Empowered by Innovation NEC

State of Pacific Rim Nanotech., specially in Asia

- Green Nanotechnology -

May 18, 2010
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NEC Corporation

Outline

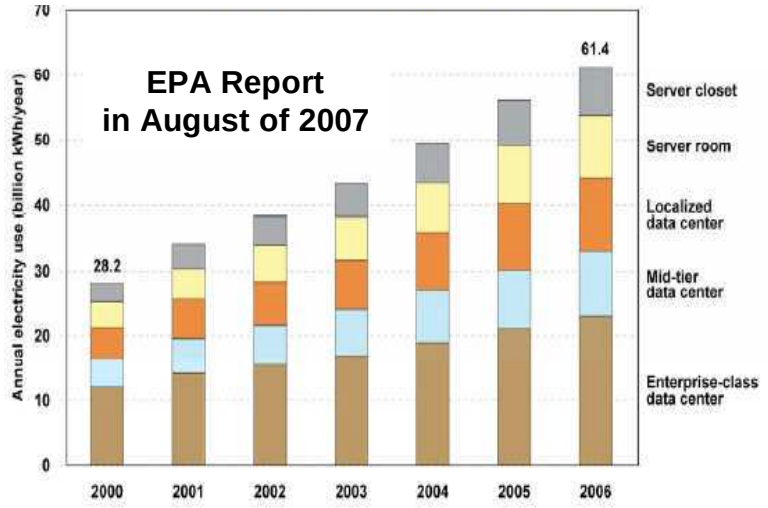
1. Introduction
2. Statistics
3. Nano-carbon
4. Energy devices with nanomaterials
5. Si Photonics

Introduction

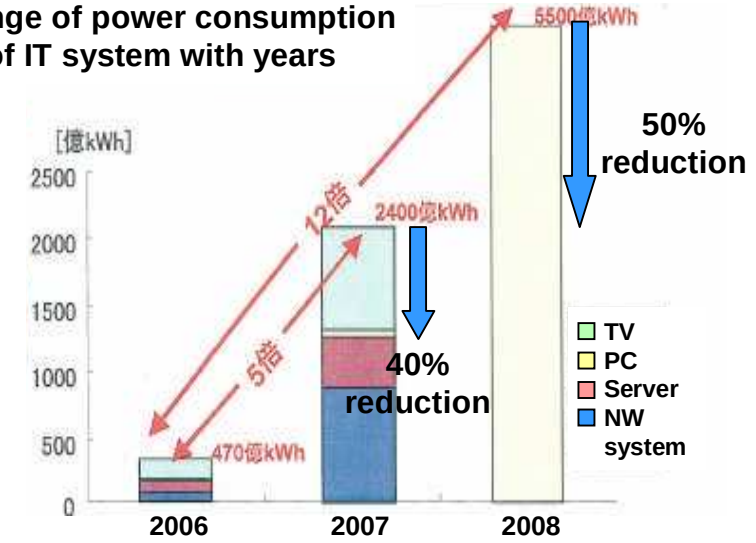
Explosion of Information Traffic and Electric Power Consumption of ICT System

- Electric power consumption at data-centers in US **was doubled in the past 6 years**, reaching to the electric power generated by 5 nuclear power plants.
- Information traffic in the Internet will increase 190 times from 637Gbps@2007 to120Tbps@2025.
- Already, the power consumption of IT system at 2007 is **five times larger** than that at 2006. The reduction of power consumption must be one of the very urgent issues.

Change of power consumption at data-centers in US from 2000 to 2006



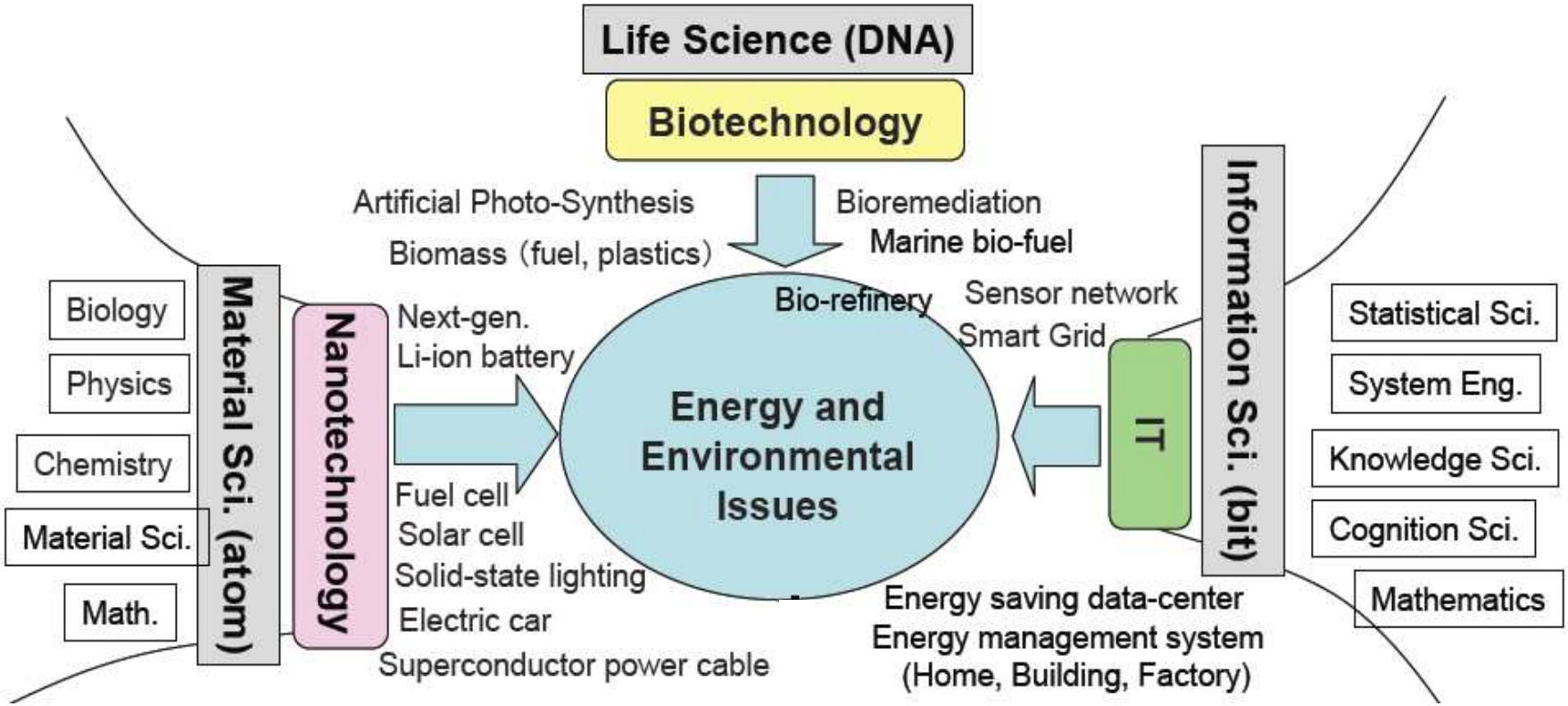
Change of power consumption of IT system with years



Source : METI "Green IT Initiative"

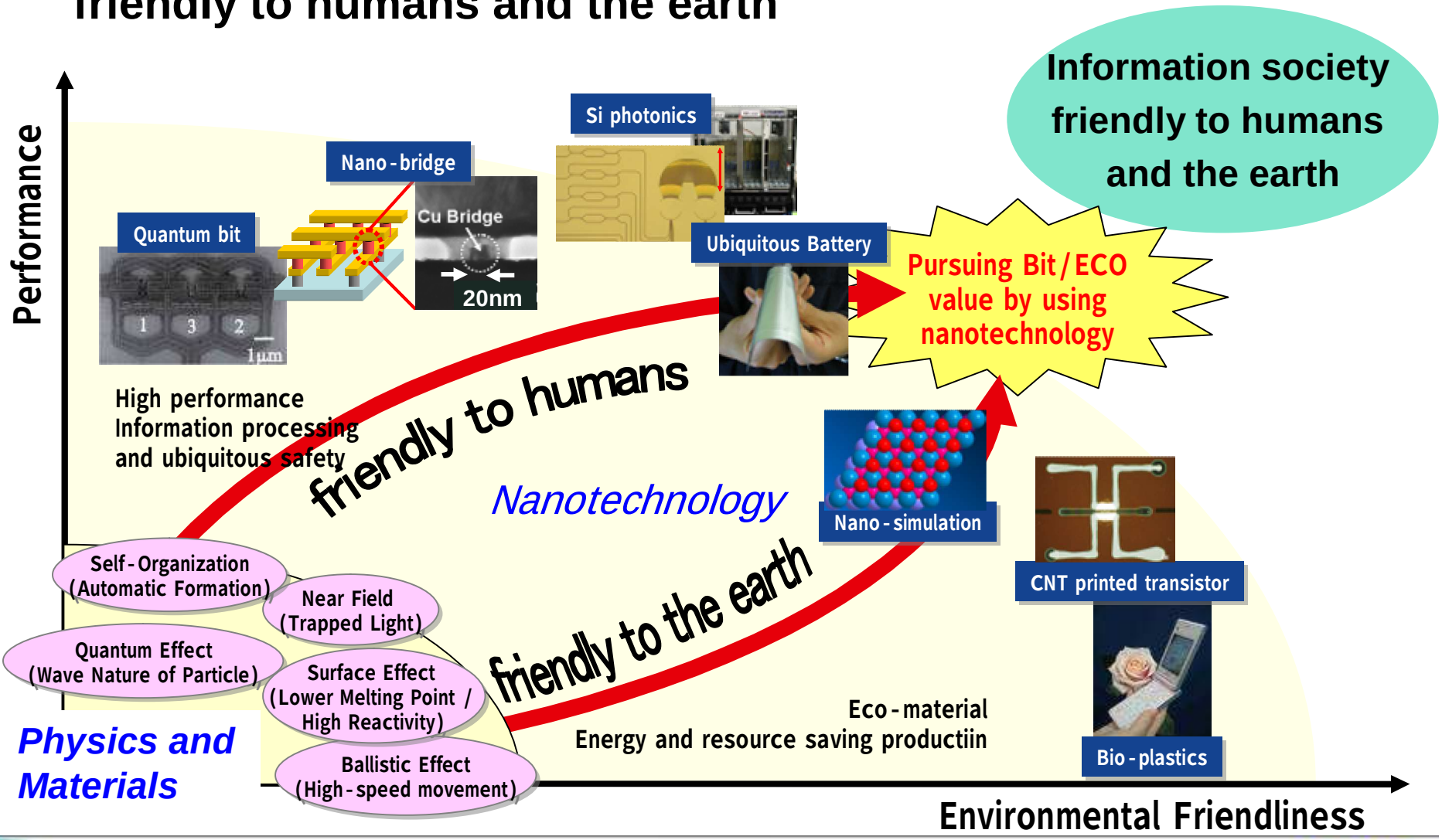
To realize sustainable society

- **Energy and environmental issues have to be solved to realize sustainable society.**
- **Many technologies in broad area have to contribute to do so.**
- **Nanotechnology is one of the most important technologies.**



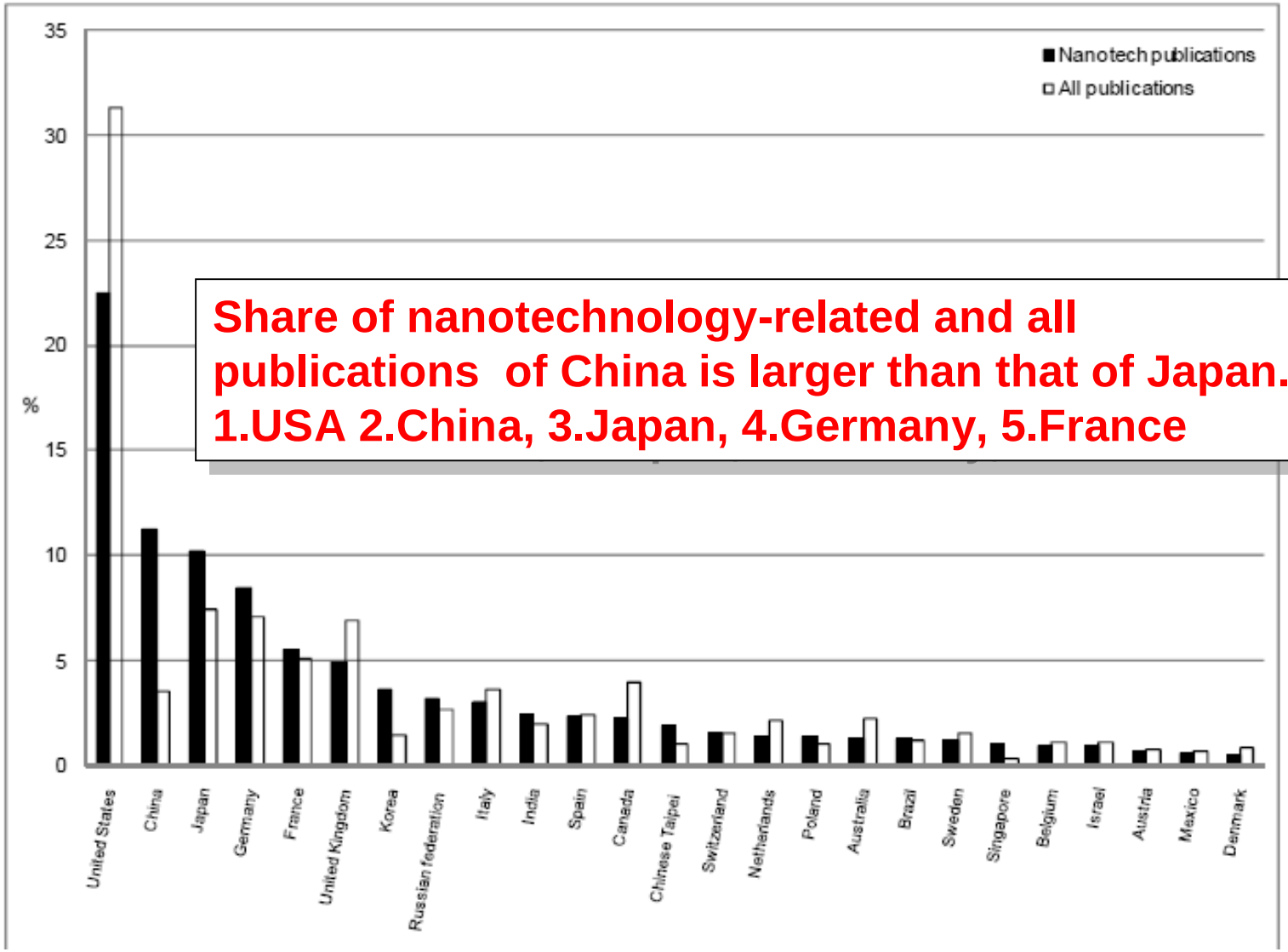
NEC's Nanotech. Development Strategy

Nanotechnology supporting to realize information society friendly to humans and the earth



Statistics

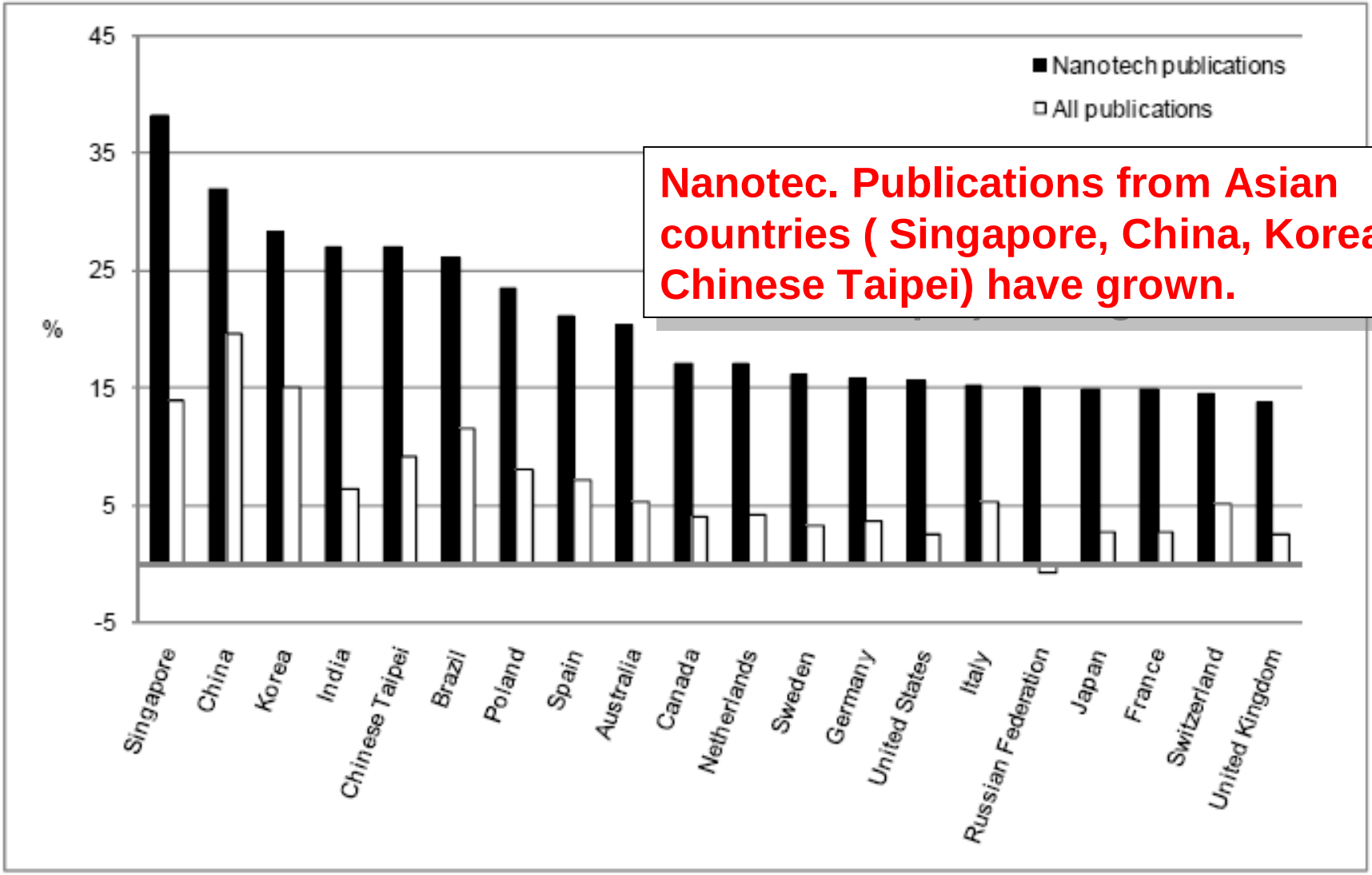
Share of nanotechnology-related and all publications by country, 1991-2007



Share of nanotechnology-related and all publications of China is larger than that of Japan.
1.USA 2.China, 3.Japan, 4.Germany, 5.France

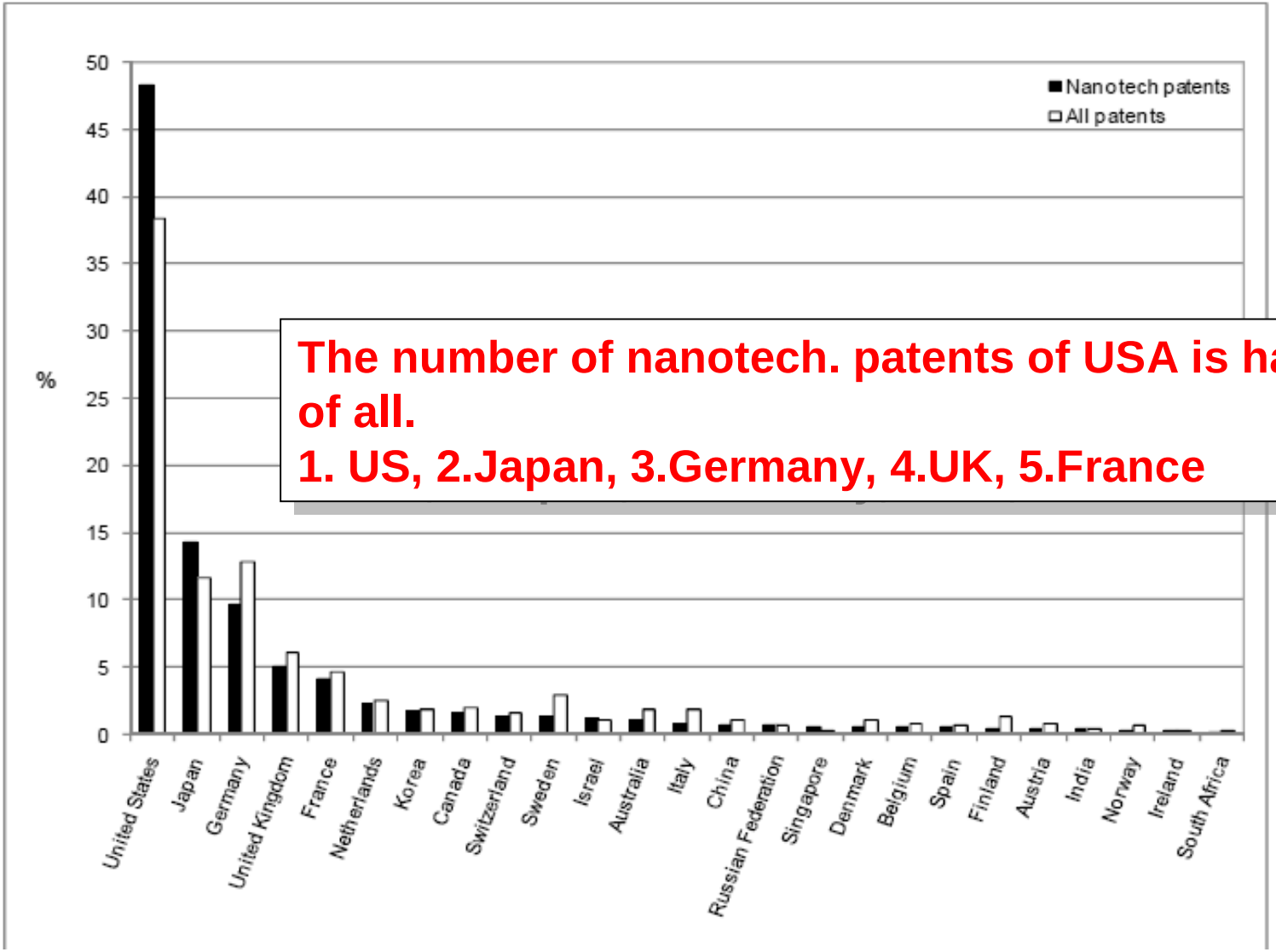
OECD: Nanotechnology: An Overview Based on Indicators and Statistics

Average annual growth rates of nanotechnology-related and all publications by country, 1996-2006



OECD: Nanotechnology: An Overview Based on Indicators and Statistics

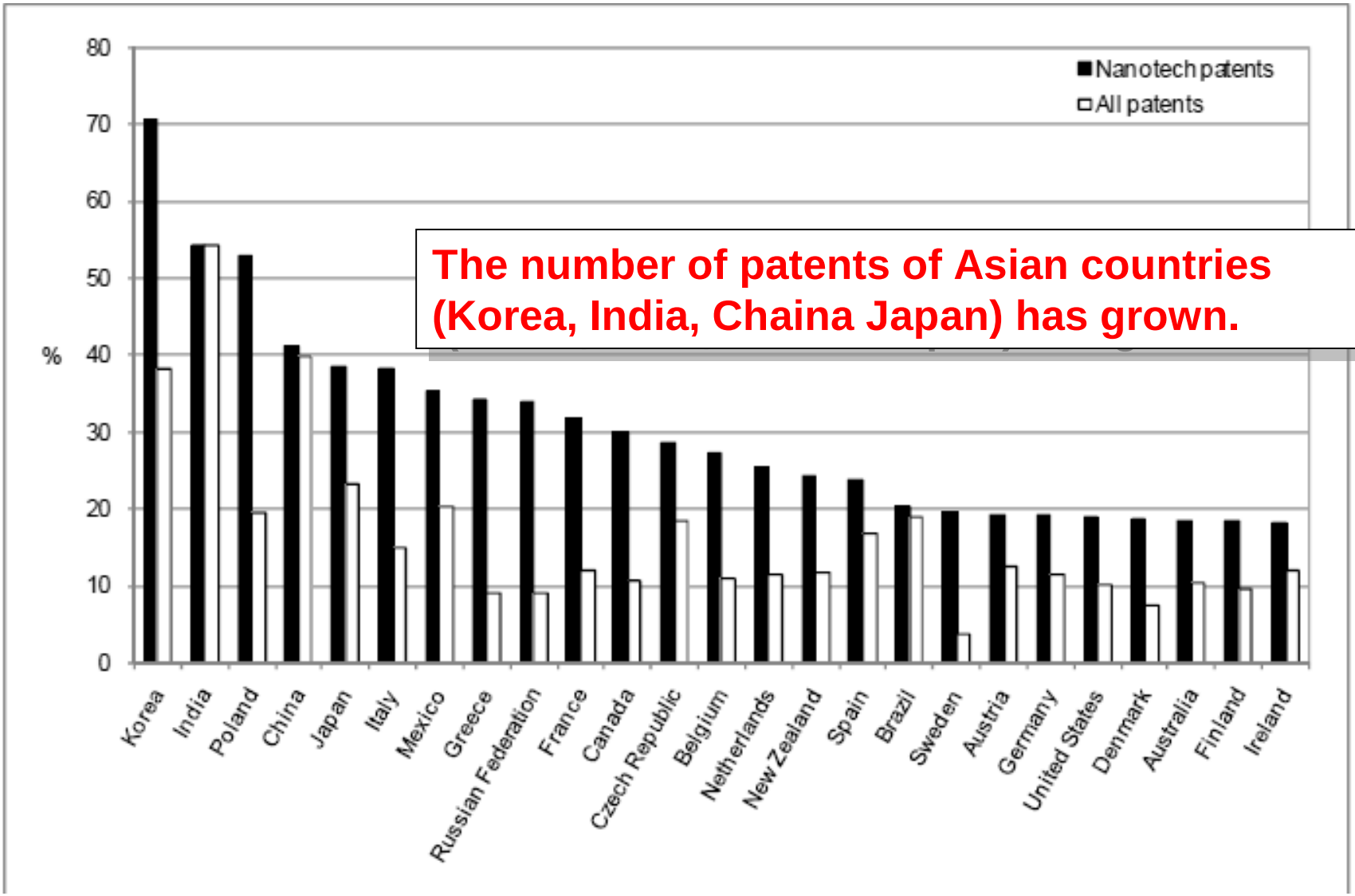
Share of nanotechnology and all patents by country, until 2005



The number of nanotech. patents of USA is half of all.
1. US, 2.Japan, 3.Germany, 4.UK, 5.France

OECD: Nanotechnology: An Overview Based on Indicators and Statistics

Average annual growth of nanotechnology and all patents by country, 1995-2004



The number of patents of Asian countries (Korea, India, Chaina Japan) has grown.

OECD: Nanotechnology: An Overview Based on Indicators and Statistics

Nanocarbon

Nanotube & Graphene Research at Asia

Focused Applications: energy and display devices

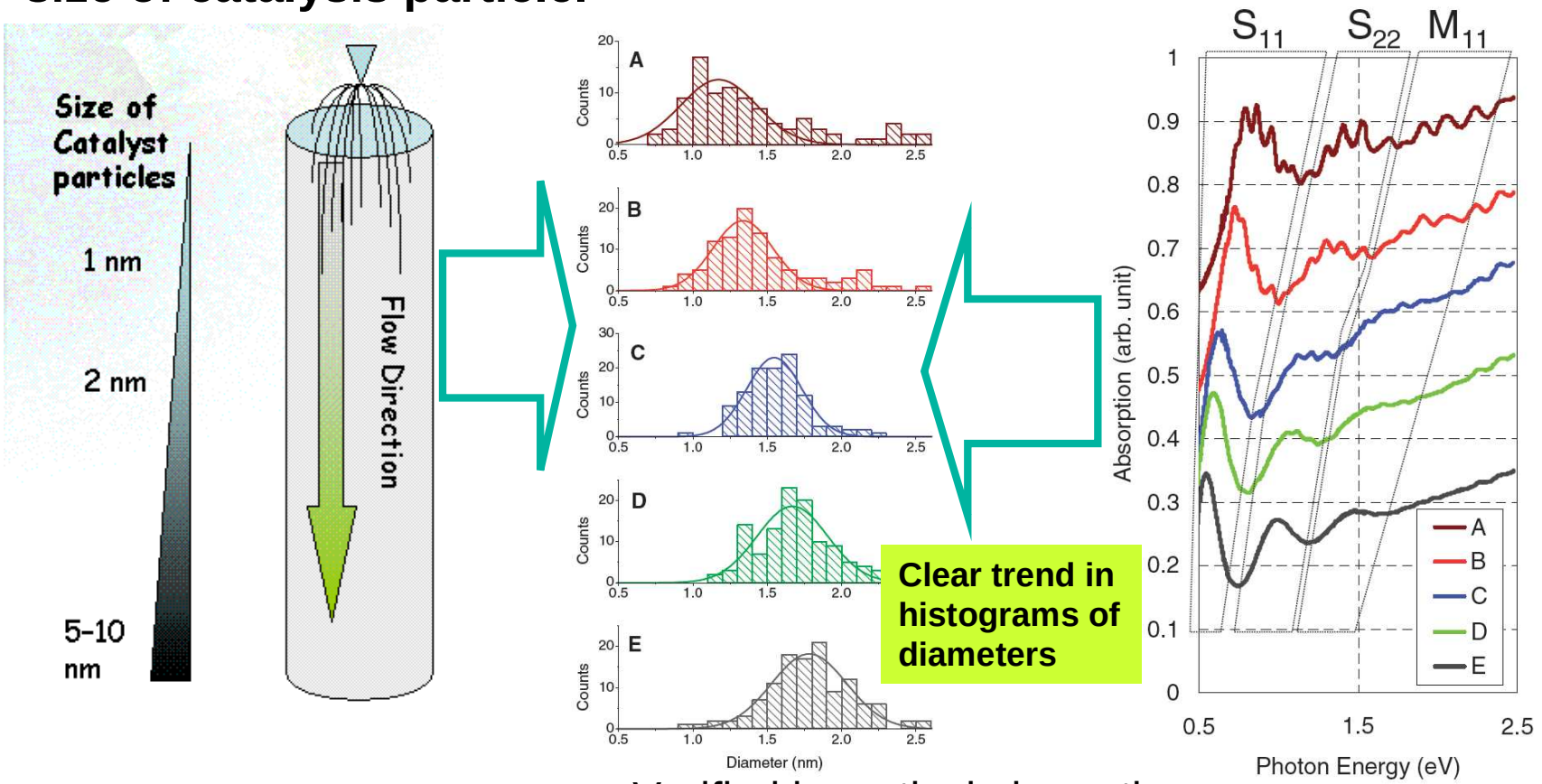
1. Battery/Capacitor with use of large surface area
2. Transparent electrode alternative to ITO
3. Printable electronics

Key Technologies

1. Controlled Growth :
   - Diameter (and chirality) control for nanotube
   - Minimized defect density for graphene
2. Large Scale Fabrication:
   - CVD technology with suitable substrates/catalysis
   - Manipulation/transfer to arbitrary substrates

Controlling diameter of CVD nanotube (AIST)

AIST Japan demonstrated a method of diameter control by tuning the size of catalysis particle.



Verified by optical absorption spectroscopy of grown nanotubes

T. Saito et al., Appl. Phys. Express. Vol. 2, 096006 (2009).

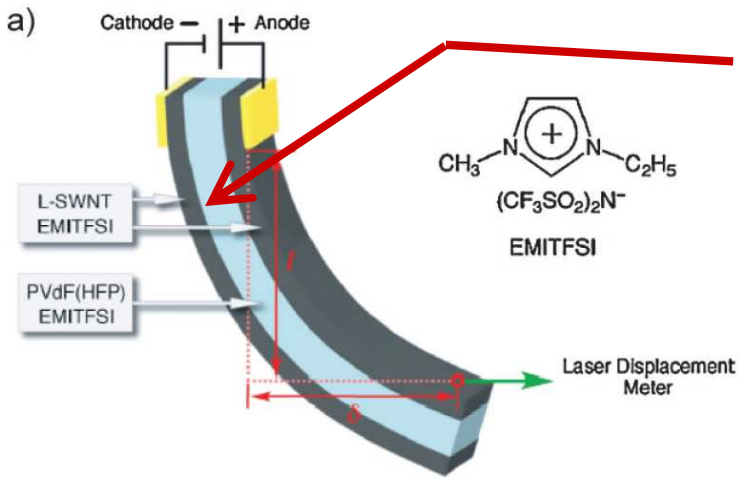
Millimeter sized super-growth of CNT (AIST)

- **The large scale growth technique of carbon nanotubes, so called “super-growth technique”, opened a door of applications of macroscopic sizes of nanotube material.**

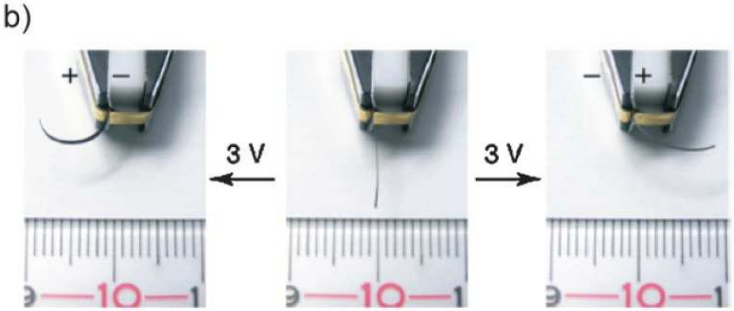
http://www.nanocarbon.jp/sg/001.html

- **Application example 1 : Actuator with significant toughness**

(K. Mukai, et al., Adv. Mat. Vol. 21, 1582 (2009).)

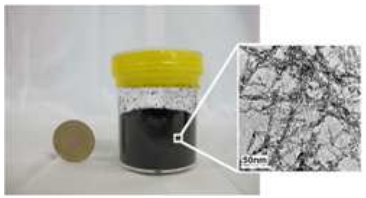


Electrolyte actuator is operable in air being sandwiched by SG-CNT electrodes.



Low-voltage fast-motion in ambient condition

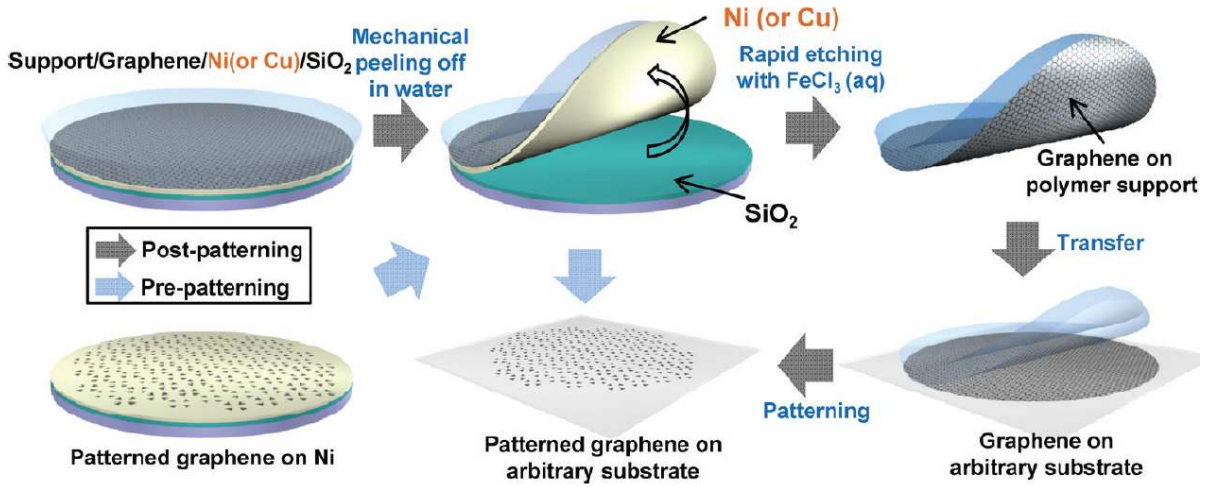
- **Application example 2 : Super-capacitor with Large surface area CNT material as possible hybrid power-source with Li ion battery**



http://www.aist.go.jp/aist_j/press_release/pr2010/pr20100104/pr20100104.html

Large area CVD growth of graphene on Ni/Cu foil and manipulation (Sungkyunkwan Univ. Samsung, Korea)

- **Sequence of CVD growth of graphene on Ni or Cu substrate, and subsequent transport process on arbitrary substrate are developed.**



Y. Lee , et al.,Nano Letters, Vol 10, 490 (2010)

Recently this technique is scaled up to A4 size of graphene sheet with roll-to-roll printing.

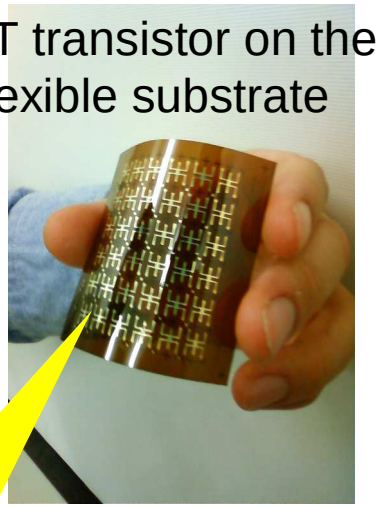
- **Possible future application: Transparent electrode for wearable touch-panel displays tougher than ITO against bending**

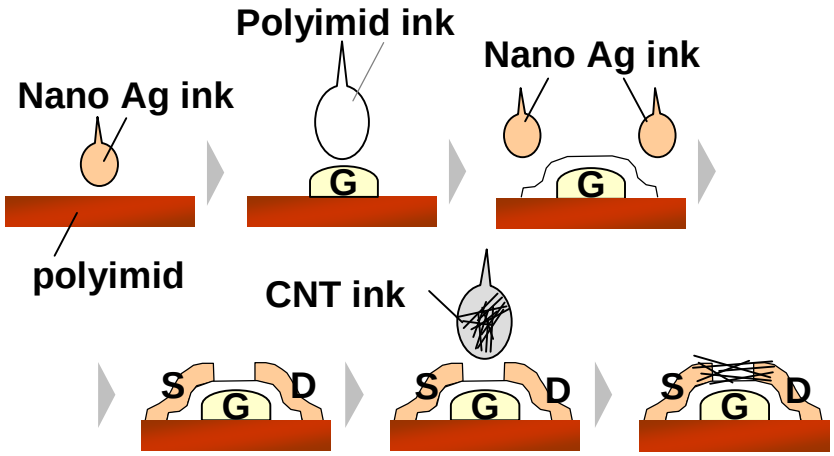
http://chem.skku.edu/graphene/

Printed CNT transistor (NEC)

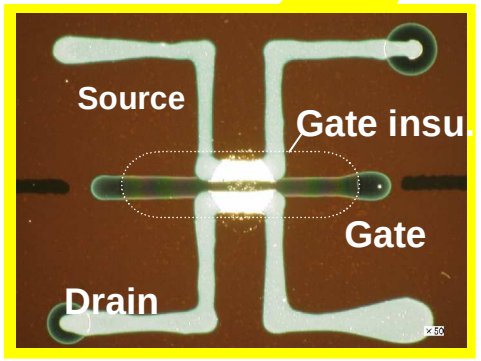
- **All parts of transistors (channel/insulator/electrodes) are printed.**
- **Process temperatures are below 200 degree C, applicable for plastic film.**
- **We succeed to fabricate printed CNT transistors, which on/off ratio is >1000.**

CNT transistor on the flexible substrate





Fabrication process



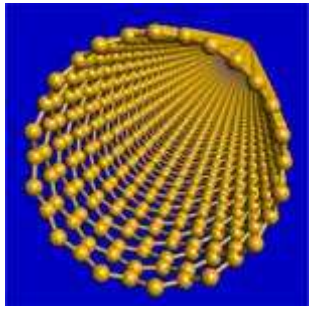
Fabricated CNT transistor

CNT ink

Carbon Nanotubes as printed electronic materials

Structural characteristics

- Chemically stable
- Mechanically stable



Electronic Characteristics

- Large carrier mobility
- Large current capacity

Handled in humid condition
No degradation in solvent

Suitable for making ink

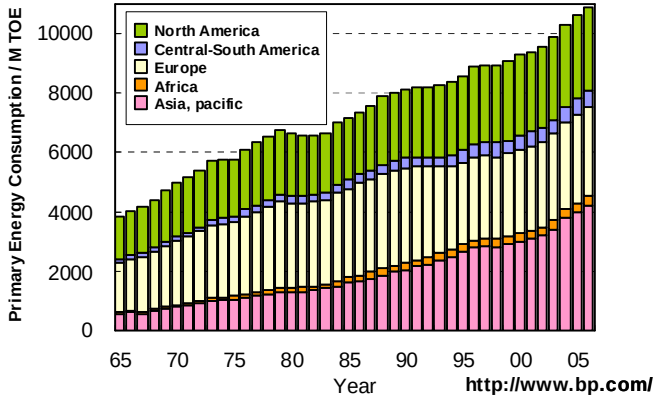
High-speed operation

Energy Devices

Trend for Rechargeable Batteries

EV mass production will lead the market expansion of Energy Devices

Background: World's primary energy consumption

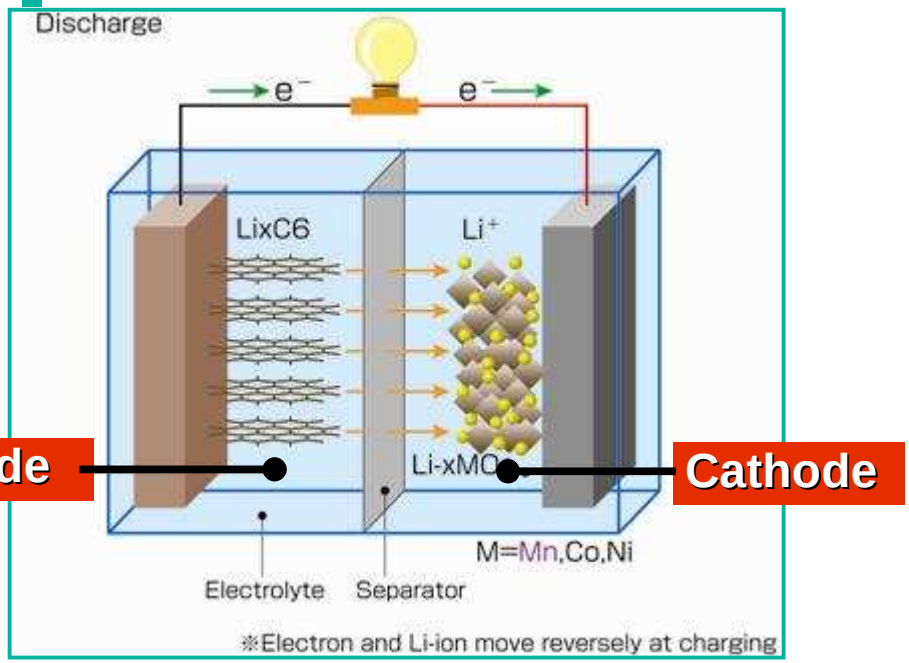


- Global warming
- Oil shortage
- Air pollutions
- Environment destructions

Advanced Energy Storage Devices

Breakthrough technologies are required for higher energy and power density.

Conventional LiB



Technical Goals/Metrics

- Cells for portable devices
- High power electrode
- Long life; stability during cycling
- Low cost operation

Technical Challenges

- Nano storage materials/structures
- Reliability, cost, lifetime, durability
- Temperature range, safety
- Manufacturing technologies

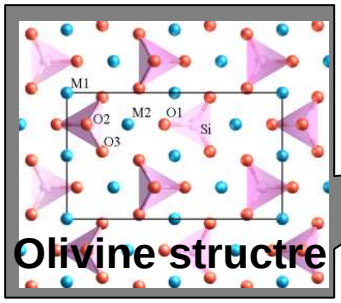
Why Nano-materials?

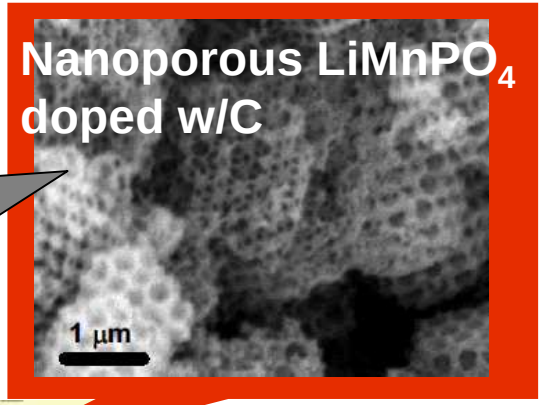
- Power: shortened e^- path length
- Rate property: increase contact area
- Energy density: high surface area

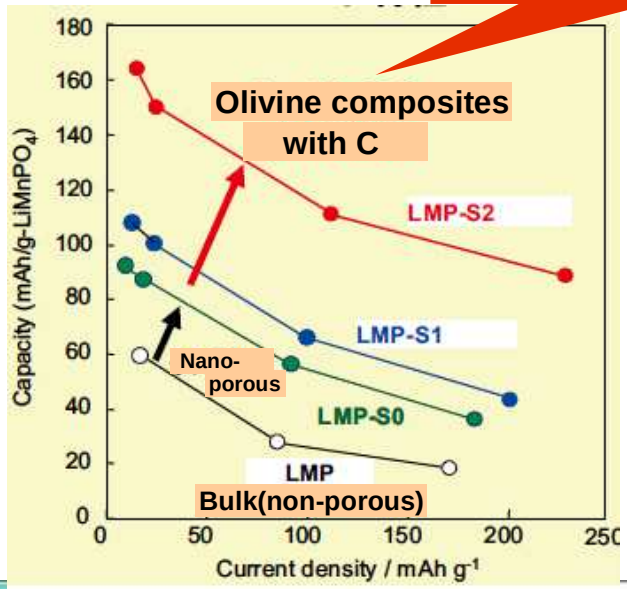
Nanomaterials chemistry is essential for the future challenges of energy strorage devices.

High-power Cathode Study (Nagasaki Univ. & AIST)

Nano-composite $LiMnPO_4$-C as cathode by Dr. Honma and Prof. Moriguchi.







Technical Accomplishments

- High power cathode
  => Rate capability x2.8
- High energy density; x2 to bulk
- Safety; low toxic materials
- Low cost (Mn)

Technical Approach

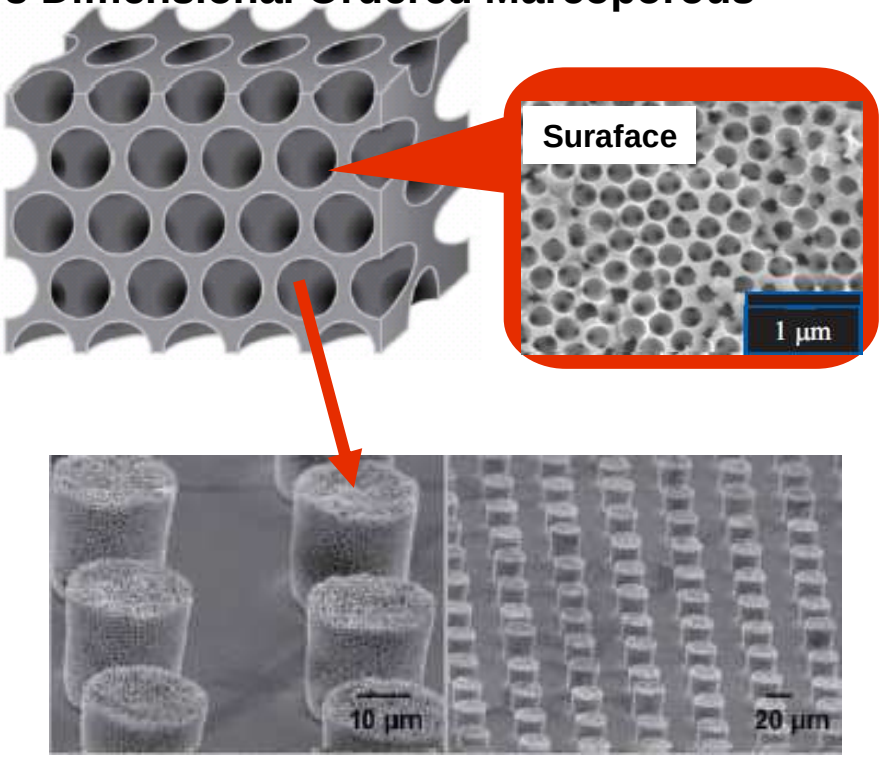
- Nano particle $LiMnPO_4$(<200 nm)
- Olivine composite with C in surface is formed successfully
- Composite interface enhances electron conductivity

M. Okubo, Y. Mizuno, H. Yamada, J. Kim, E. Hosono, H. Zhou, T. Kudo, I. Honma
"Fast Li-ion insertion into nanosized LiMn2O4 without domain boundaries"
ACS Nano, 4(2), pp.741-752 (2010).

Highly-structured Alloy as Anode (Tokyo Metro. Univ.)

Lithium ion battery with 3DOM* Sn-Ni alloy as anode by Prof. Kanamura.

***3 Dimensional Ordered Marcoporous**



Domain-structured anode was formed using lithographic technique

Technical Accomplishments

- **Potentiality of Sn-based electrode has been shown**
- **High energy density; 993 mAh/g(ideal) >500mAh/g(current), x1.5 to graphite**
- **60%@60Cycling; Long life as Sn-based material**
- **99% of charge-discharge efficiency**

Technical Approach

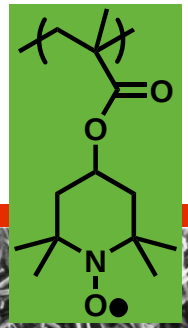
- **Colloidal particles as template for 3DOM structure**
- **Relaxation of mechanical stress by volume expansion**

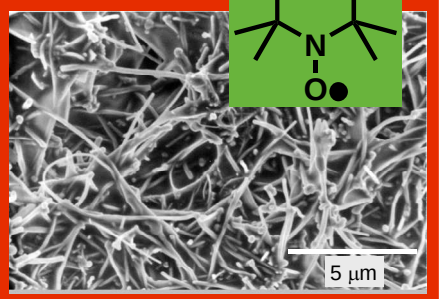
J. Hamagami, K. Hasegawa, K. Kanamura
"3D particle assembley in micro-scale by using electrohphoretic micro-fabrication technique"
Key Engineering Materials, **314**, 7-12(2006).

Organic Radical Battery (NEC)

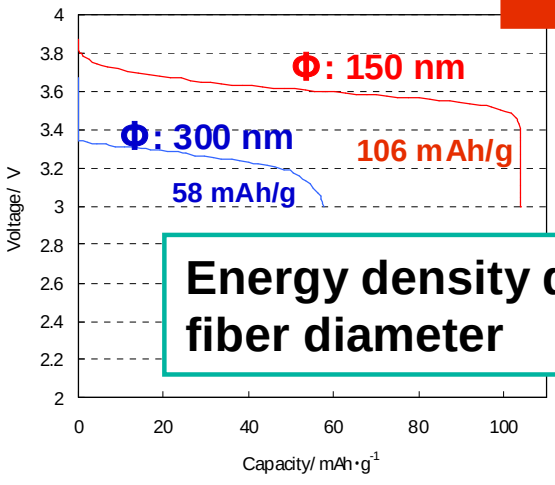
A new class of rechargeable battery using flexible plastic by NEC.

PTMA;
polymer electrode material





PTMA/nano-carbon fiber composite cathode



Energy density depends on fiber diameter

Technical Accomplishments

- Flexible/Thin(<1 mm) battery: reduce volume, free form
- ECO-friendly: no harmful metals such as Pb, Sn, Co, etc
- High power: 6.7 kWh/L
- Rapid recharging

Technical Approach

- Nitroxyl-radical polymer (PTMA); as a charge storage material
- Lithium-ion operating battery
- Nano-carbon fiber as conductivity path in composites cathode

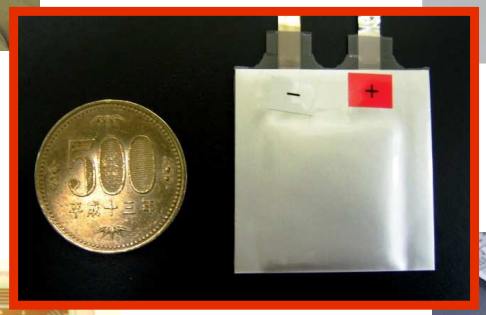
K. Nakahara et al., *Chem. Phys. Lett.*, **359**, 351(2002)

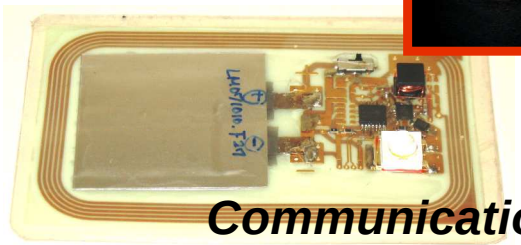
Organic Radical Battery (2) (NEC)

Application images of micro-power battery for ubiquitous/ sensor-NW devices.

Wearable device

Active cards





Communication cards
(Wireless charging)

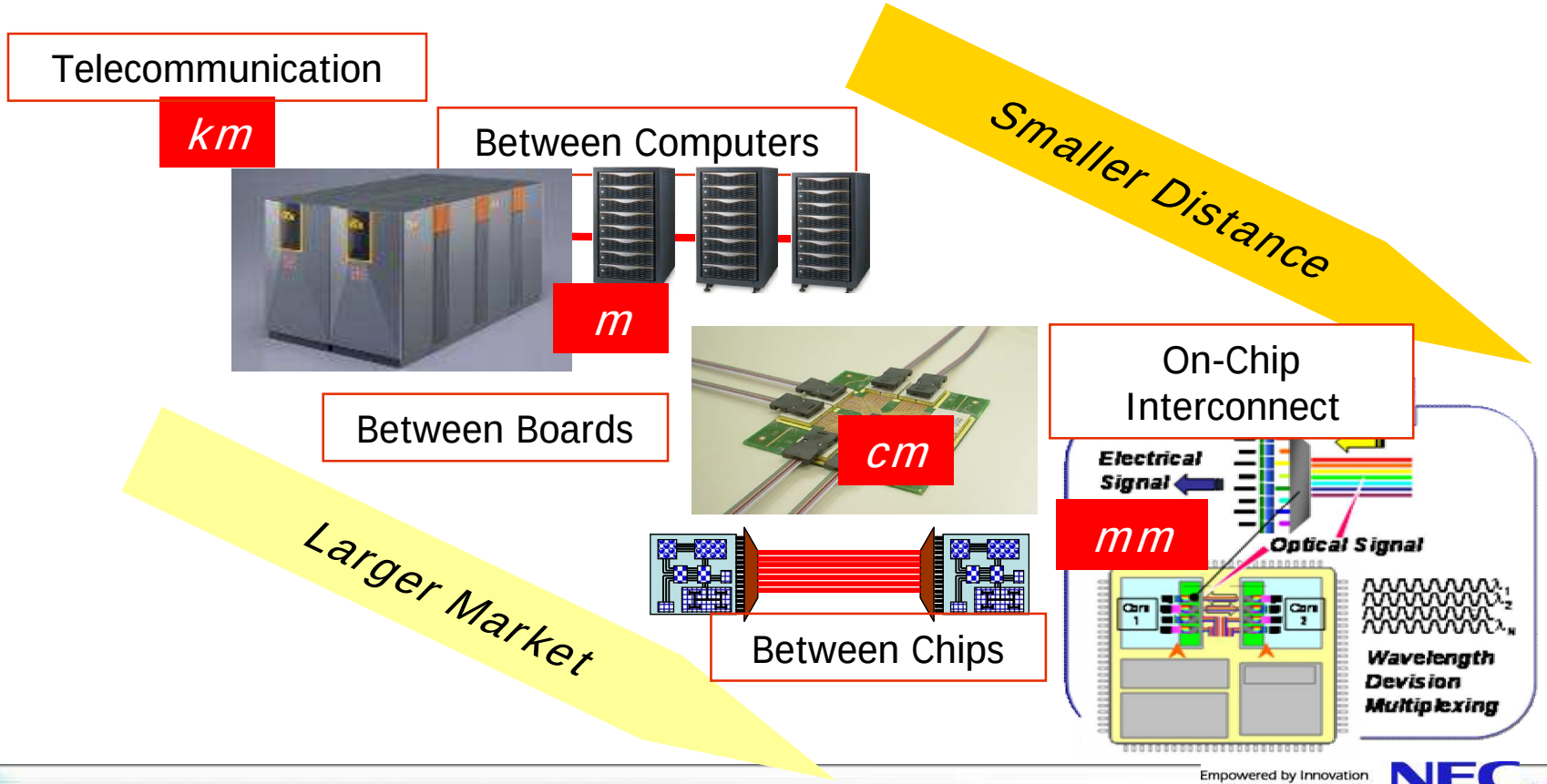
USB charger

Small Organic radical batteries would be possible solution for man-wearable power such as activation cards/tags

Si photonics

Optical Interconnects in Electronics

- **Optical communication has been employed to long haul telecommunication for internet progress.**
- **High data capacity optical communication has been penetrating from long-haul to short–distance interconnect. Also, market will be increased in short distance interconnect.**



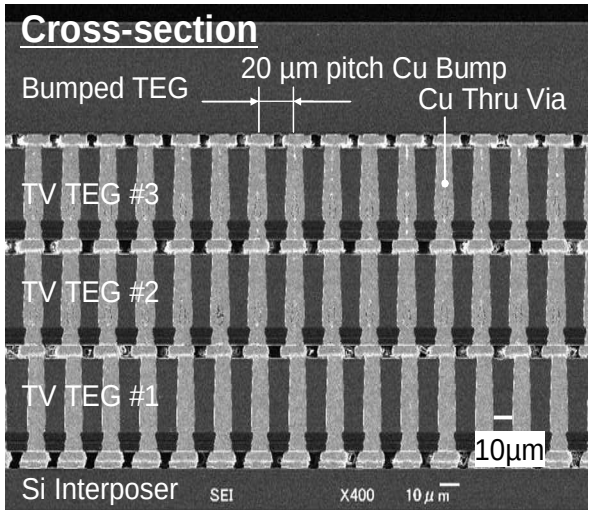
Bottleneck of Global Interconnects

In 2012, a 1-mm-long interconnect's latency will be 100 times larger, and its binary switching energy will be 30 times larger, than a corresponding transistor.

J. D. Meindl, *Computing in Sci. & Engrng*, 2003.

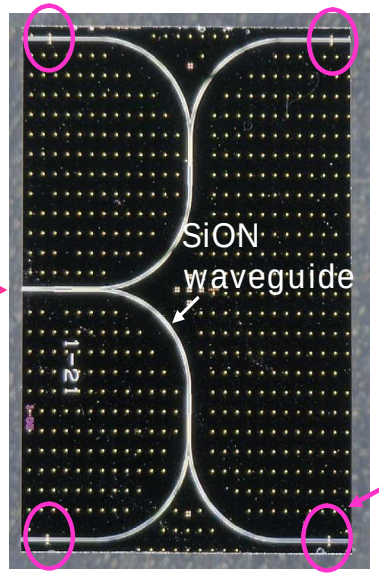
Shorter Length by Vertical Connection

3D-Integration



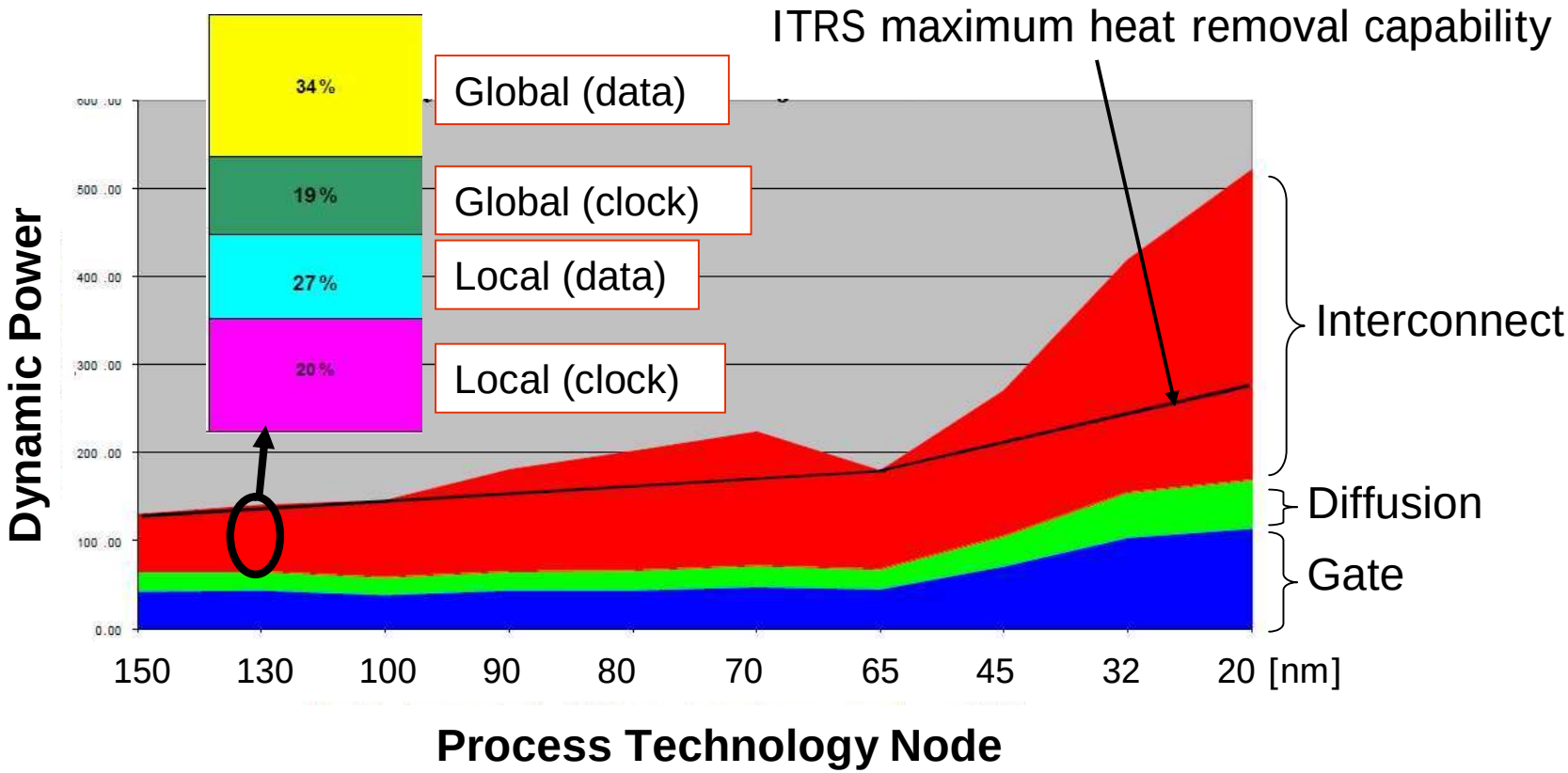
Different Physics for Lateral Connection

Optical Interconnect



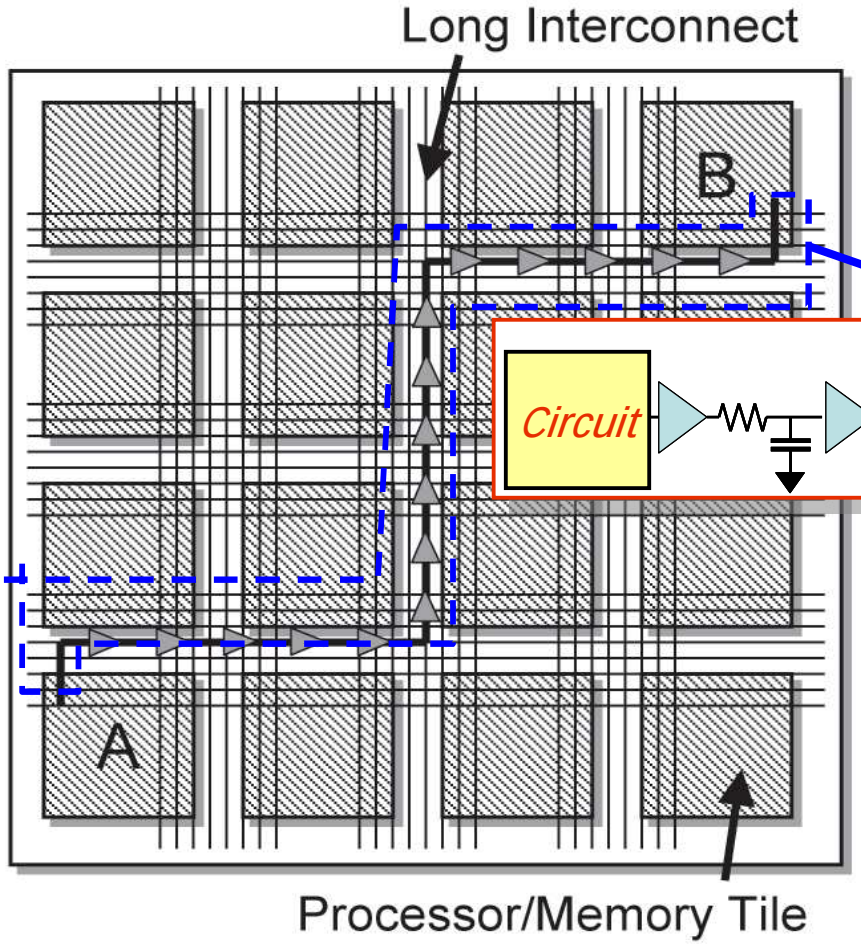
Power Consumption in LSI

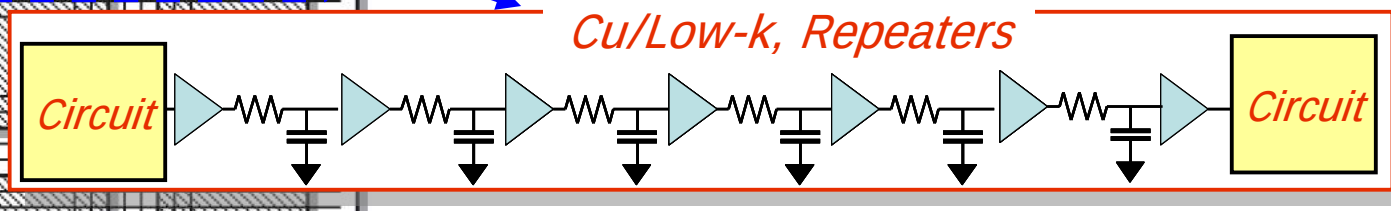
- **Dynamic power will grow larger than maximum heat removal capability. Especially, interconnect have large proportion according to progress of process technology node. This means interconnect will be very important for progress of LSI**



N. Magen et al, SLIP 04

Electrical Interconnect



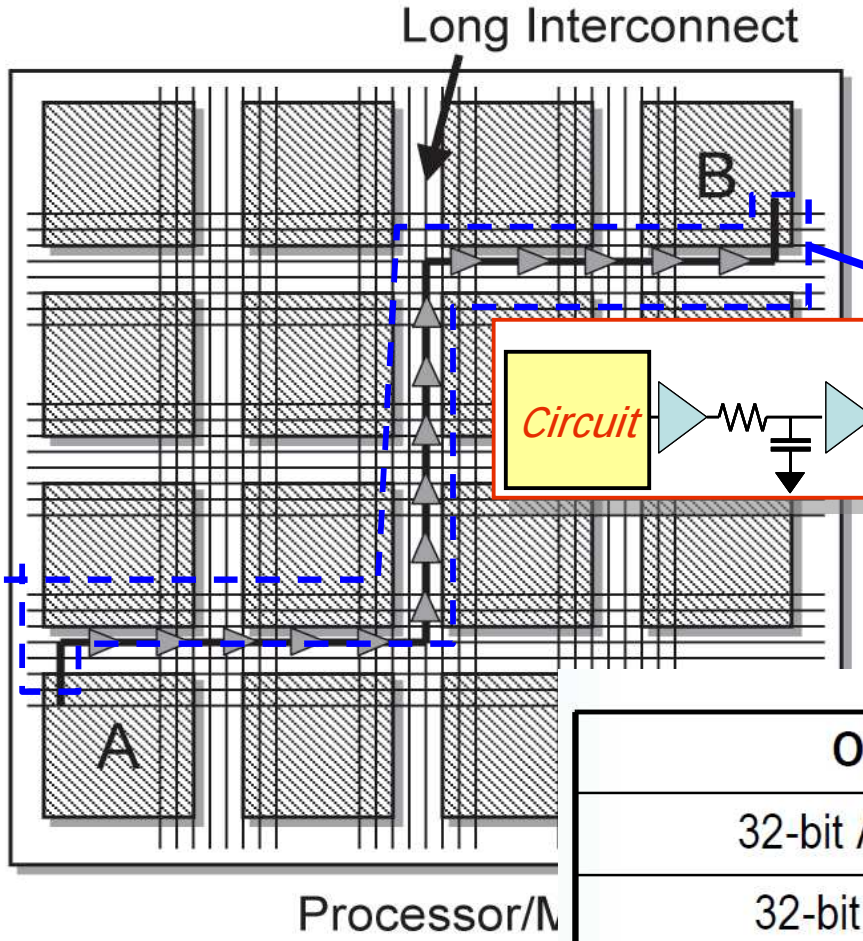


Electrical interconnect, especially global wiring, have to use many repeaters for escaping delay at long interconnect and also at high speed.

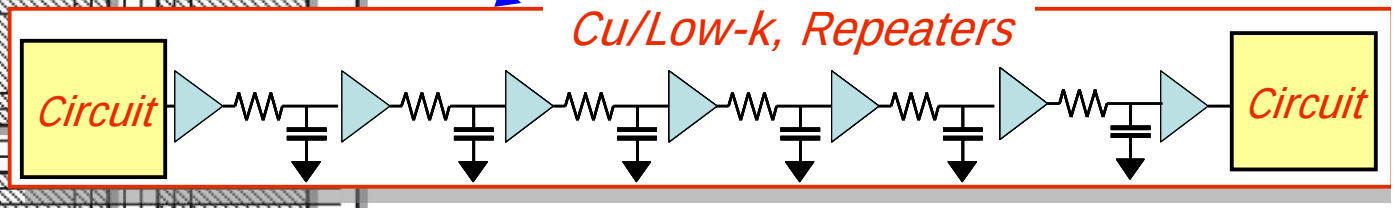
20 mm-interconnects
with repeaters

M. Mizuno et al., ISSCC 2001

Electrical Interconnect



Electrical Interconnect

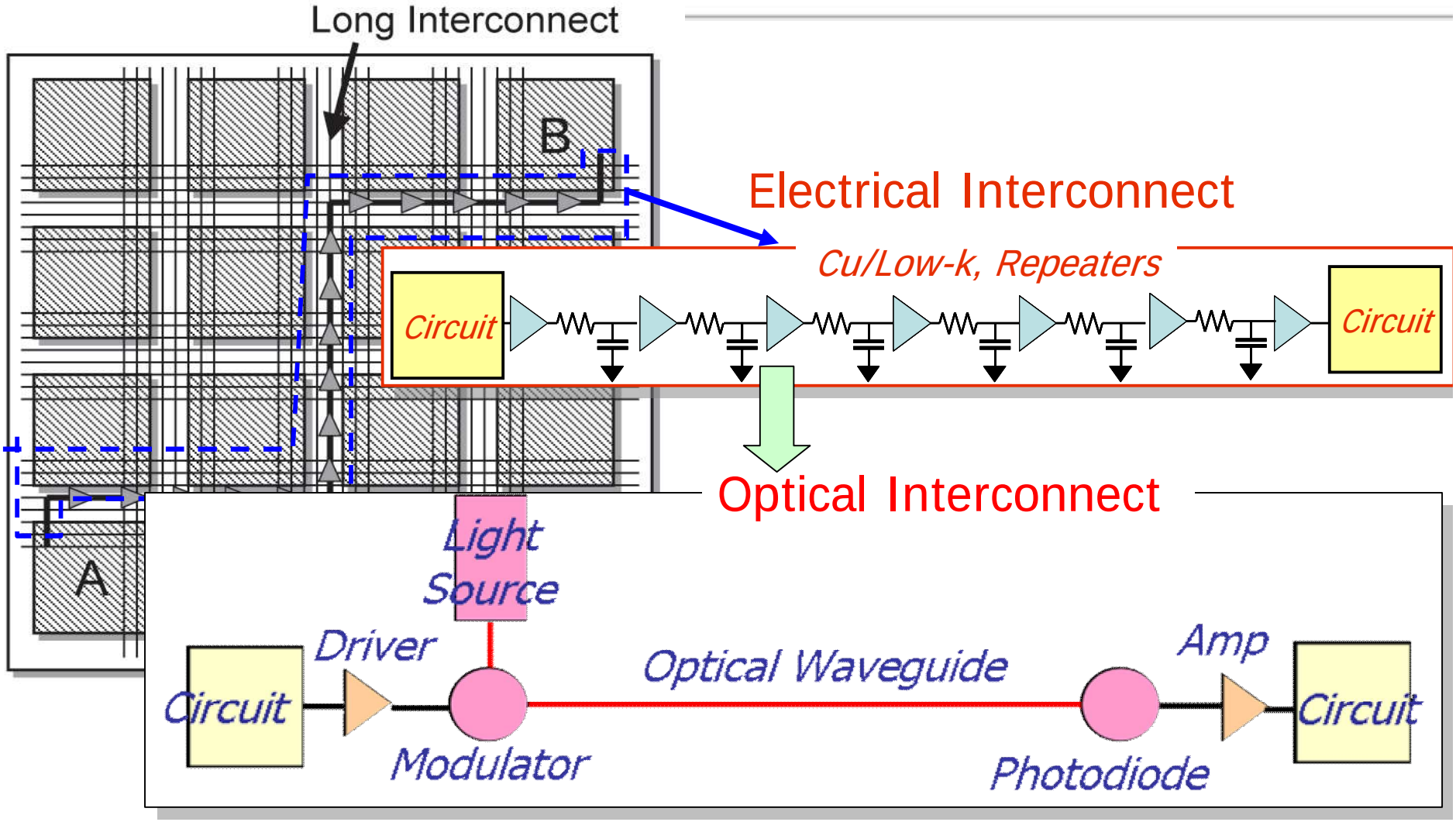


High Power Consumption by Interconnect

Operation	**Energy** (130 nm, 1.2 V)
32-bit ALU operation	**5 pJ**
32-bit register read	**10 pJ**
Read 32 bits from 8K RAM	**50 pJ**
Move 32 bits across 10 mm chip	**100 pJ**
Move 32 bits off chip	**1300 to 1900 pJ**

Bill Dally, ISSCC 2005

From Electrical To Optical



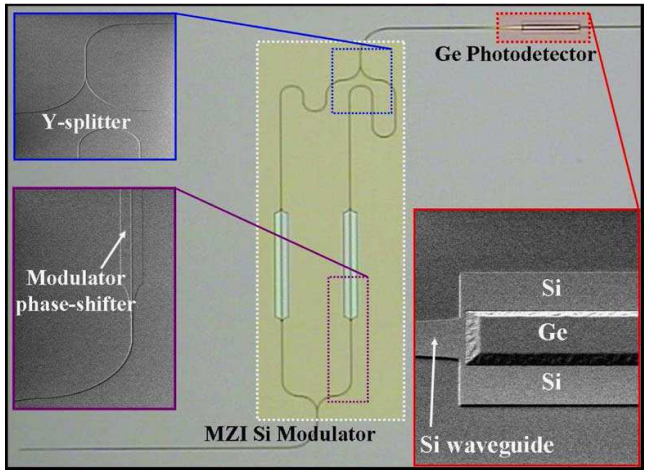
Advantages: **No repeaters, Small delay, Small jitter, EMI, High data capacity, …**
Issues: **Power consumption overhead of EO/OE conversion**

Silicon Phtonics activities in Asia

Si photonics are investigated by using 6 & 8-inch CMOS Lines in Singapore and Shanghai.

- **Institute of Microelectronics, Singapore**

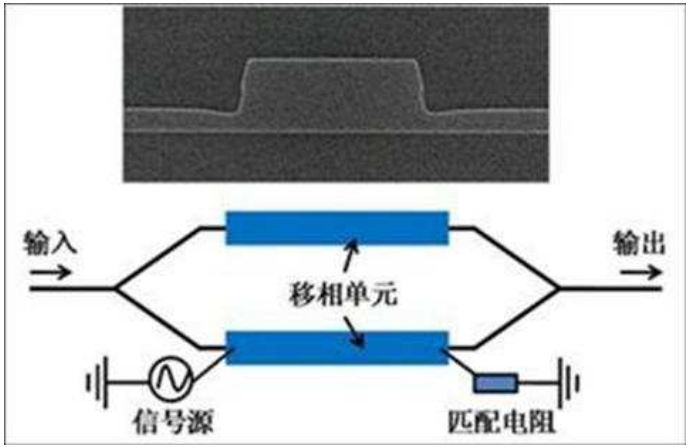
Si modulators and Ge detectors are monolithically integrated.
Si modulator achieves 10Gbps operation at 2-mm-long device.



IEEE Journal of Selected Topics in Quantum Electronics

- **Shanghai Institute of Microsystem and Information Technology (SIMIT) & Institute of Semiconductor, Chinese Academy of Sciences**

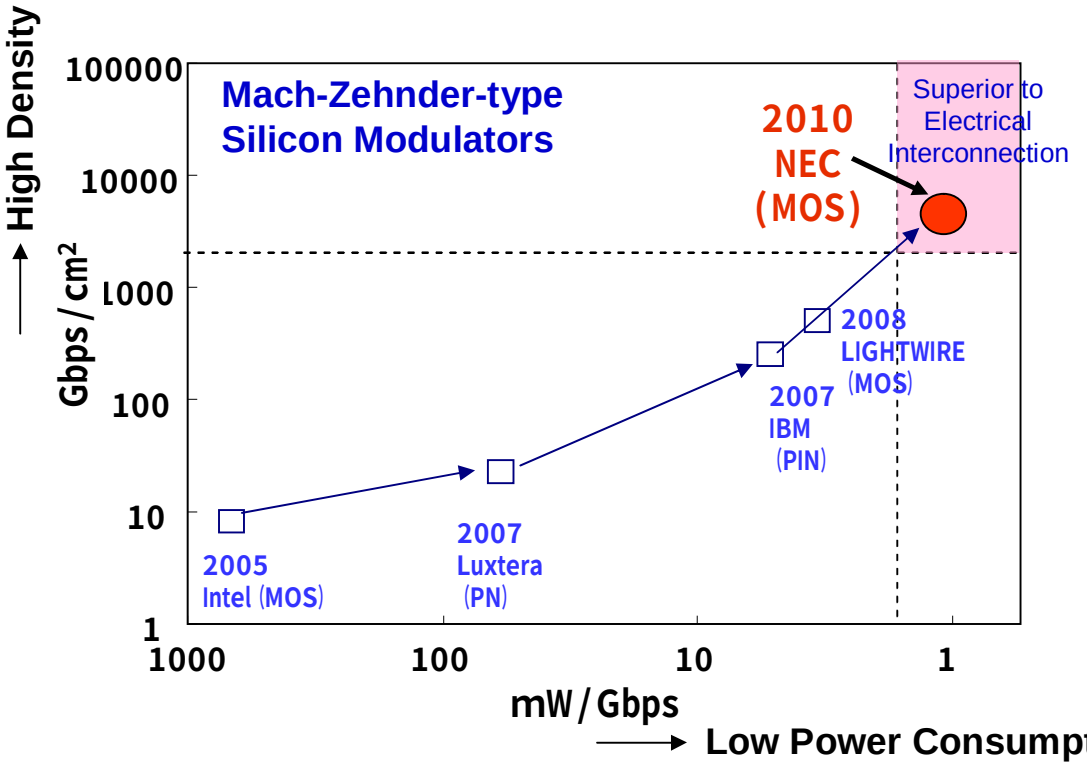
Si modulator achieves 10Gbps operation.



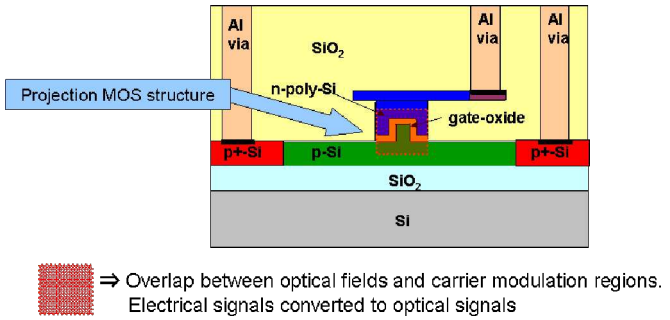
http://www.sim.cas.cn/xwzx/kyjz/201003/t20100323_2804854.html

Small, High-Efficiency and High-Speed Mach-Zehnder-Type MOS-structured Silicon Modulators

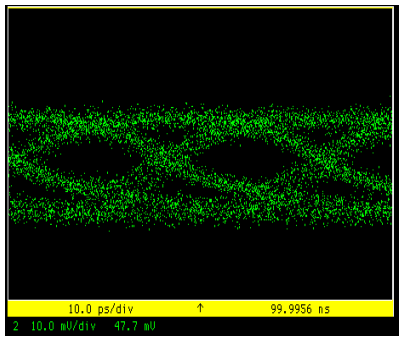
- **Silicon MOS (metal-oxide-semiconductor) optical modulator that boasts a leading power-consumption efficiency of less than 1mW/Gbps, a compact size of 120-μm in length and high-speed operation of 25Gbps.**



Benchmark of Mach-Zehnder-type Silicon Modulators



Cross-section of the Si Modulator

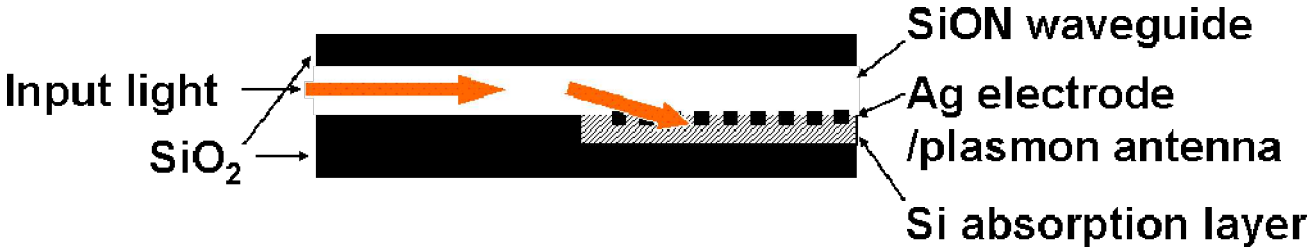


25Gbps Eye diagrams

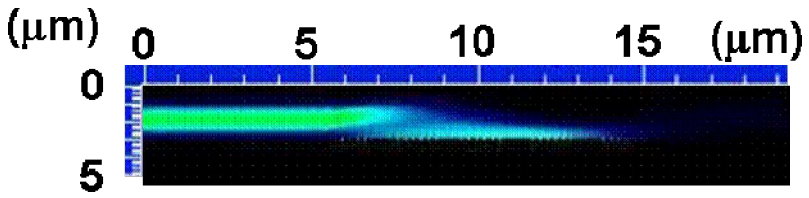
Si nanophotodiode with surface plasmon antenna

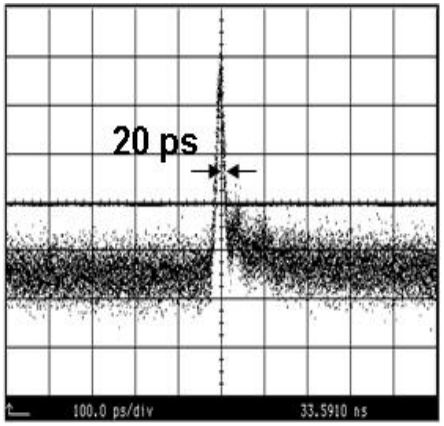
- Ag plasmon antenna assists effective absorption of light in Si from SiON waveguide
- Ultra-small (<10μm), High-speed (>50GHz) & High-sensitivity PD by novel surface-plasmon effects

Si nanophotodiode with surface plasmon antenna



Absorption of light in Si (simulation)





Fastest response in Si-PDs (>50GHz)

Summary

- Nanotechnologies are very important to realize the future sustainable society.
- Nanocarbon, such as CNT and graphene, electronics are useful for printable electronics, large-area electronics
- Nano-material technologies are essential to improve the capacity, stability and reliability for energy and environmental devices.
- Si photonics is one of the key technologies for interconnections in the future IT/NW systems.

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