Nanotechnology in NEC

Jun'ichi Sone

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NEC Corporation

NEC Members

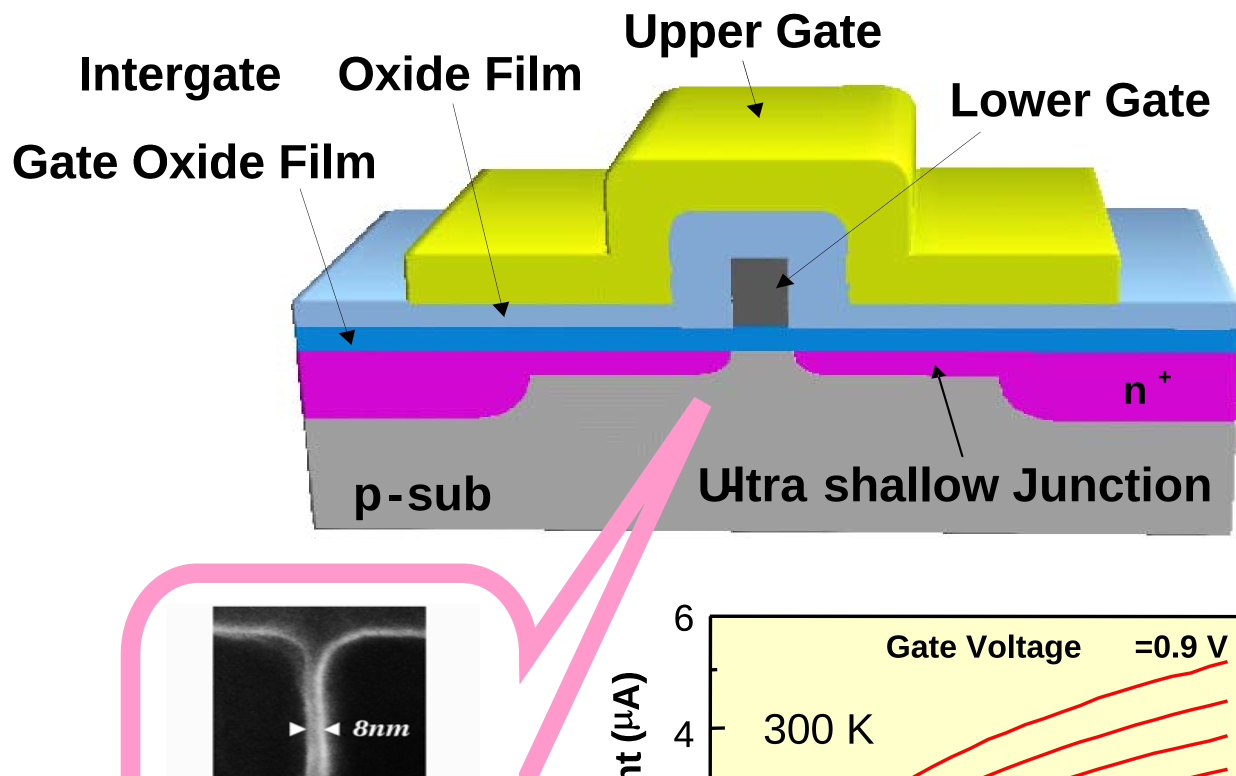
- **T.Baba : Nanoelectronics, CNT electronics**
- **K.Ohashi : Nanophotonics, Spintronics**
- **H.Kawaura : Nanoelectronics, Nanobio technology**

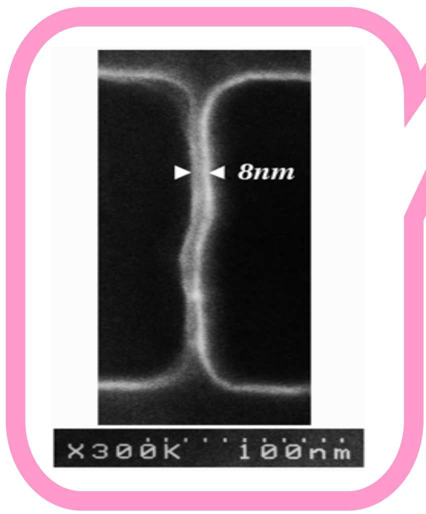
Nanoelectronics

- World’s Smallest MOS Transistors
- Nanofabrication
- NanoBridge
- Carbon Nanotube Applications
- Quantum Bit Devices

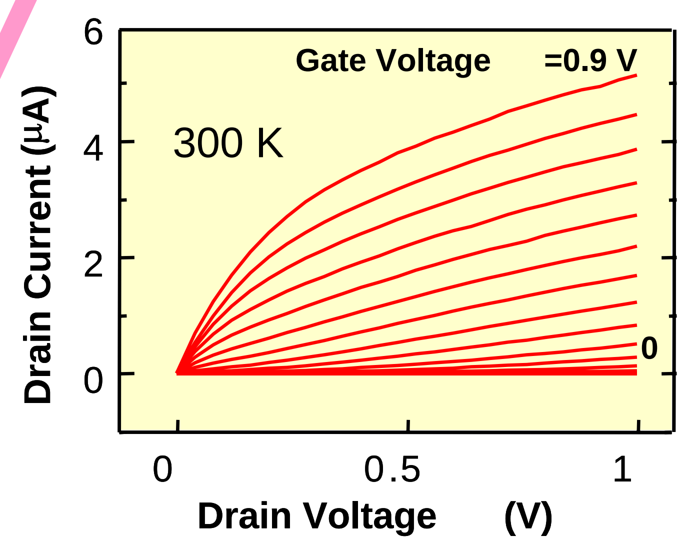
World's Smallest Si MOS Transistor

H.Kawaura,
T.Sakamoto,
et.al.





Electron Micrograph
of 8nm Gate

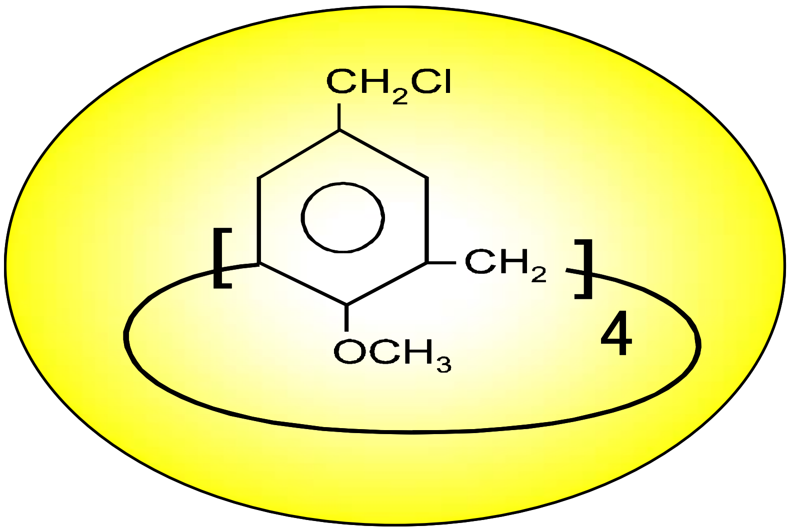


Current -Voltage Characteristic

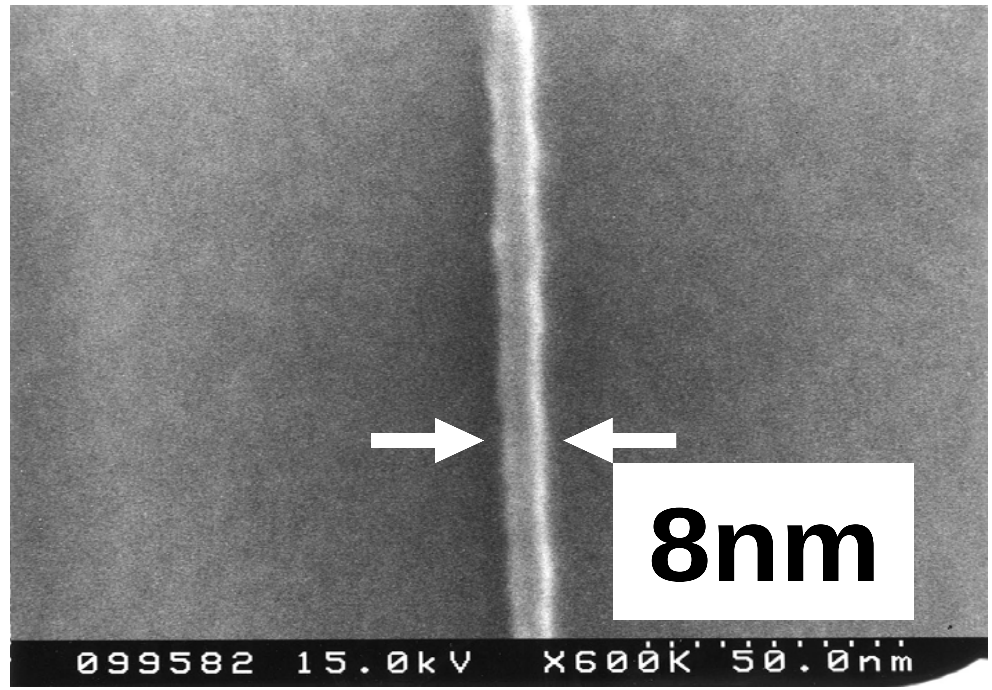
Nanofabrication

Nanofab. Group (Ochiai et.al.)

"10nm-EB lithography with Calix Arene resist"



Molecular Structure for Calix Arene



SEM image of Calix Arene resist pattern

Commercially available from Tokuyama Corp.

- CMOS devices show proper transistor operation by careful design and fabrication even when the gate length is reduced to 5nm. However, we encounter many problems. In particular,

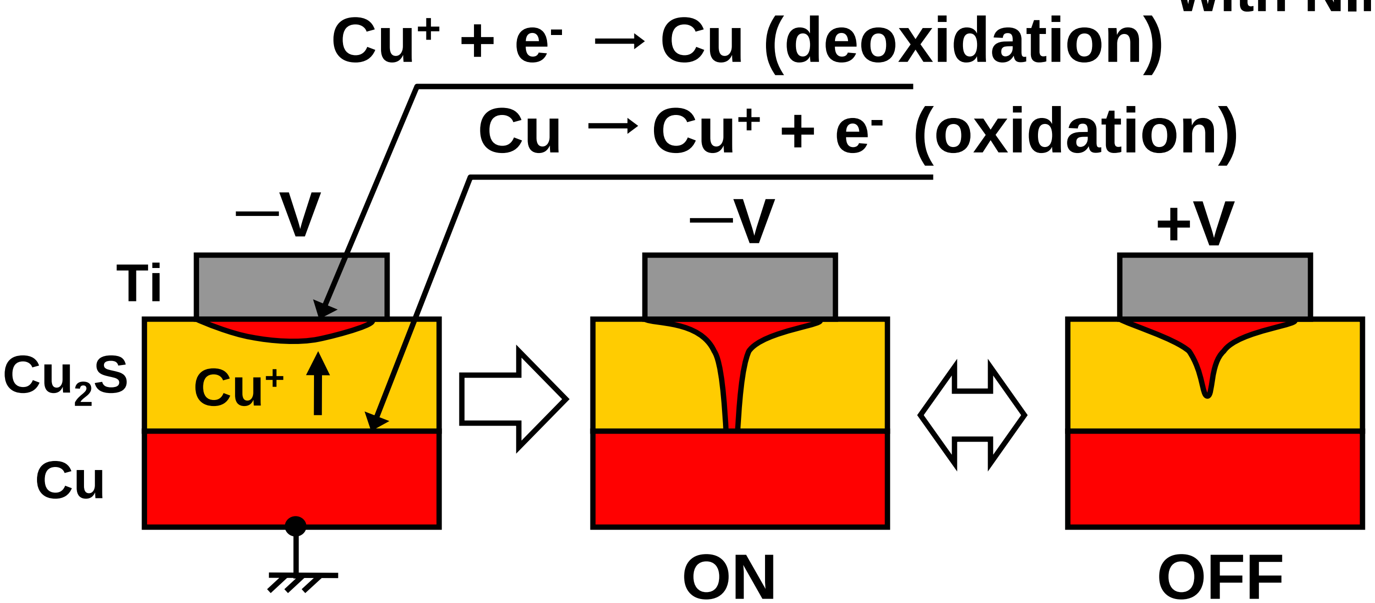
  - ✓Difficulties to suppress the fluctuation of device parameters gate length, impurity profile (number of impurities) and others
  - ✓Difficulties of high-through-put production for small structures with nm-scale or even atomic-scale accuracy
  - ✓Difficultiers of the transistor design due to appearance of quantum effect

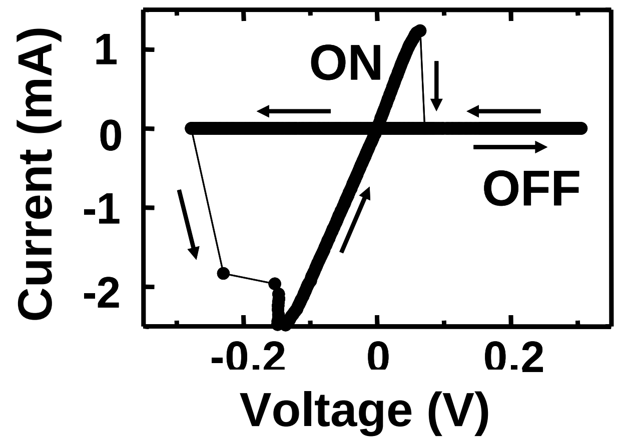
➢ To utilize self-assembled nanostructures, CNTs, metallic nano-pipe structures (NanoBridge), molecular devices and so on.

➢ To utilize quantum effects as an operation principle, Quantum computing devices (Q-bits)

Principle of NanoBridge

T.Sakamoto et al. (APL, 2003)
with NIMS Dr.Aono's Group





- Atom (ion) transfer through solid electrolyte
- Electrochemical reaction on both electrodes

➡ Stretching of metal nanobridge

- Compact ($4F^2$)
- Low ON resistance (<50Ω)
- Scalable (<30nm) ~50ohm
- repeatable (10^3～10^5 times)

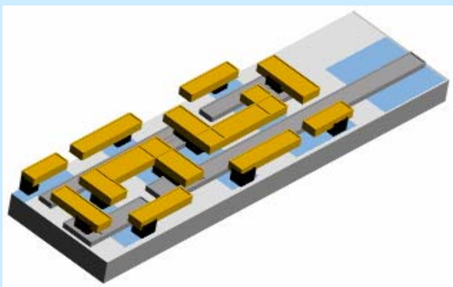
✓ Low switching voltage（0.05～0.2V）
✓ Nonvolatile (>1 month)
✓ ON/OFF ratio (>10^5)

Programmable CBIC

T.Sakamoto et al. (ISSCC2004) with NIMS Dr.Aono's Group

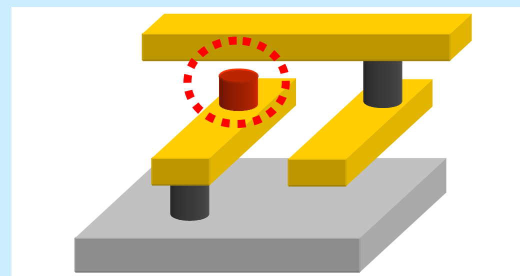
Conventional FPGA switch (SRAM & pass Tr.)

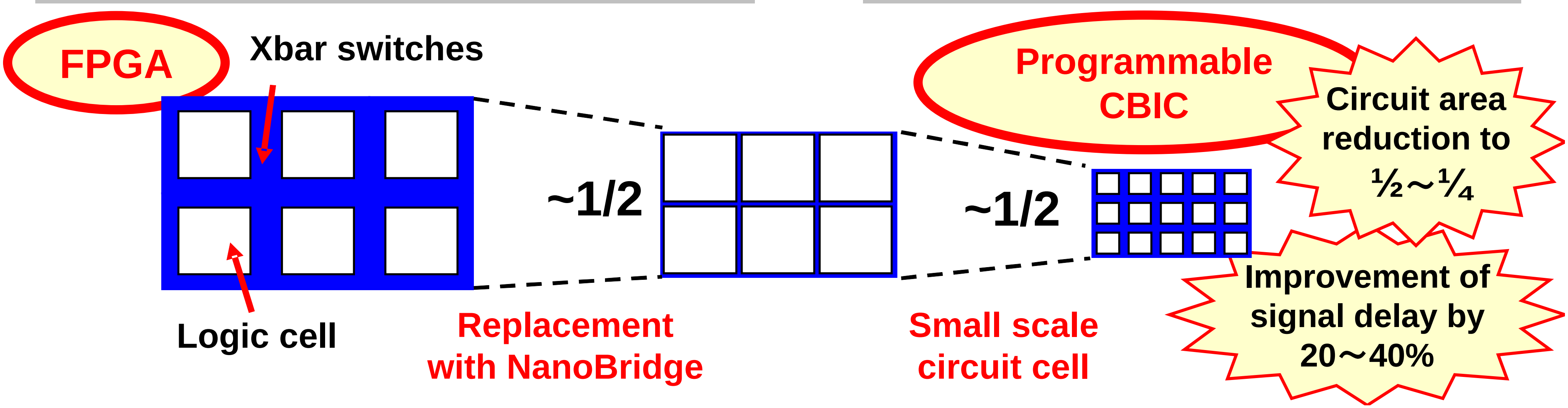
- Huge (120F^2)
- Resistive (2kΩ)
- In logic plane



NanoBridge

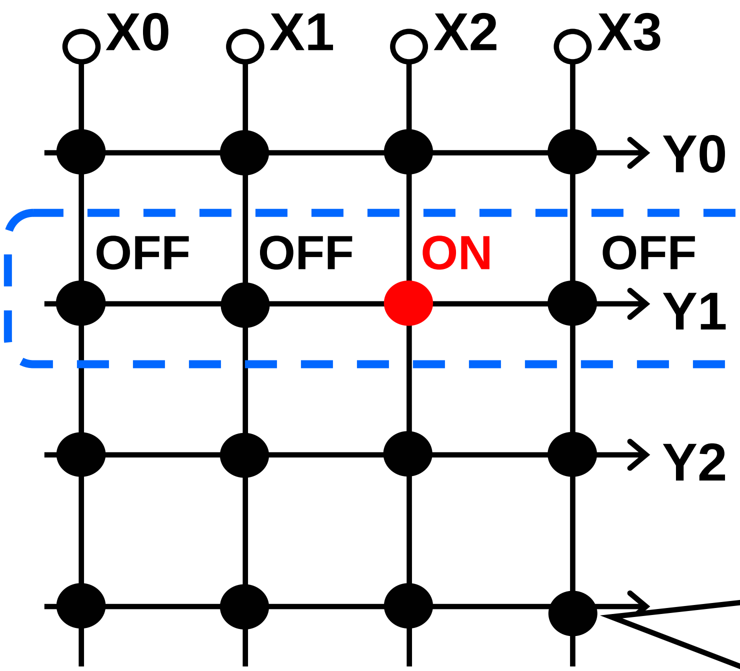
- Tiny (4F^2)
- Low resistive (50Ω)
- On logic plane



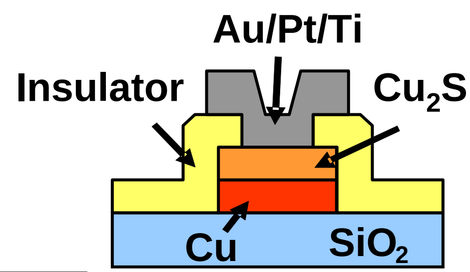


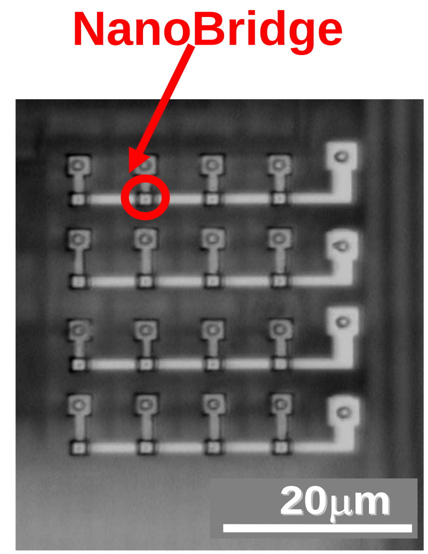
4x4 Xbar switches

Xbar circuit on CMOS substrate

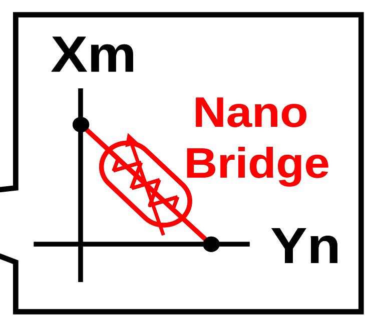


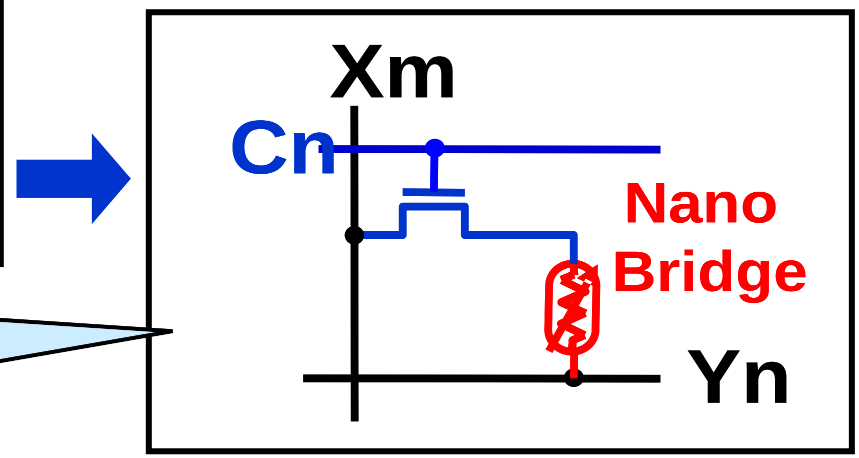
ON/OFF state at each Xpoint is selectable.





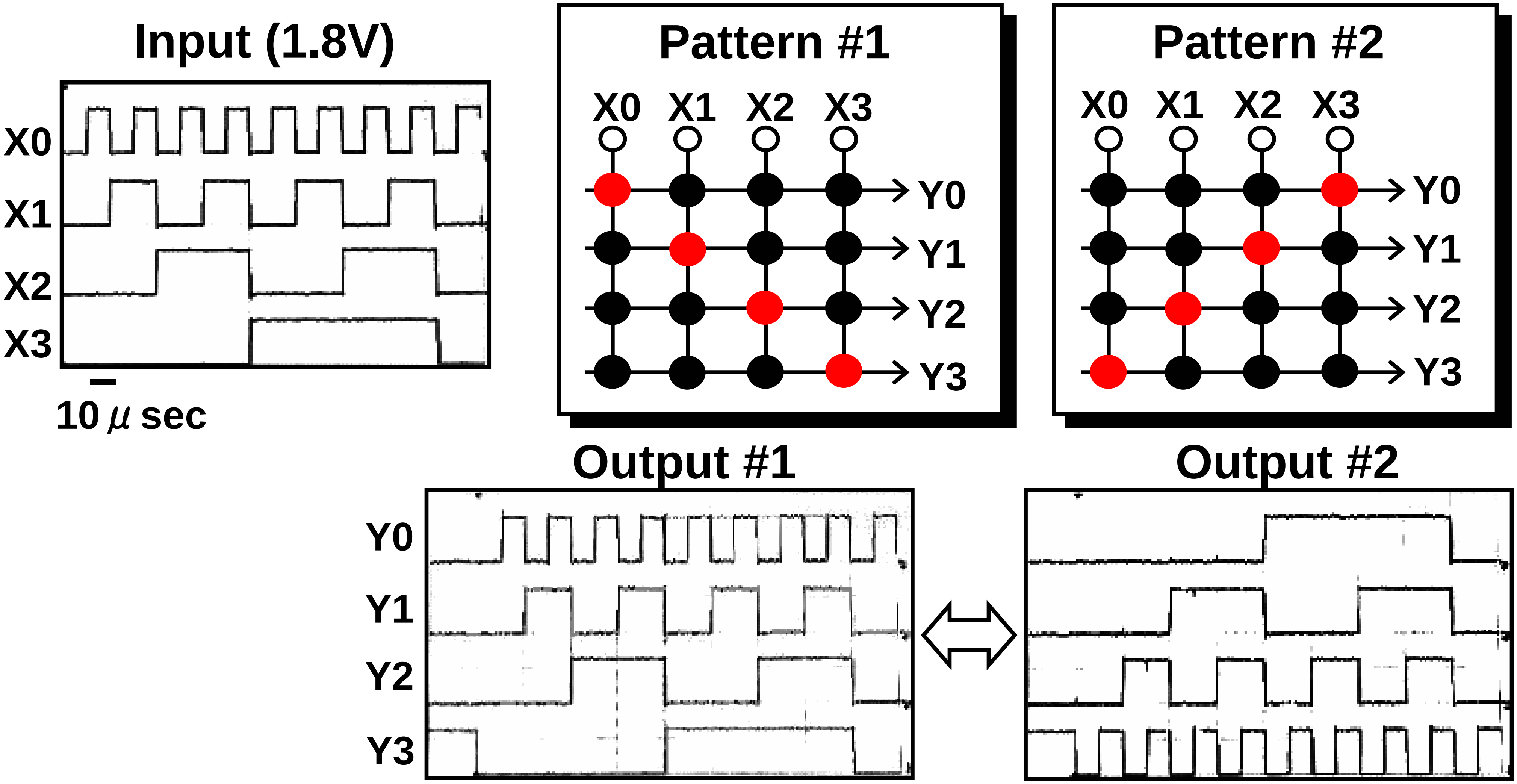
(X0, X1, X2, X3) = (0, 0, 1, 0)
(Y0, Y1, Y2, Y3) = (–, 0, –, –)
(C0, C1, C2, C3) = (0, 1, 0, 0)



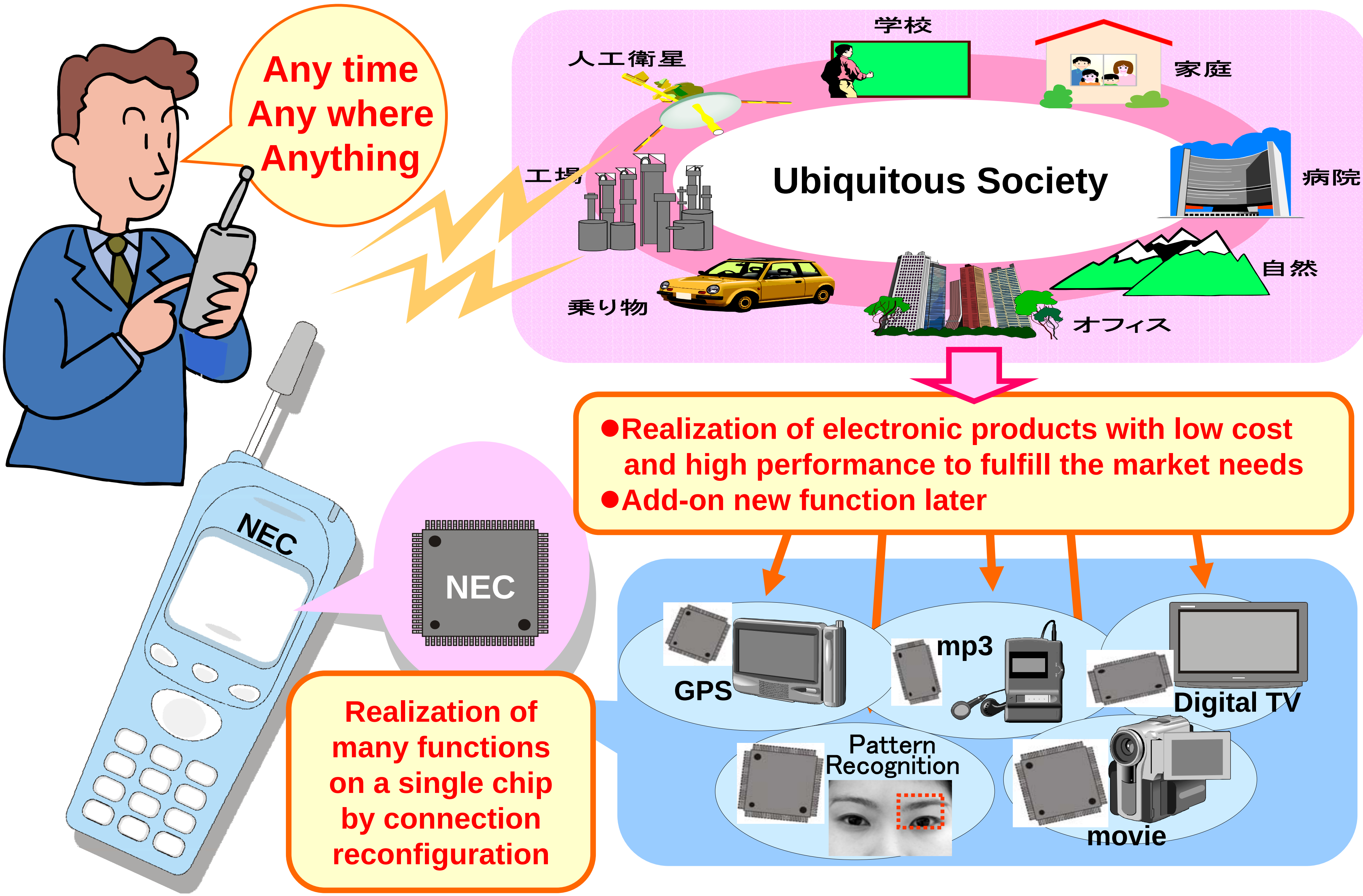


Extra Tr. is used for cell selection because of broad distribution of switching voltage

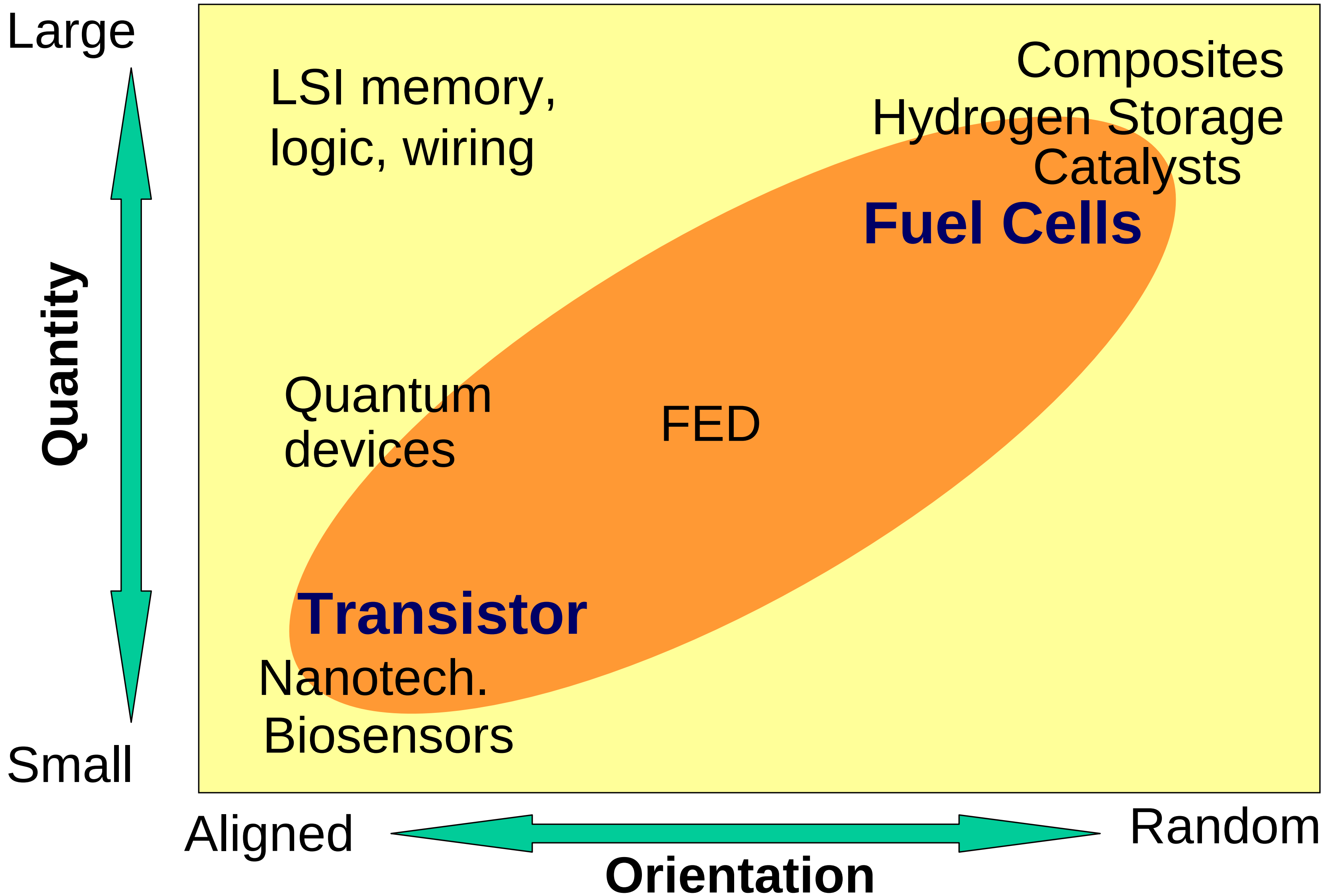
Programming operation of 4X4 Xbar switches



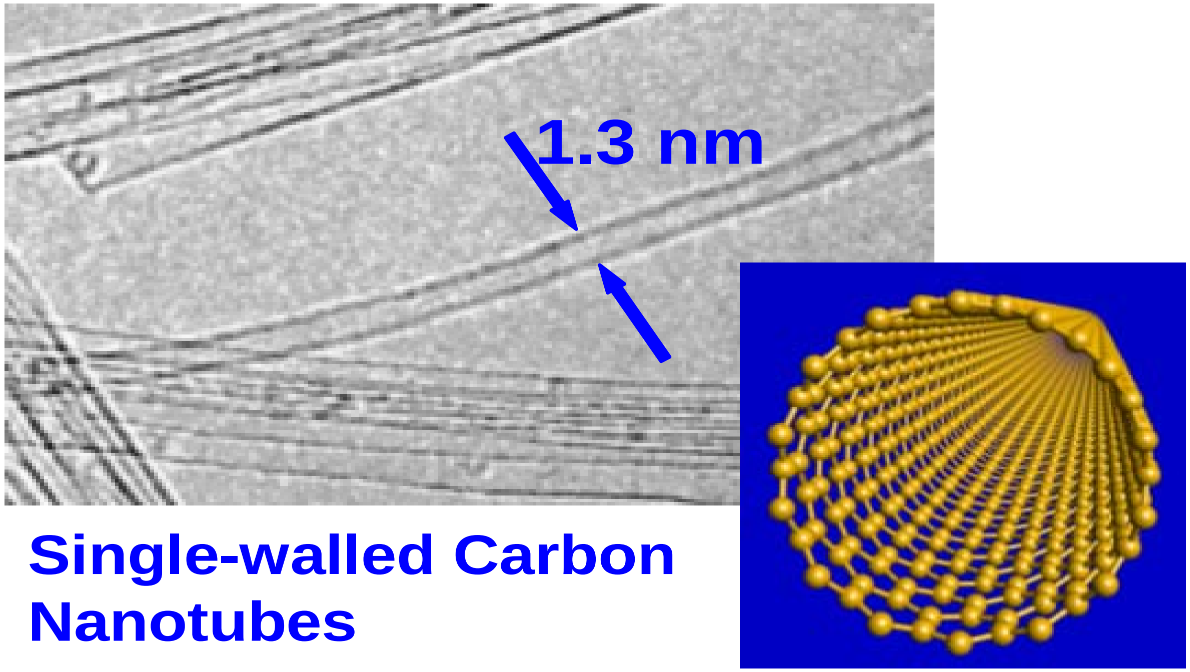
Application of programmable CBIC



Applications of Carbon Nanotubes

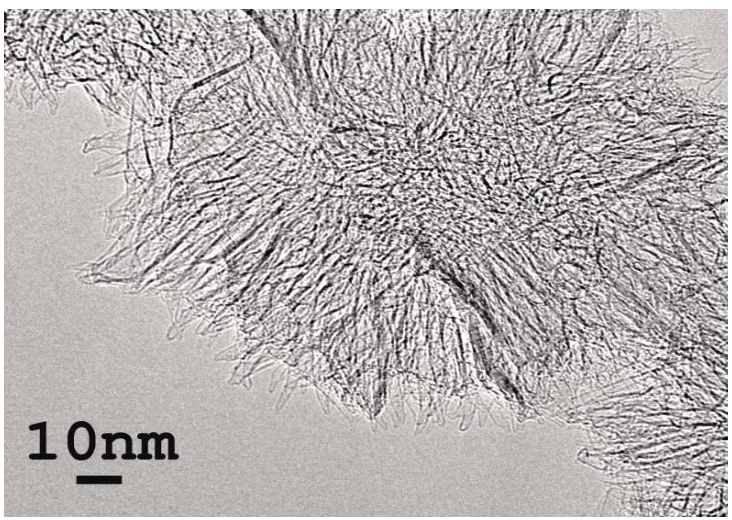


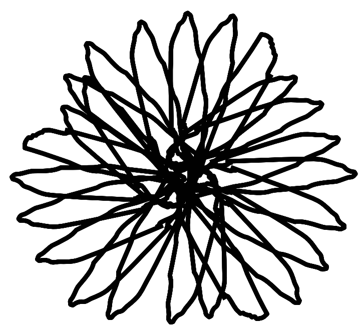
010708b



Iijima, S.
Nature (1993)

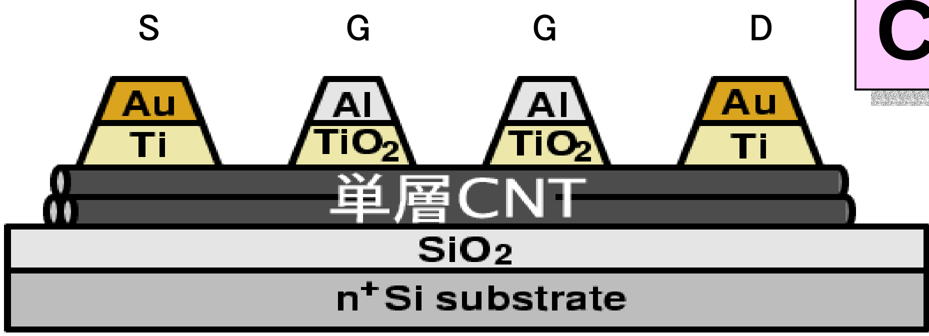
Single-walled Carbon Nanotubes





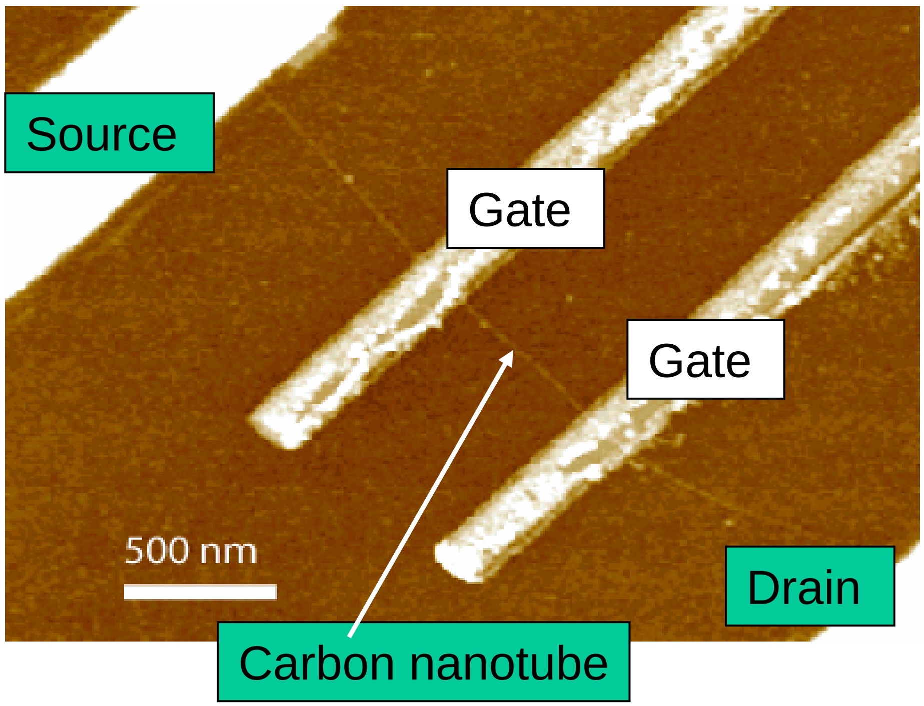
Iijima, S. et al.
Chem. Phys. Lett.
309, 165 (1999).

Single-walled Carbon Nanohorn Aggregate

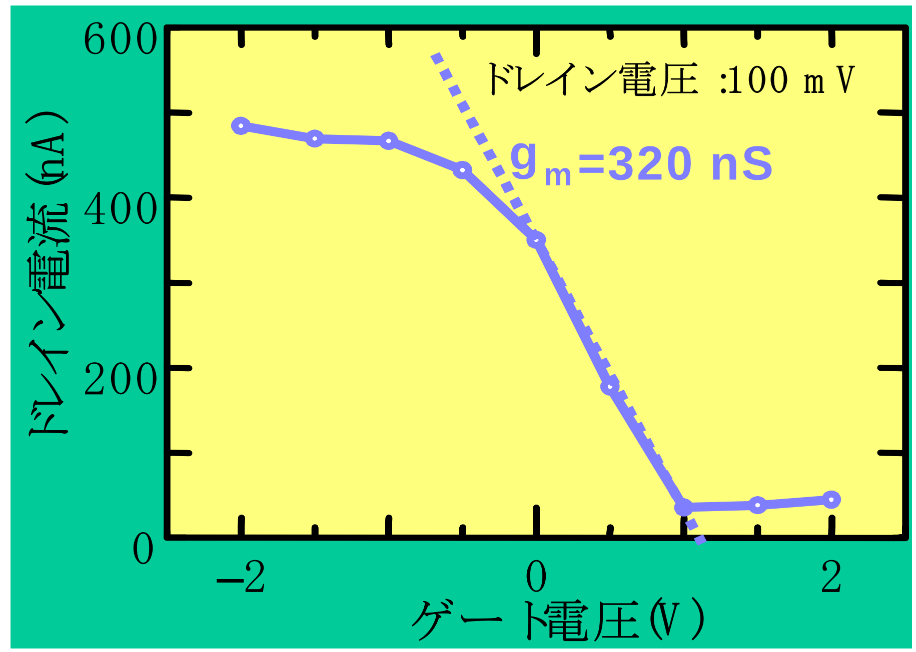


CNT Transistors

F.Nihey et al.



"Excelling present Si transistors in performance"

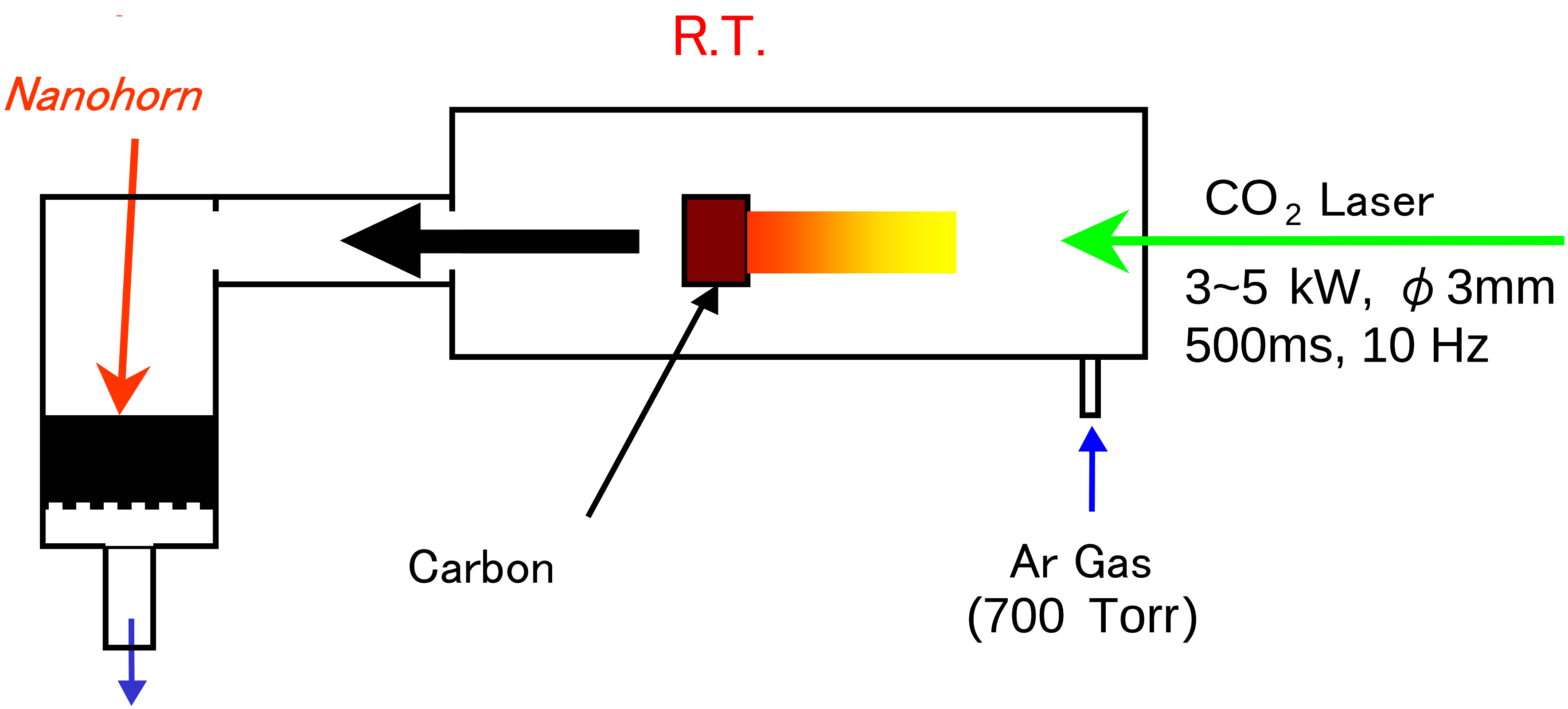


Carbon Nanotube Transistor Structure Model, Scanning Probe Micrograph Image, Transistor Characteristics

Fabrication of Single Wall Carbon Nanohorn

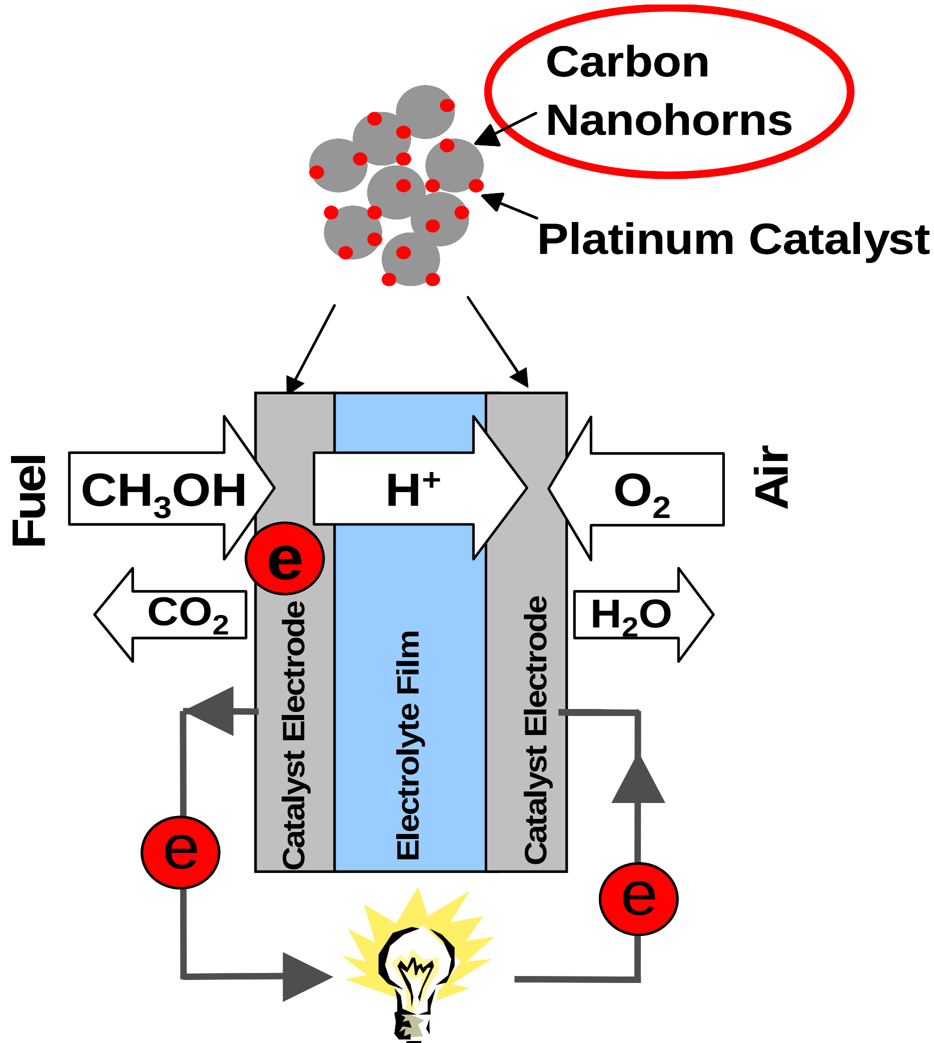
Iijima, Yudasaka, et.al.

Laser Ablation (Iijima Group, JST)

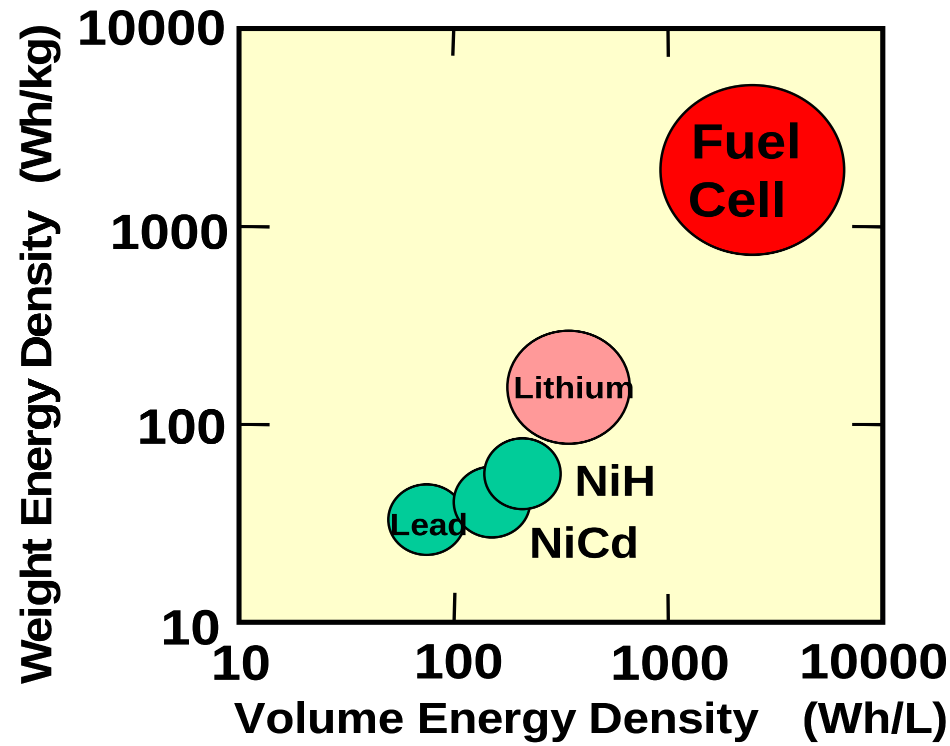


Carbon Nanotube Fuel Cells

CNT Technologies Group
(Y.Kubo et.al.)

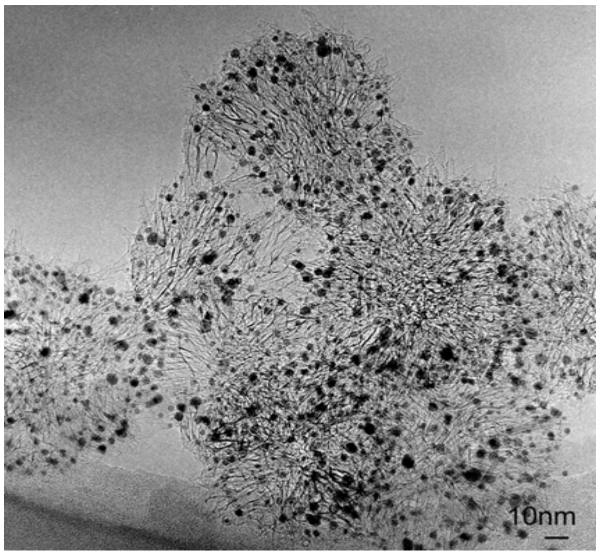


Principle Diagram of Portable Fuel Cell

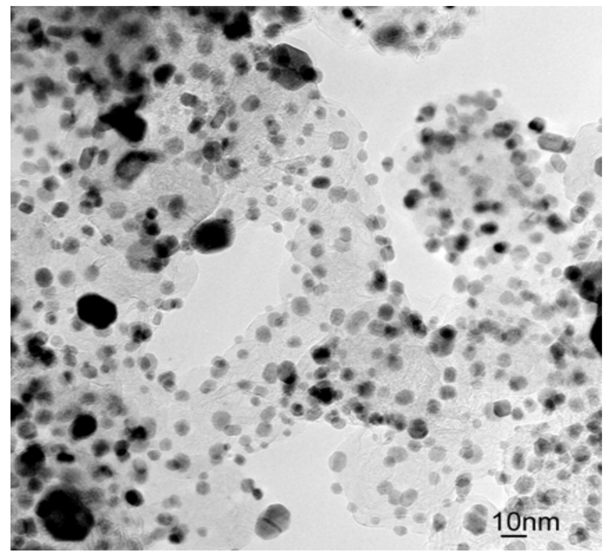


TEM images of Nanohorn with Pt catalyst

Carbon nanohorn



Conventional carbon material
(acetylene black)



※ Black particles : Pt catalyst

- Finer Pt catalyst is dispersed homogeneously on the surface of carbon nanohorns
- Finer particles have better catalyst capability

Note PC with DM-Fuel Cell inside

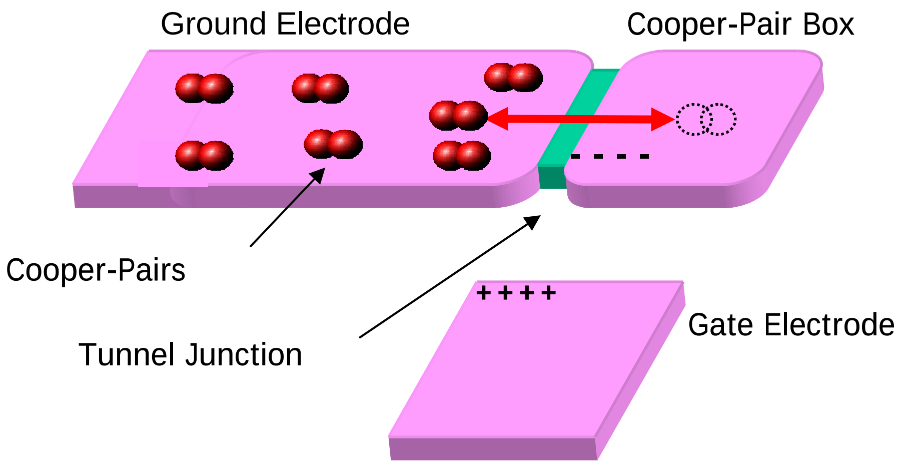
Demonstration of the operation in 2003 World-PC in September, 2003.

CNT Technologies Gr.
(Y.Kubo et.al.)

Quantum-Bit Device for Quantum Computer

Tsai, Nakamura, Yamamoto, Pashkin*, Astafiev* **(* RIKEN)**

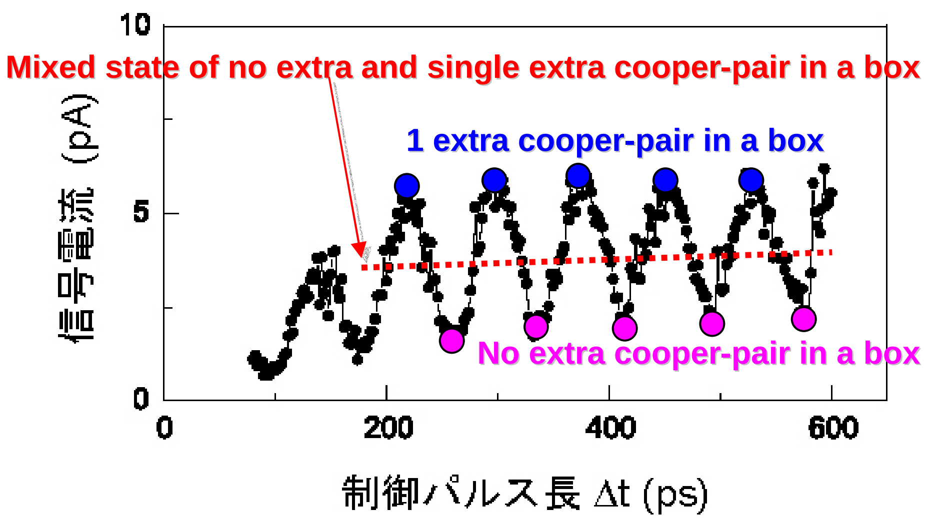
Nature, 30 Oct., 2003



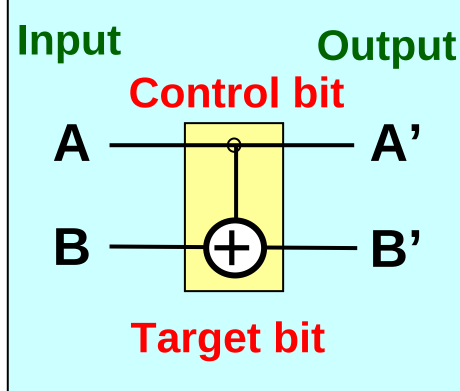
Superconducting quantum bit

Possible high-speed computing

Factoring,
Date search,
Quantum-simulation,
NP problems



Quantum coherence control

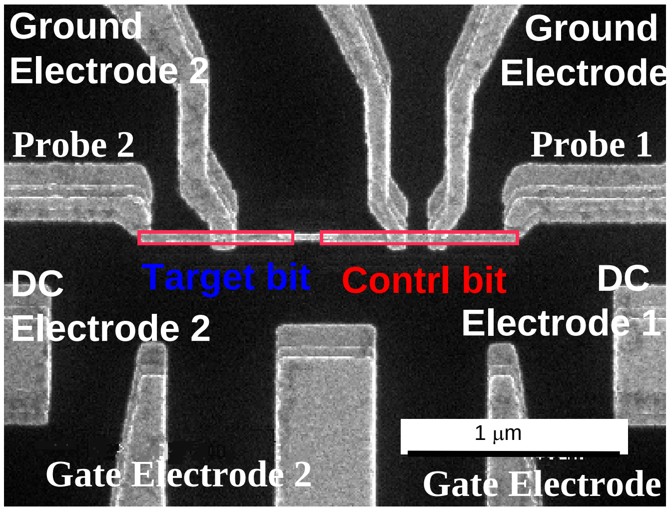


Input		Output	
A	B	A'	B'
0	0	0	1
0	1	0	0
1	0	1	0
1	1	1	1

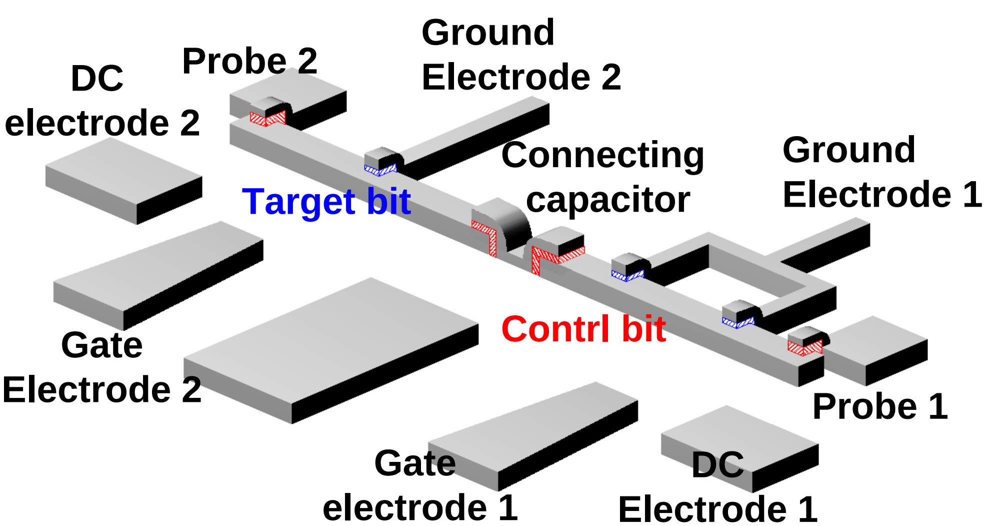
Logic operation truth table for C-NOT gate

Operation Principle of C-NOT Quantum Bits

SEM of C-NOT Gate

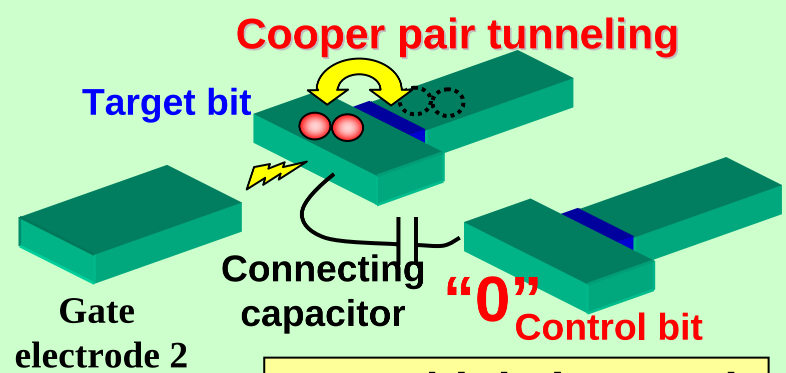


Scematics of the device



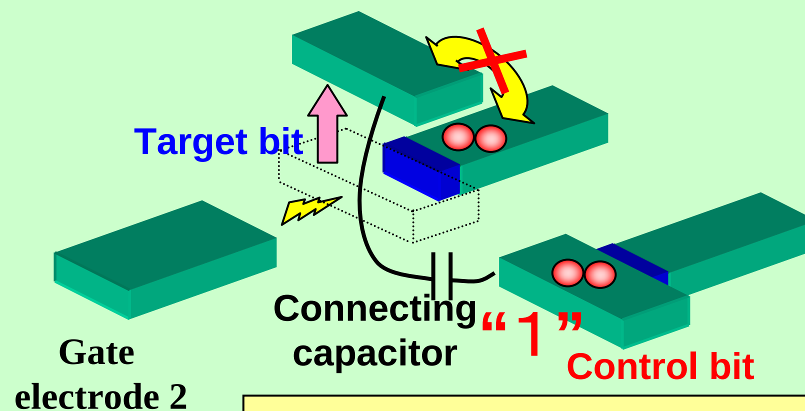
Inverting of target bit only when control bit is "0"

When control bit is "0",



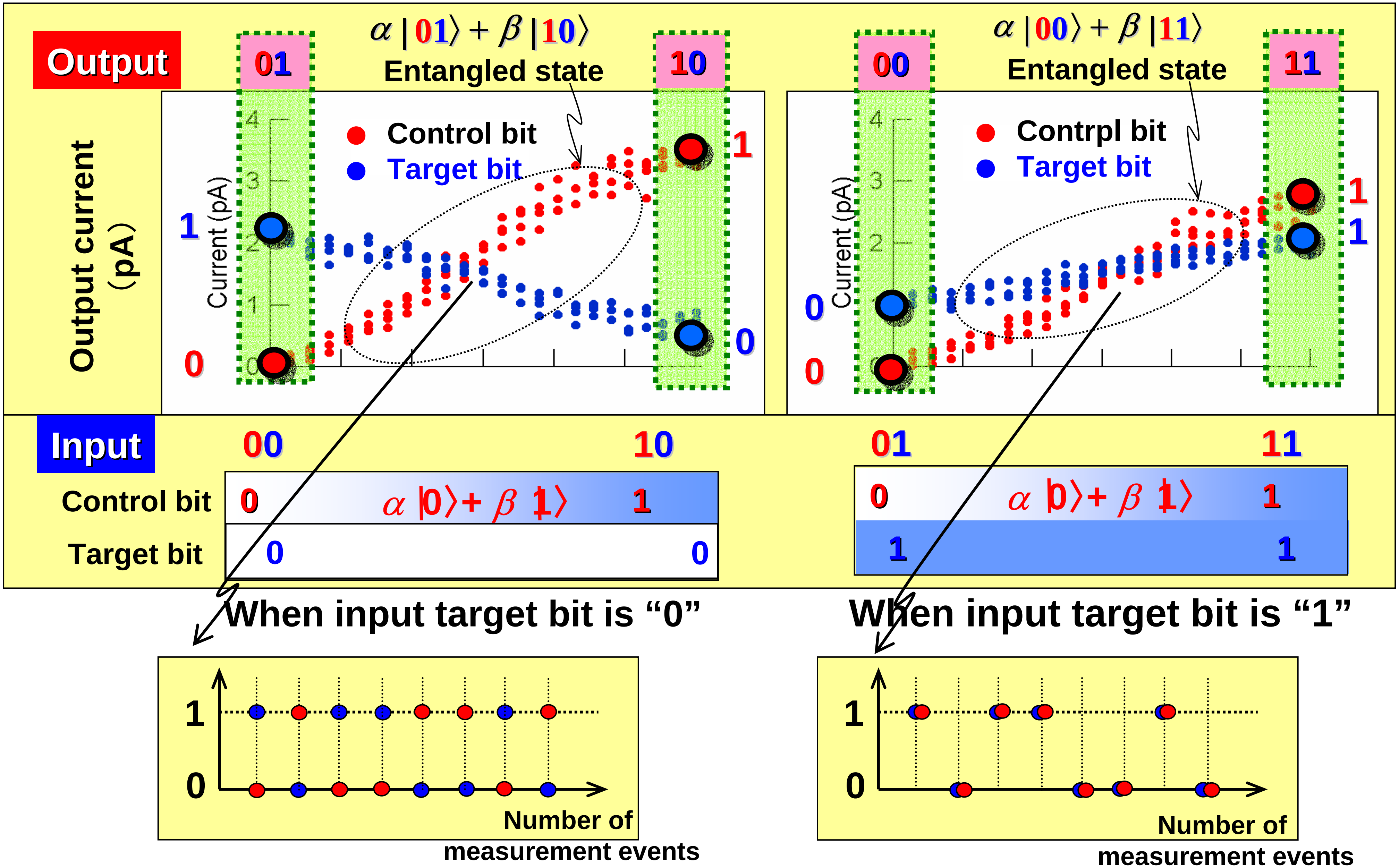
Taget bit is inverted

When control bit is "1",



Taget bit is not inverted

Experimental results of C-NOT gate operation



Nanobio Technology & Nanophotonics

- DNA and Protein Separation by Nano-Pillar Gel
- Surface Plasmon Technology

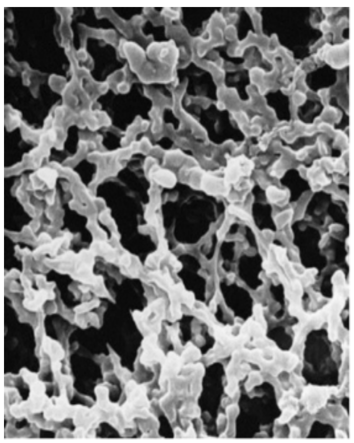
Nanobio Technology

Kawaura et.al.

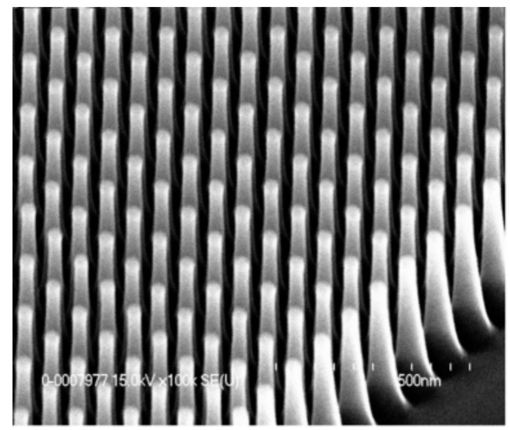
DNA and Protein separation by using nano-pillar gel

● **High-resolution separation of DNAs and proteins by using artificial gel fabricated by nanotechnology → health care chip**

DNA (100- or more several ten nm), and protein (several ten nm)



natural gel (random)



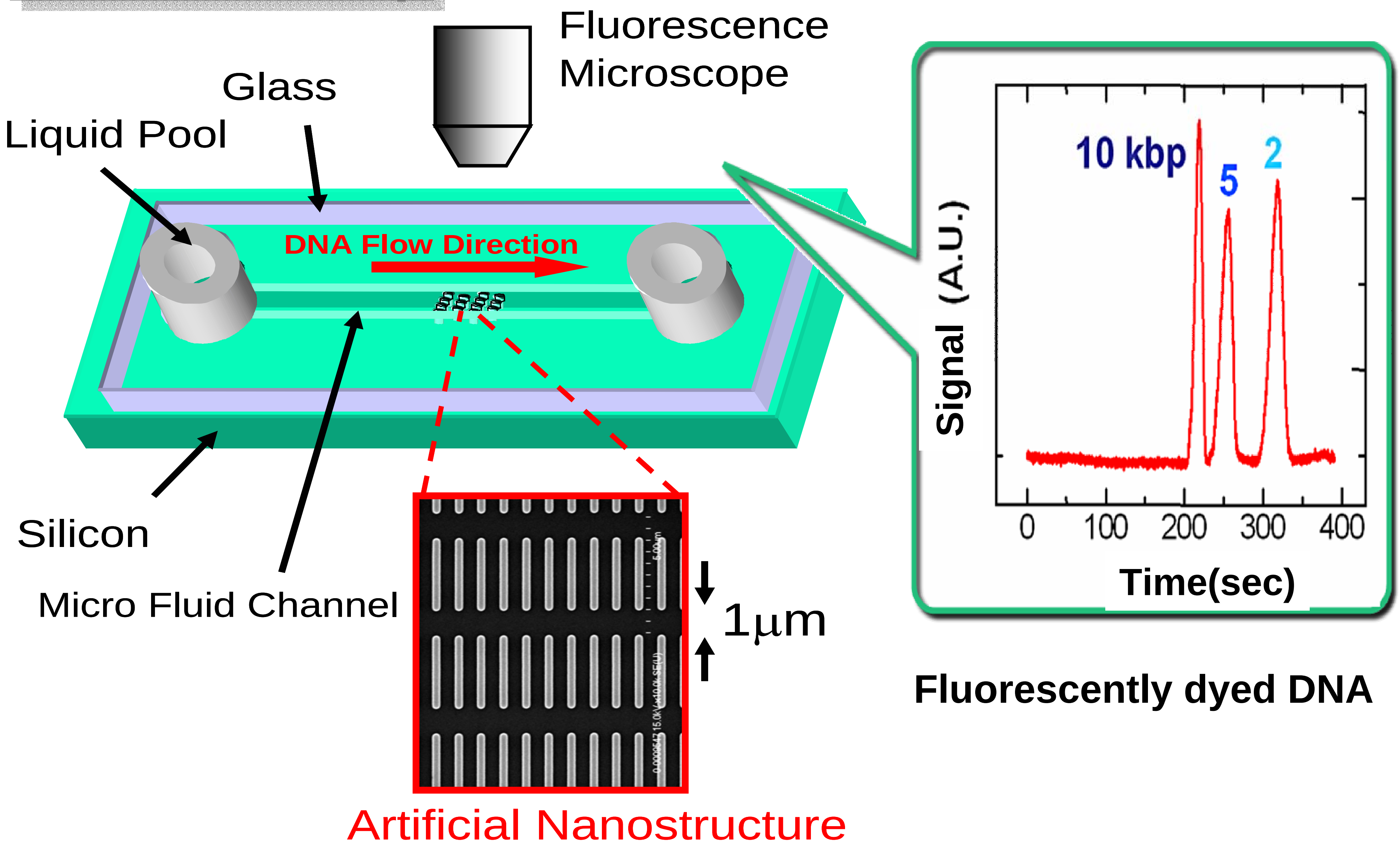
artificial gel (uniform)
with 200nm diameter

◆ **Features**

High through-put, high resolution, and high reproducibility

Control of dynamic range and separation band by the design

Nanobio Chip



DNA Size-Separation Chip with Artificial Nanostructure

Surface Plasmon Technology

news and views

Photonics

More than transparent

Roy Sambles

So you thought your microwave oven couldn't radiate through the mesh of metal on the windowed door? Experiments tell us that hardly any radiation penetrates a metal plate with holes of diameter smaller than the radiation's wavelength. But it appears, from new experiments reported by Ebbesen and co-workers on page 667 of this issue[1], that such metal grids may not be as impervious to radiation as we had believed. Silver is an excellent conductor of electricity and so should screen out radiation very effectively, yet Ebbesen *et al.* found that thin, perforated silver films deposited on quartz are remarkably transparent. There is strong and selective transmission of radiation with wavelengths greater than the hole diameter.

Why should this be? Crucially, the structure is not just a random array of holes in the silver film but a regular, periodic two-dimensional grating structure (Fig. 1). The

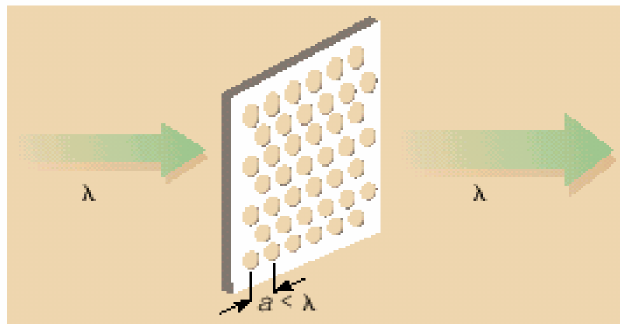


Figure 1 **The phenomenon described by Ebbesen *et al.*[1]. Holes in a metal screen with a diameter less than the radiation wavelength, arranged in an array with a periodicity that is also less than the radiation wavelength, can selectively transmit normal-incidence radiation.**

is only possible with no deflection) for radiation of wavelength λ above 0.6 to 1.8 μm on the air side (0.88 to 2.6 μm on the quartz side). Remarkably, the 0.6-μm-spaced square-array grating transmits very strongly at 0.96 μm —

in similar metal mono- and bi-gratings[2,3], but this seems to be the first observation of selective transmission. The explanation for this extraordinary behaviour appears to rest with the excitation of surface modes called surface plasmons. These are oscillating electromagnetic fields, strongly localized at the surface of a metal on which there are associated charge oscillations.

On a flat plate, an incident photon can only be converted to a surface plasmon (or vice versa) if it has the same momentum (equivalently, wave number, $1/\lambda$) parallel to the surface, and the same energy. So a normal-incidence photon cannot excite a surface plasmon. But scattering of plasmons from a periodic array of holes allows the excitation of the surface plasmon resonance, because diffraction allows the addition of multiples of the wave number to the in-plane wave number (for normal incidence this is zero).

The lowest-momentum surface plasmon (hence, lowest energy radiation, or longest wavelength) to be excited in this way has exactly the wavelength of the grid. Higher-momentum components demand higher-energy, shorter-wavelength radiation, which

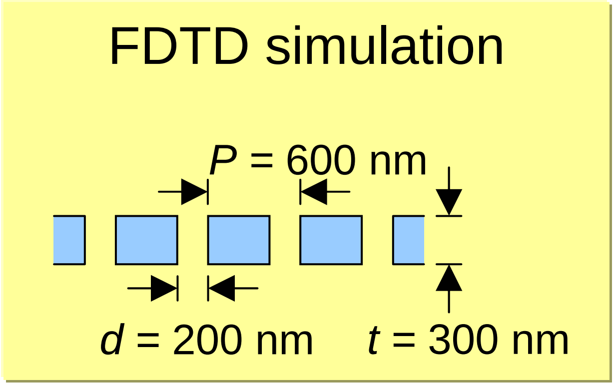
Nature, vol. 391, p. 641, 12 Feb. 1998

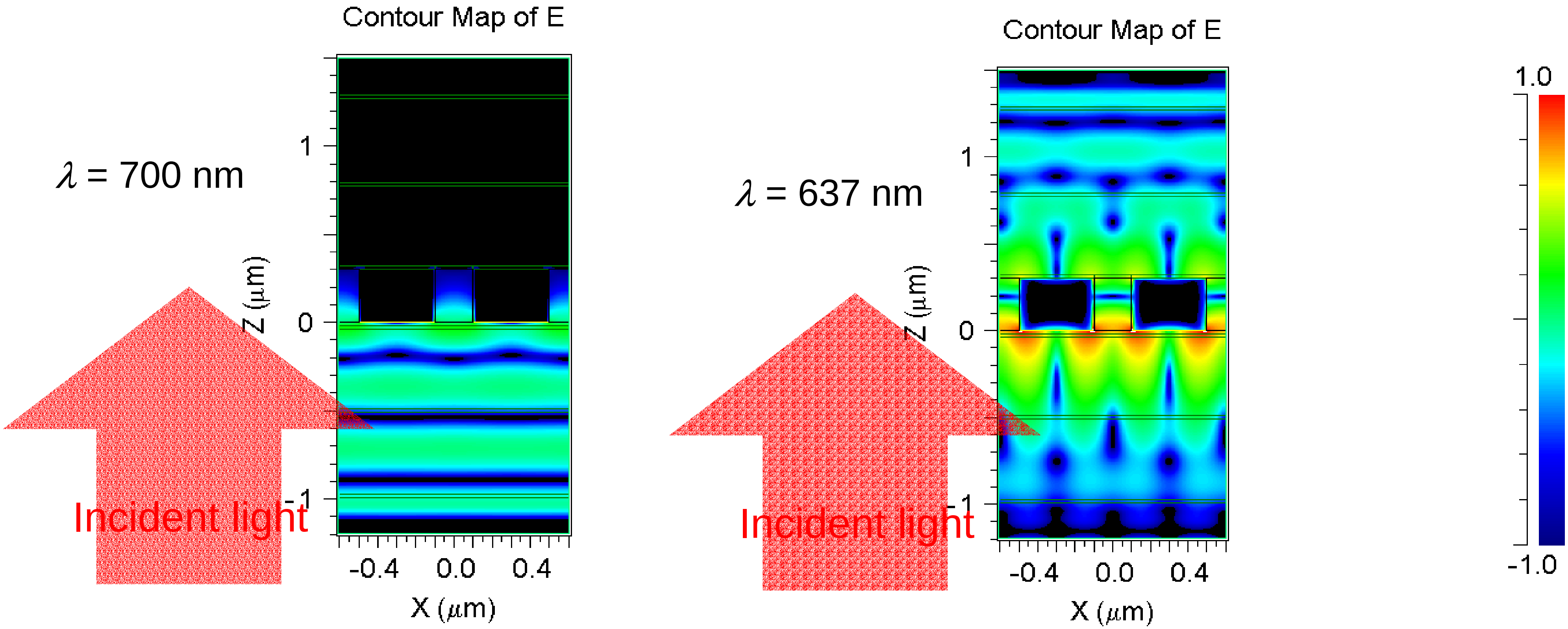
Ebbesen et.al.
(presently, Leus Pastuer University)

NEC

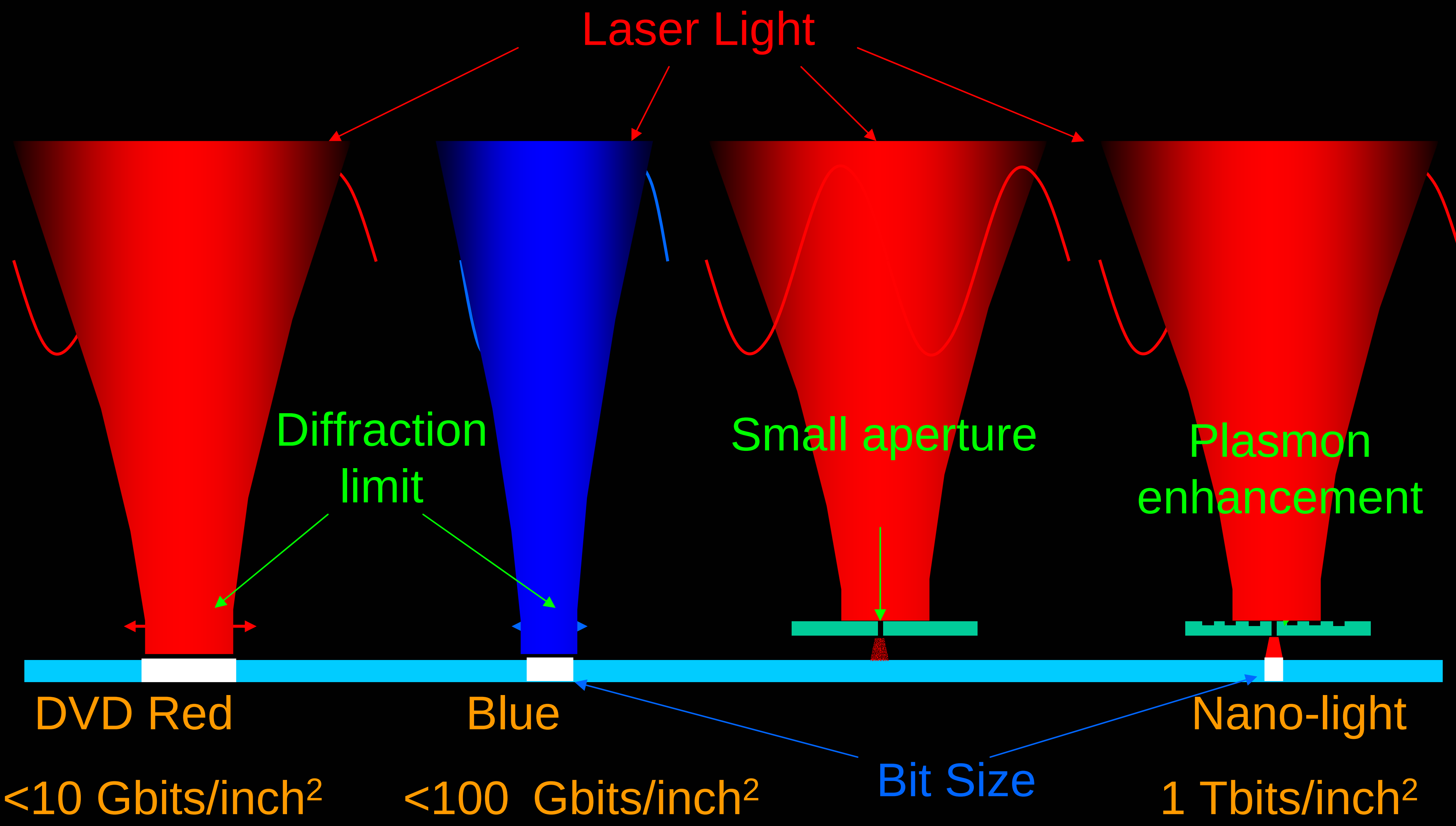
Enhancement of photon tunneling

Ohashi. et. al.



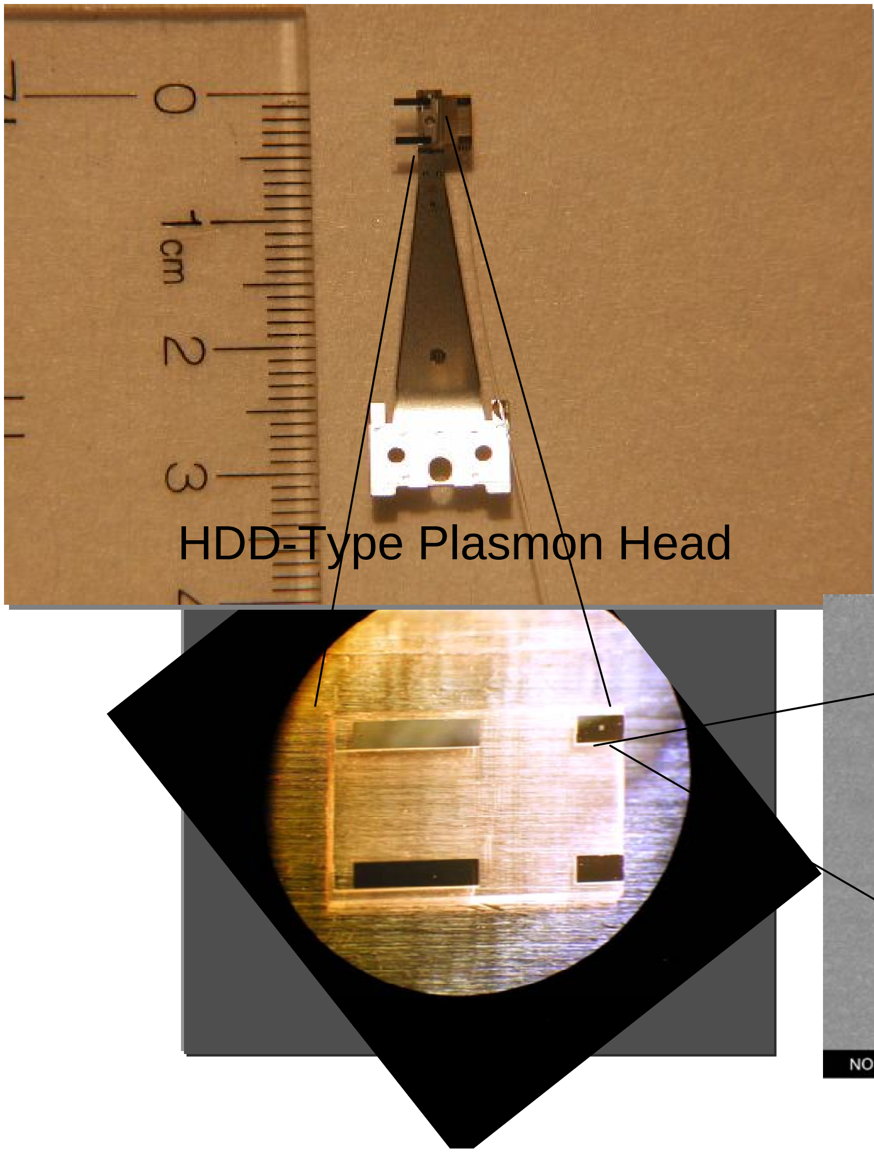


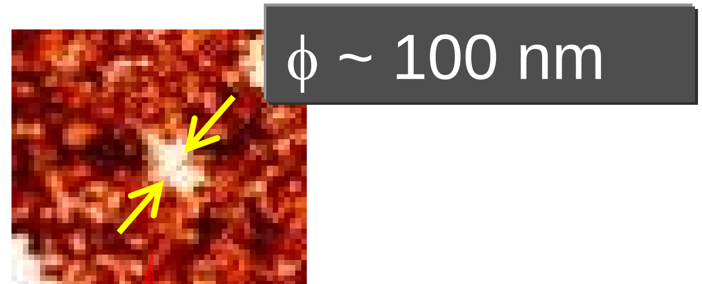
Concept of Nano-light Recording



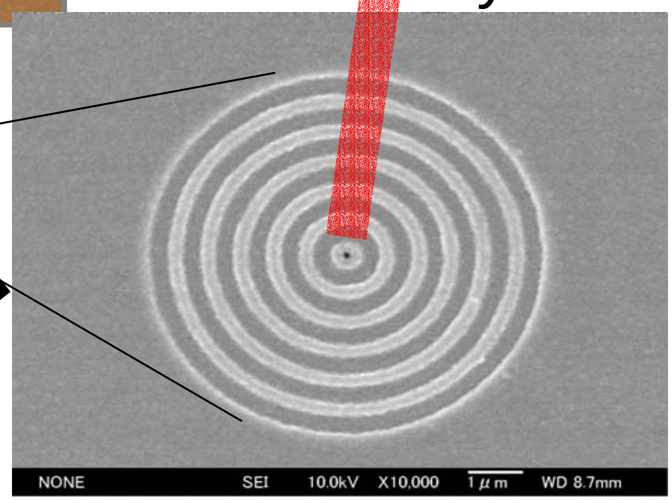
Near-Field Recording by Plasmon Head

Strong near-field light from a nano hole





Pits are recorded on a DVD medium (GeSbTe) by near-field light.



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