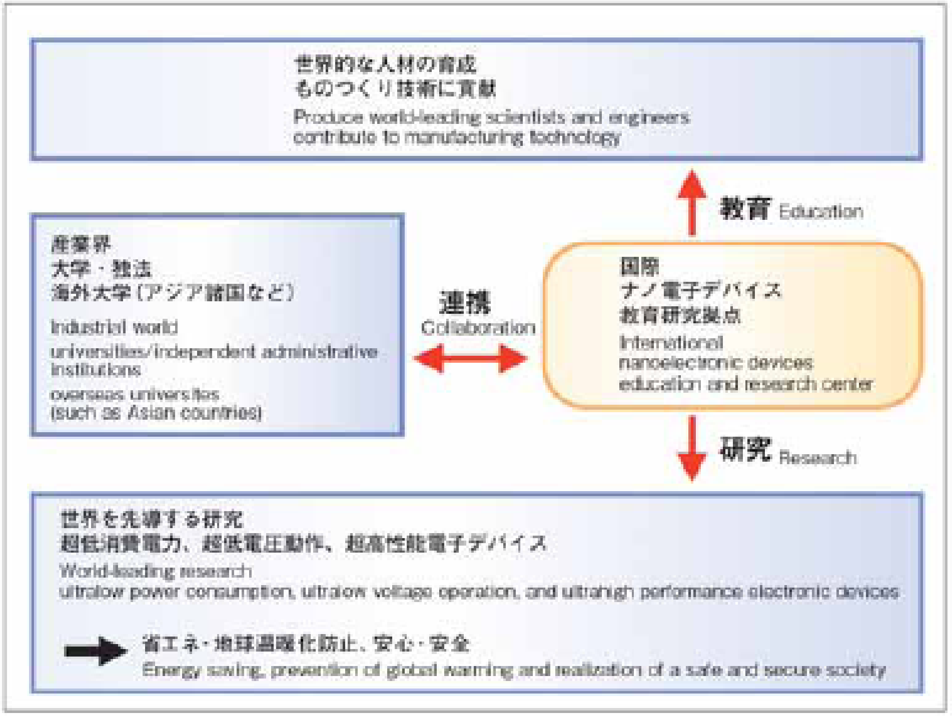
（B4）

[illegible]
（B4）



世界的な人材の育成
ものつくり技術に貢献
Produce world-leading scientists and engineers
contribute to manufacturing technology

教育 Education

産業界
大学・独法
海外大学（アジア諸国など）
Industrial world
universities/independent administrative institutions
overseas universities
(such as Asian countries)

連携
Collaboration

国際
ナノ電子デバイス
教育研究拠点
International
nanoelectronic devices
education and research center

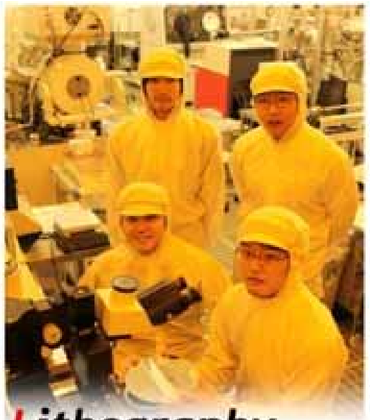
研究 Research

世界を先導する研究
超低消費電力、超低電圧動作、超高性能電子デバイス
World-leading research
ultralow power consumption, ultralow voltage operation, and ultrahigh performance electronic devices

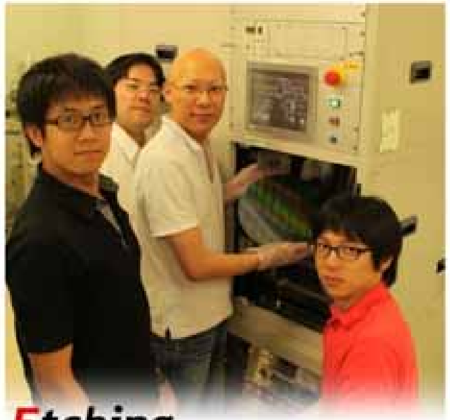
省エネ・地球温暖化防止、安心・安全
Energy saving, prevention of global warming and realization of a safe and secure society

研究風景

Deposition

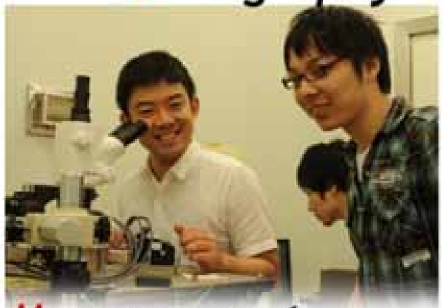


Lithography

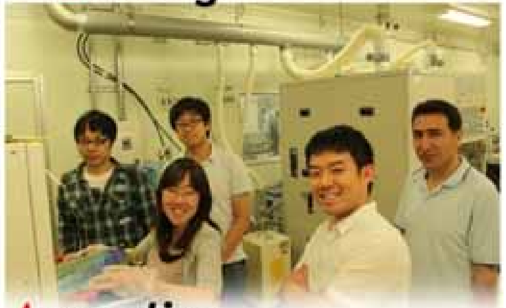


Etching

Analysis



Measurement

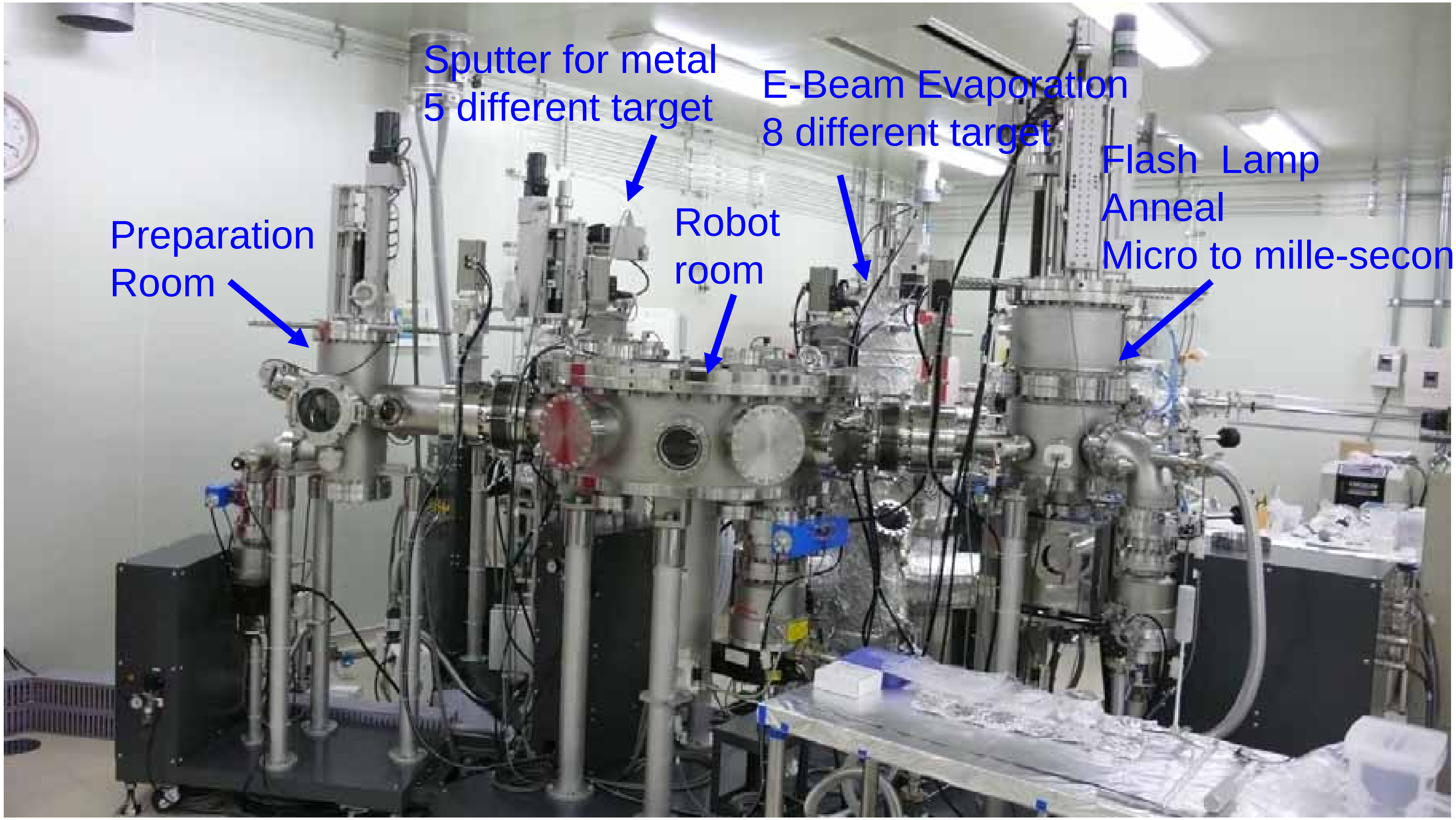


Annealing

Office

Si MOSFET IWAI LAB.®

Cluster tool for high-k thin film deposition



- There were many inventions in the 20th century:

  Airplane, Nuclear Power generation, Computer,

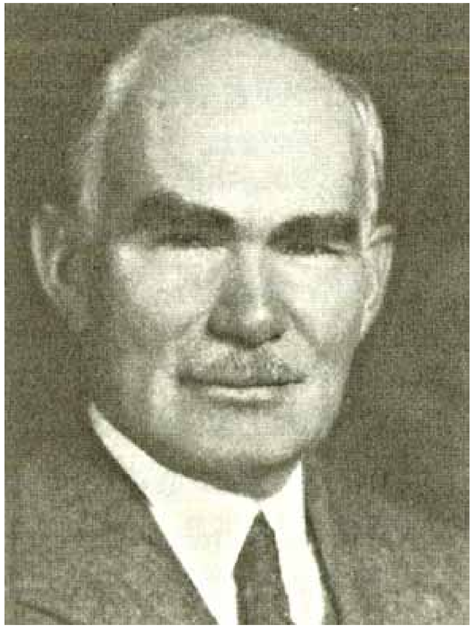
  Space aircraft, etc
- However, everything has to be controlled by electronics
- Electronics

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

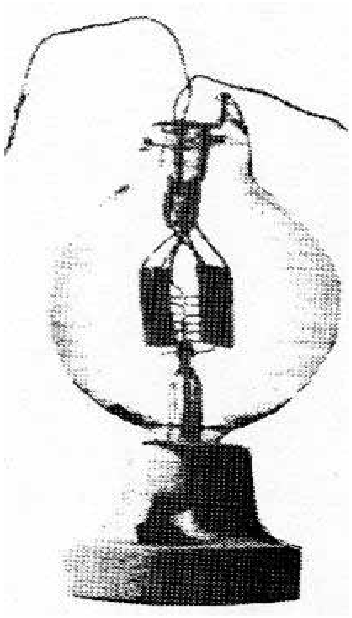
  Electronic Circuits or Integrated Circuits, or

  Microprocessor

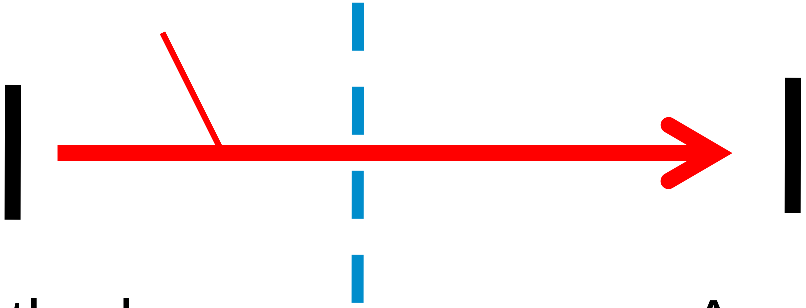
Electronic Circuits started by the invention of vacuum tube (Triode) in 1906



Lee De Forest



Thermal electrons from cathode controlled by grid bias



Cathode
(heated)

Grid

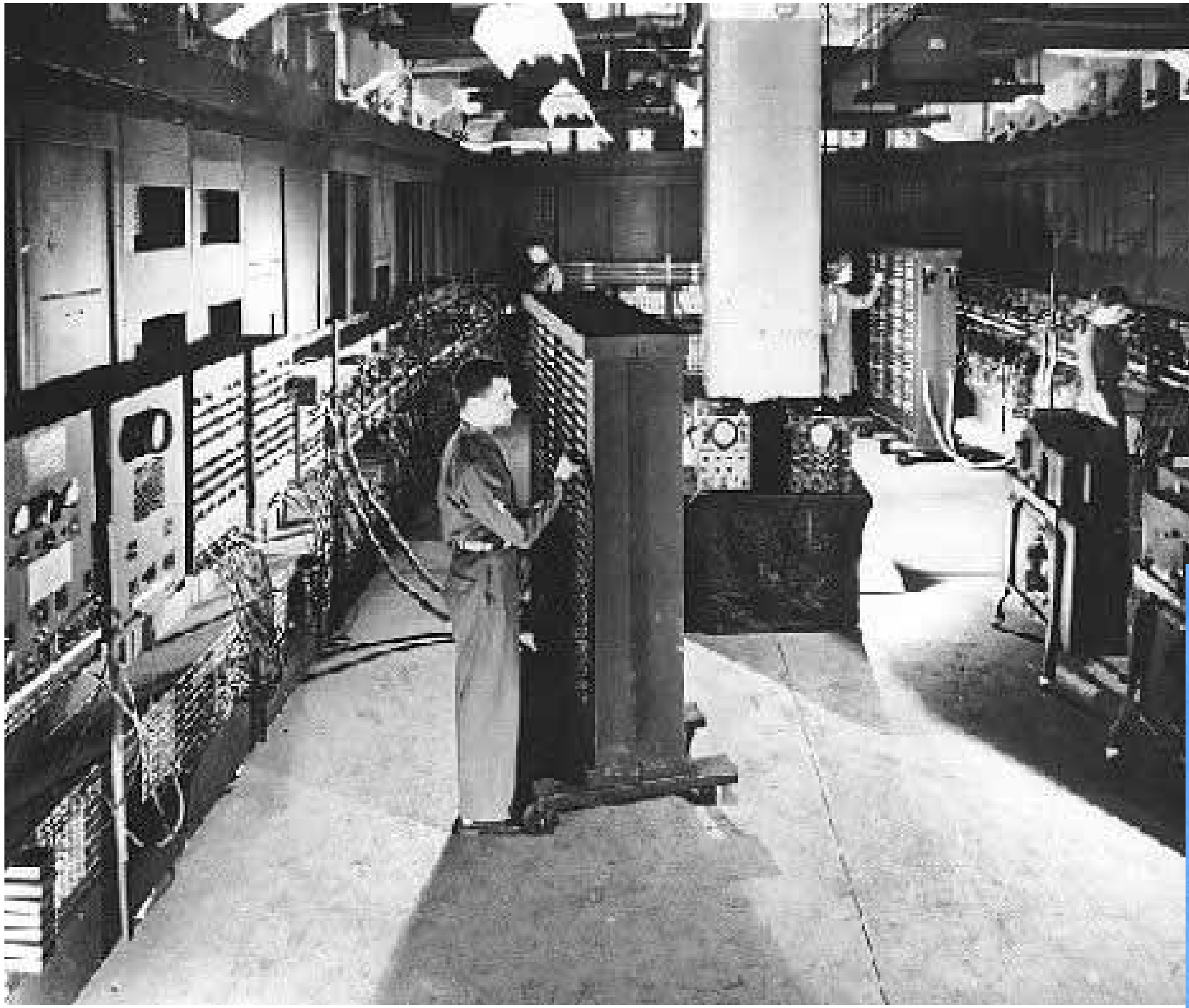
Anode
(Positive bias)

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

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.

Integrated Circuits Technologies are still very important for Green or power saving!

1. Green by Integrated Circuits

Power saving by Microprocessor control for all the human systems

2. Green of Integrated Circuits

Power saving of Integrated Circuits by Down Scaling of MOSFETs in PC, Data Center, Router, etc.

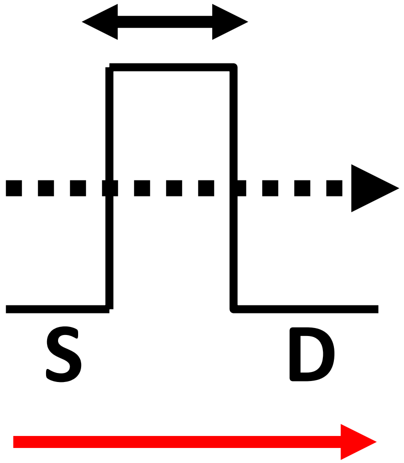
Question:

How far we can go with downscaling?

Predicted limit now

Tunneling distance

3 nm



MOSFET operation

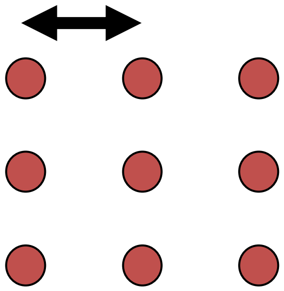
Lg = 3 nm?

**Below this,
no one knows future!**

Ultimate Limit

Atom distance

0.3 nm



How far can we go?

Past

0.7 times per 3 years

In 40 years: 15 generations,
Size 1/200, Area 1/40,000

1973年

↓

Now

8μm → 6μm → 4μm → 3μm → 2μm → 1.2μm → 0.8μm → 0.5μm

→ 0.35μm → 0.25μm → 180nm → 130nm → 90nm → 65nm → 45nm

Future

→ 32nm → 22nm → 16nm → 11.5 nm → 8nm → 5.5nm? → 4nm? → 2.9 nm?

- **At least 5,6 generations, for 15 ~ 20 years**
- **Hopefully 8 generations, for 30 years**

How far can we go?

Need to consider the cost and profit.

Cost for Technology development,
Production.

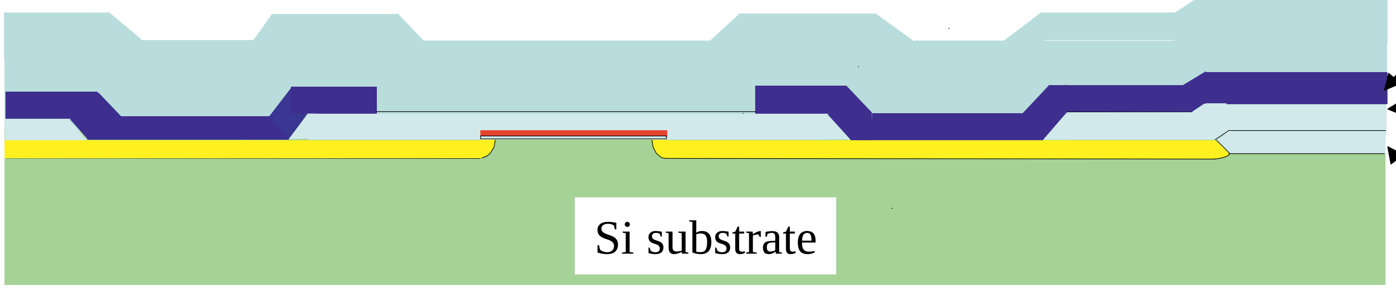
Also, need to consider if still be able to get the merit in performance and power Consumption by downsising.

New Technologies?

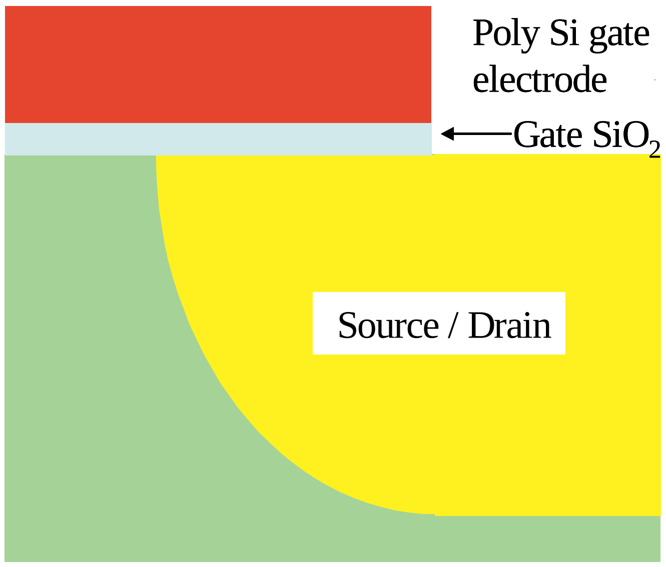
Introduction of new materials and new structures and new applications.

New Materials

6 μm NMOS LSI in 1974



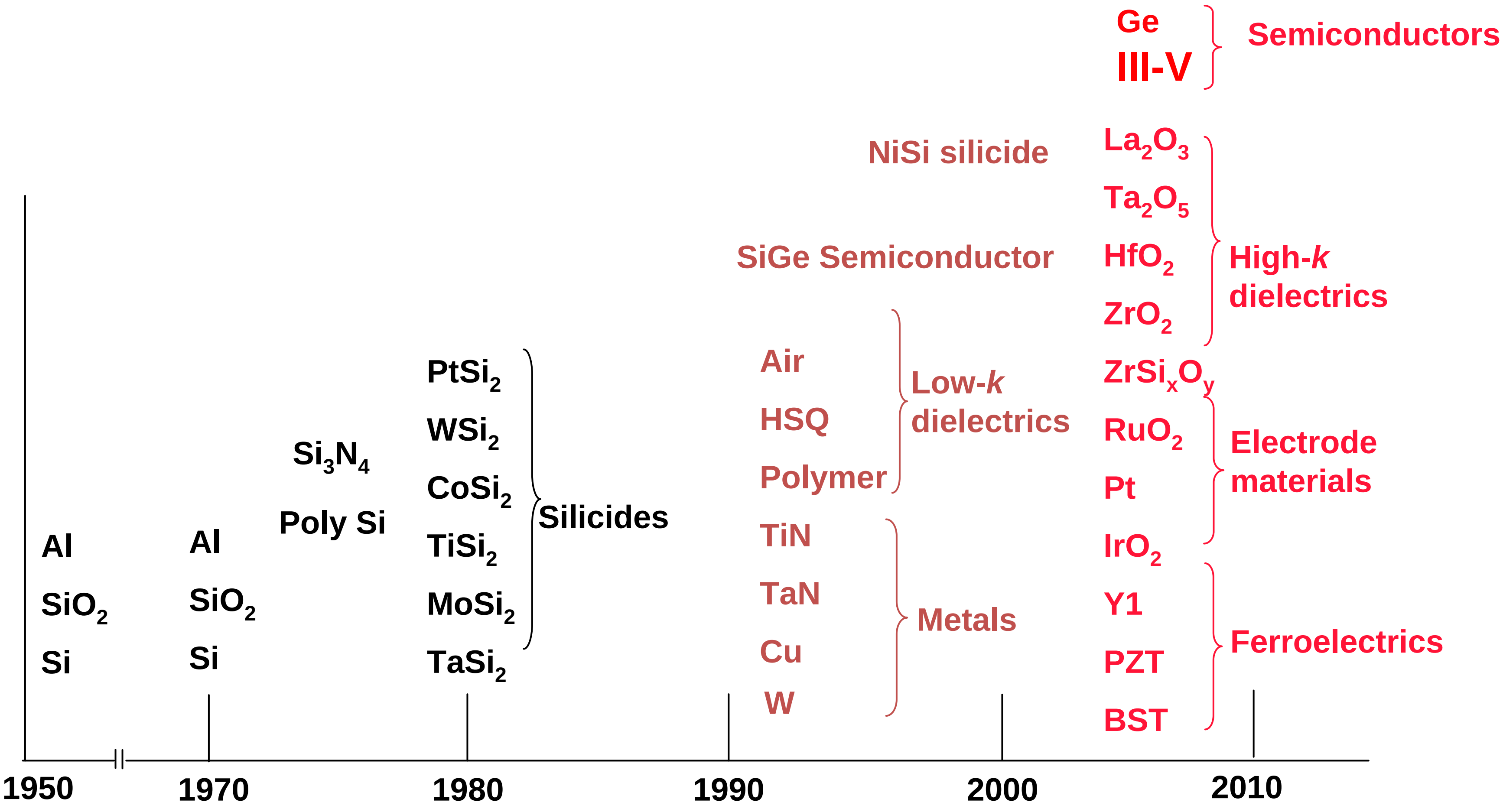
magnification



Layers	Materials	Atoms
1. Si substrate	1. Si	1. Si
2. Field oxide	2. SiO_2	2. O
3. Gate oxide	3. BPSG	3. P
4. Poly Si	4. Al	4. B
5. S/D	5. PSG	5. Al
6. Interlayer		(H, N, Cl)
7. Aluminum		
8. Passivation		

New materials

Just examples!
Many other candidates



Al
SiO_2
Si

Al
SiO_2
Si

Si_3N_4
Poly Si

$PtSi_2$
WSi_2
$CoSi_2$
$TiSi_2$
$MoSi_2$
$TaSi_2$
Silicides

NiSi silicide

SiGe Semiconductor

Air
HSQ
Polymer
Low-*k* dielectrics

TiN
TaN
Cu
W
Metals

Ge
III-V
Semiconductors

La_2O_3
Ta_2O_5
HfO_2
ZrO_2
High-*k* dielectrics

$ZrSi_xO_y$

RuO_2
Pt
IrO_2
Electrode materials

Y1
PZT
BST
Ferroelectrics

1950
1970
1980
1990
2000
2010

Y. Nishi, Si Nano Workshop, 2006,

(S. Sze, Based on invited talk at Stanford Univ., Aug. 1999)

Choice of High-k elements for oxide

Candidates 🟦

● Gas or liquid at 1000 K

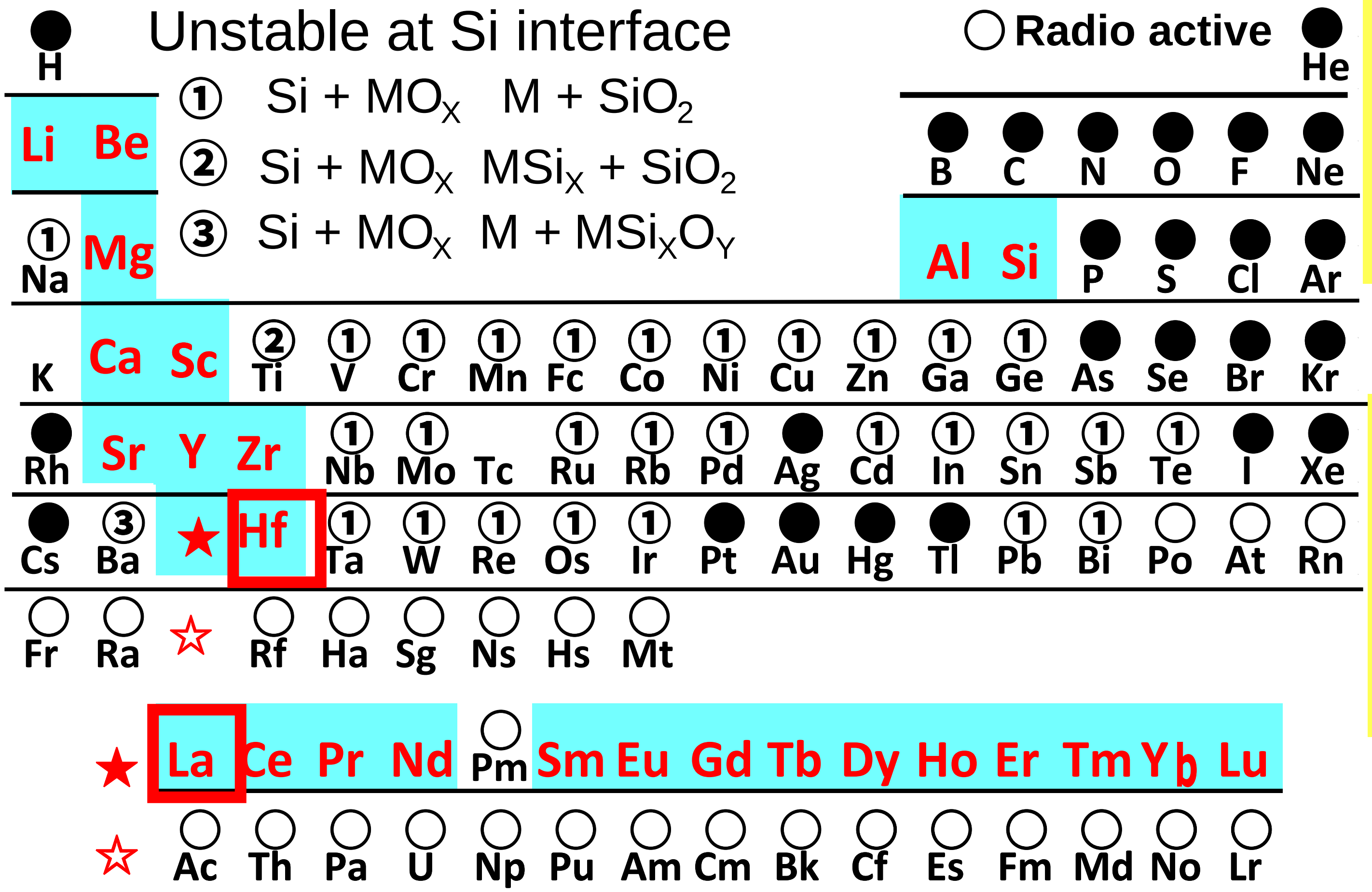
○ Radio active

Unstable at Si interface

① Si + MO_X M + SiO_2

② Si + MO_X MSi_X + SiO_2

③ Si + MO_X M + MSi_XO_Y



HfO_2 based dielectrics are selected as the first generation materials, because of their merit in
1) band-offset,
2) dielectric constant
3) thermal stability

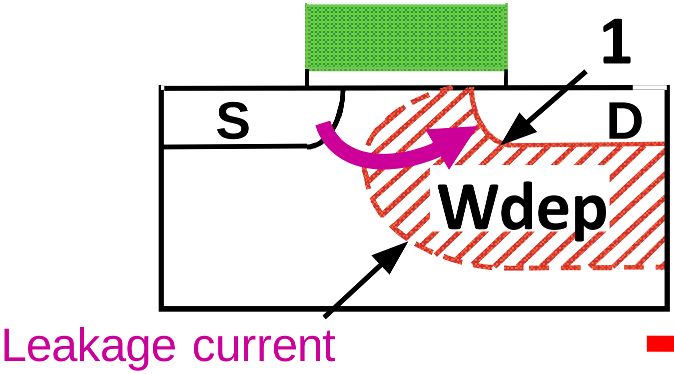
La_2O_3 based dielectrics are thought to be the next generation materials, which may not need a thicker interfacial layer

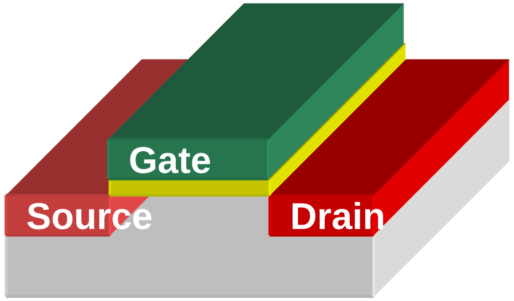
R. Hauser, IEDM Short Course, 1999
Hubbard and Schlom, J Mater Res 11 2757 (1996)

New Structures

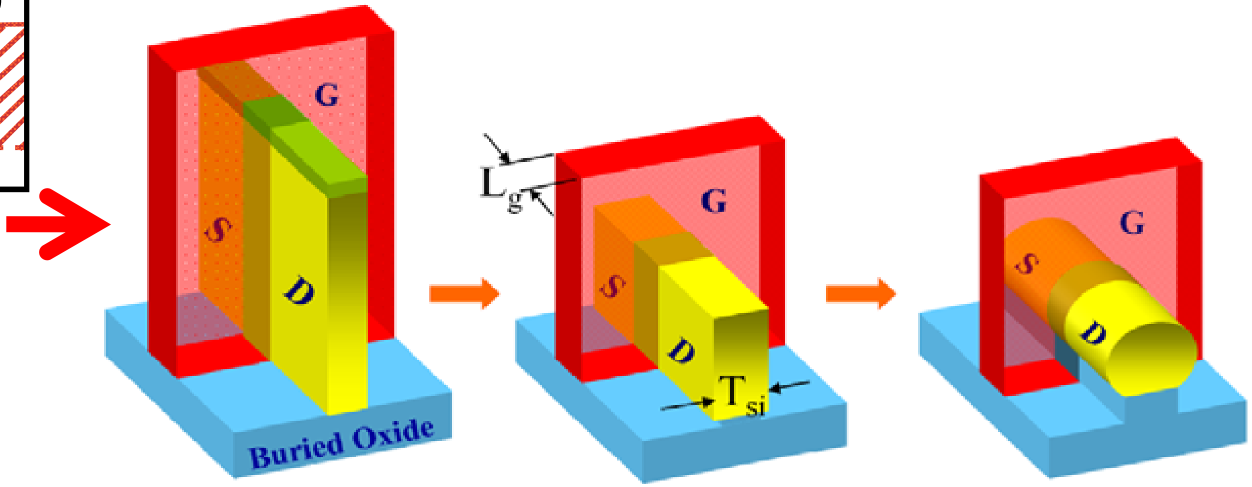
Because of off-leakage control,

Planar → Fin→ Nanowire





Planar FET



Double-Gate FinFET ($T_{si} = {}^{2}/_{3}\ L_g$)

Omega FinFET ($T_{si} = L_g$)

Nanowire FinFET ($T_{si} = 2L_g$)

Fin FET

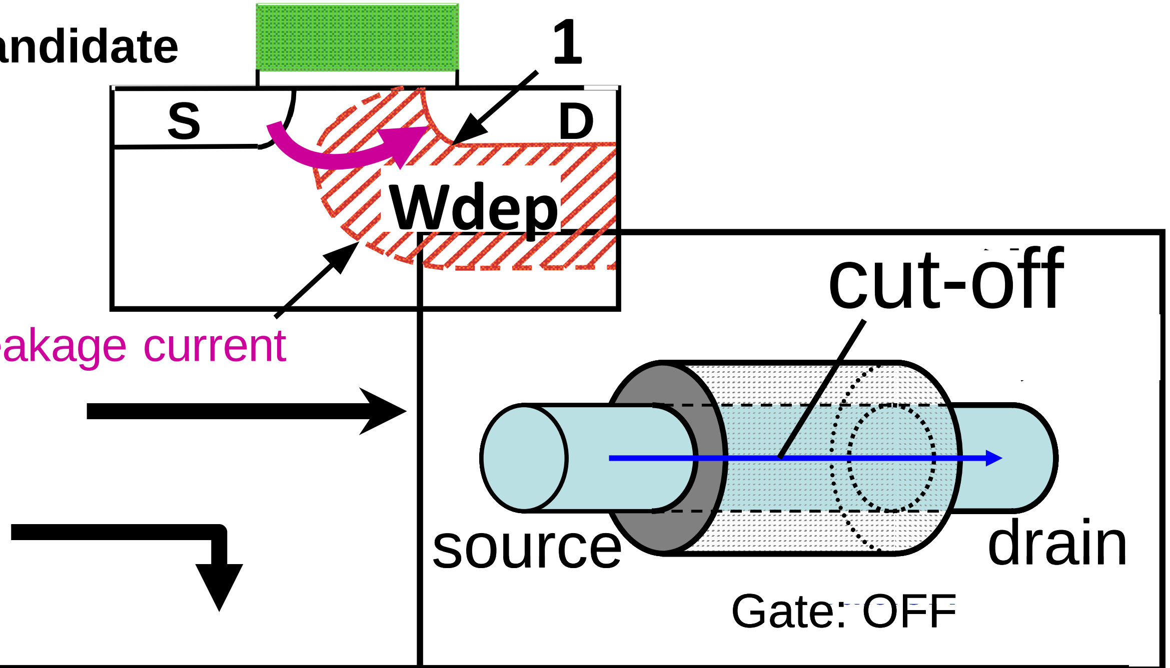
Nanowire FET

Si nanowire FET as a strong candidate

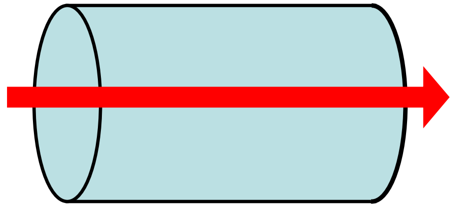
1. Compatibility with current CMOS process

2. Good controllability of I_{OFF}

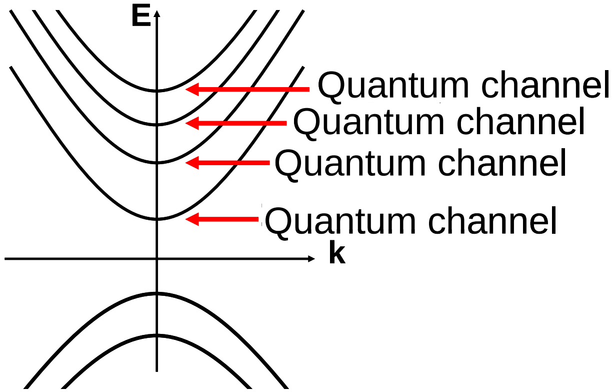
3. High drive current



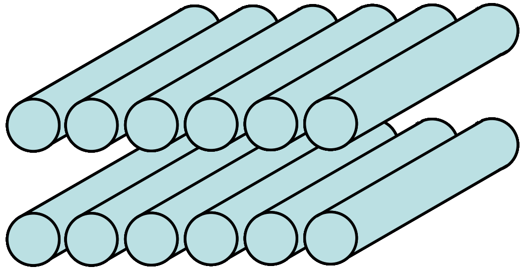
1D ballistic conduction



Multi quantum Channel

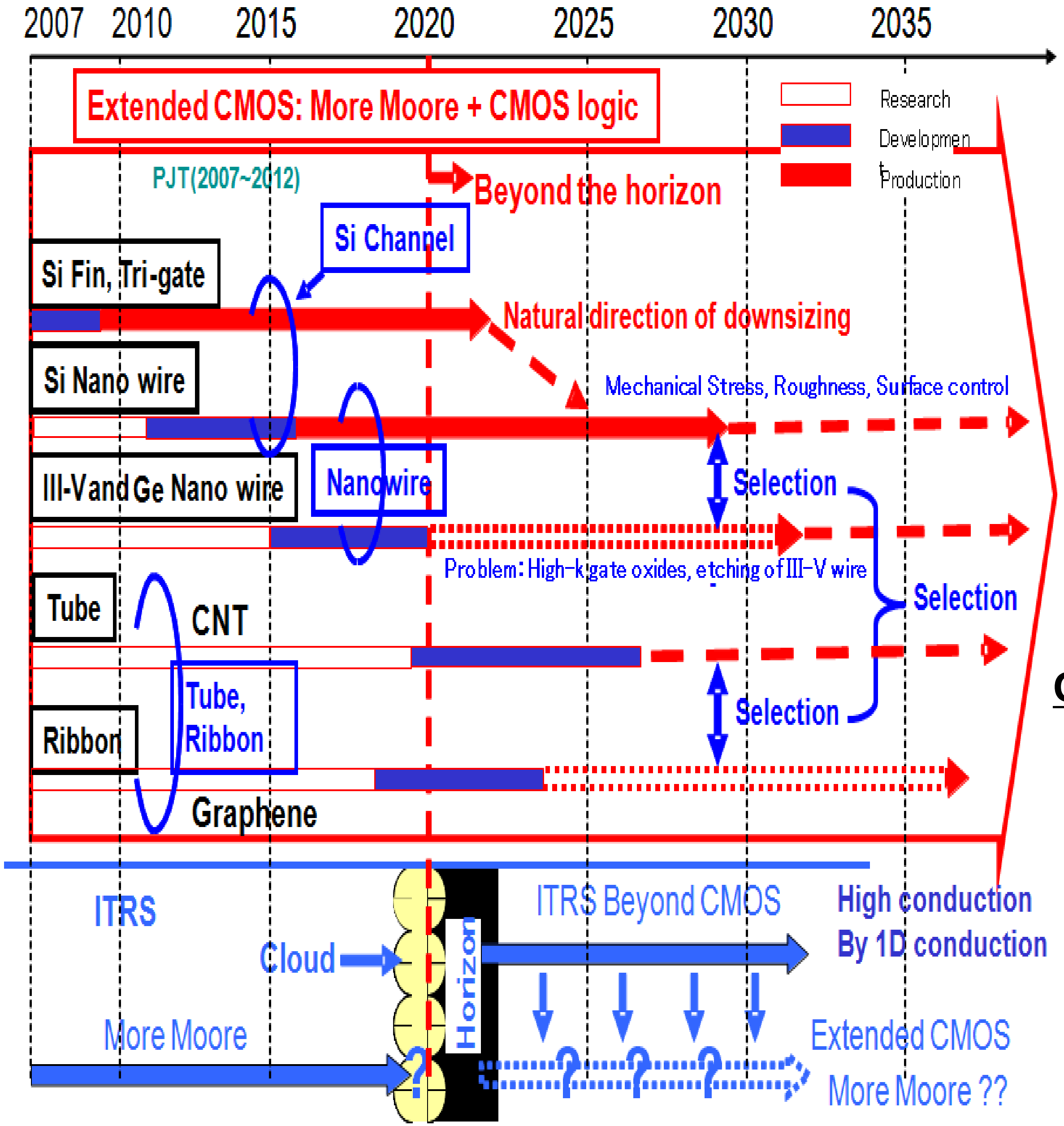


High integration of wires



Our roadmap for R &D

Source: H. Iwai, IWJT 2008



Current Issues

Si Nanowire

Control of wire surface property
Source Drain contact
Optimization of wire diameter
Compact I-V model

III-V & Ge Nanowire

High-k gate insulator
Wire formation technique

CNT:

Growth and integration of CNT
Width and Chirality control
Chirality determines conduction types: metal or semiconductor

Graphene:

Graphene formation technique
Suppression of off-current

Very small bandgap or no bandgap (semi-metal)

Control of ribbon edge structure which affects bandgap

Discussion

Not only for designing but also manufacturing for micro and nano electronics is important for India.

How it could be done quickly?

Thank you
for your attention!