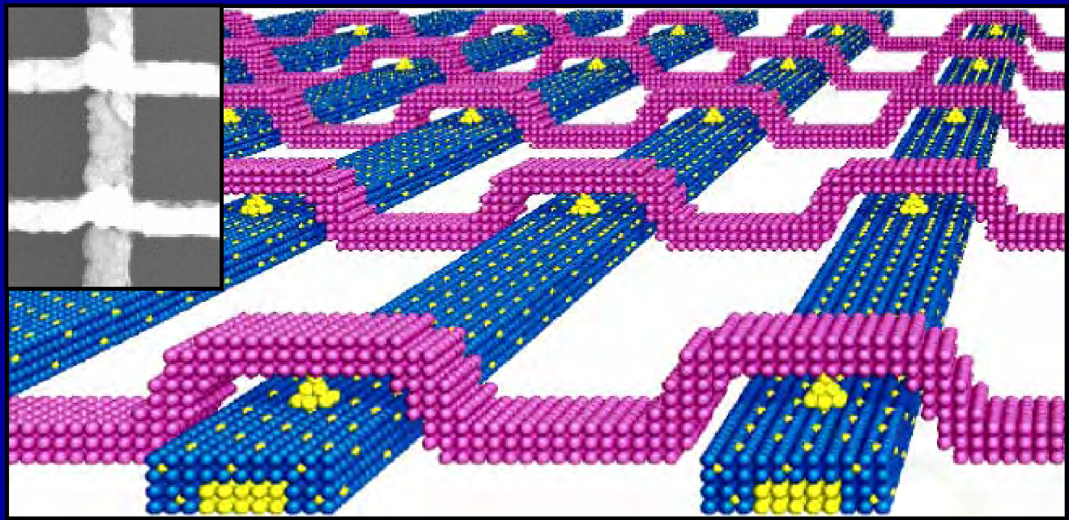
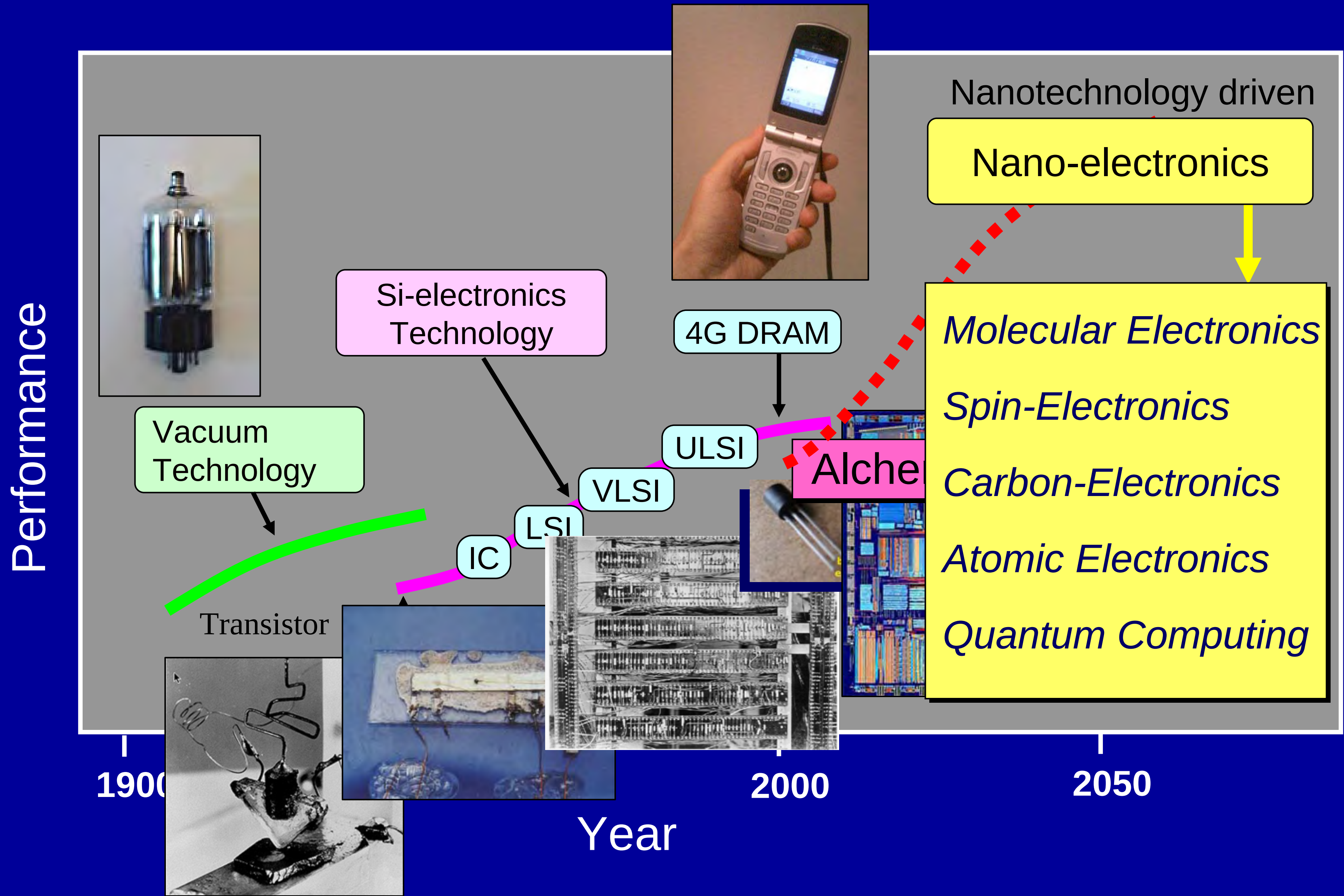
2008.3.6

Atomic Switch for making new type of electronic devices and systems



Tsuyoshi Hasegawa
WPI Center for Materials Nanoarchitectonics
National Institute for Materials Science, Japan

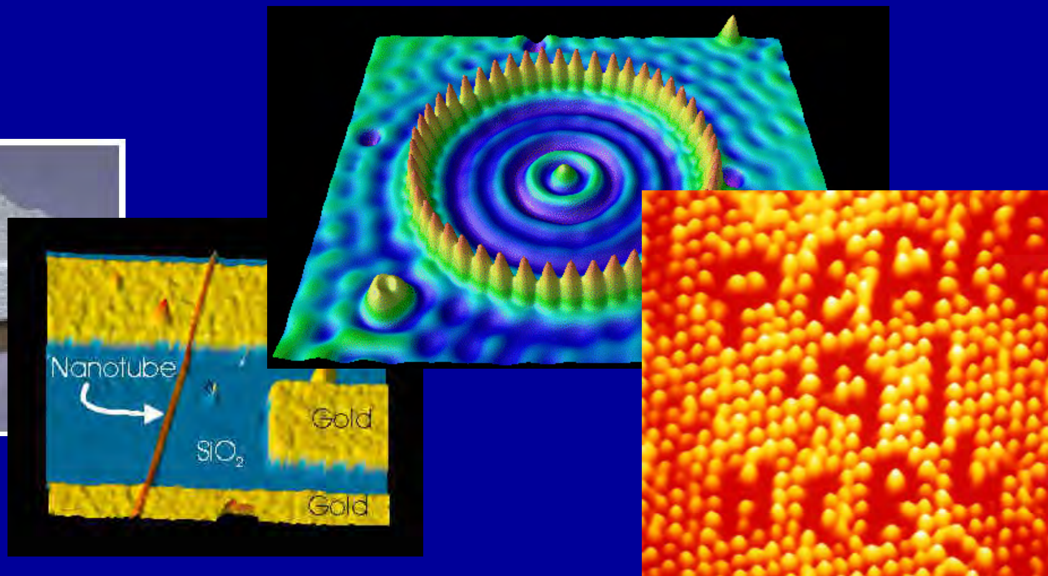
Further Progress by Nanotechnology



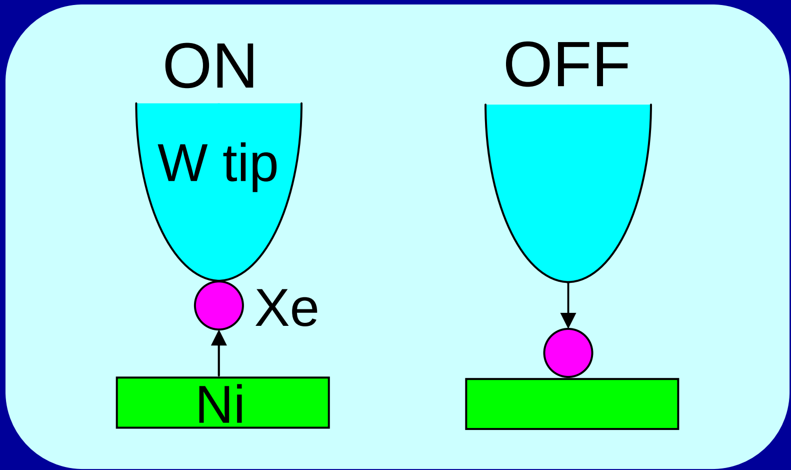
Key point for the further progress

Miniaturization ⇨ Using new functions by new materials & new structures

Molecules & Atoms
smallest building blocks



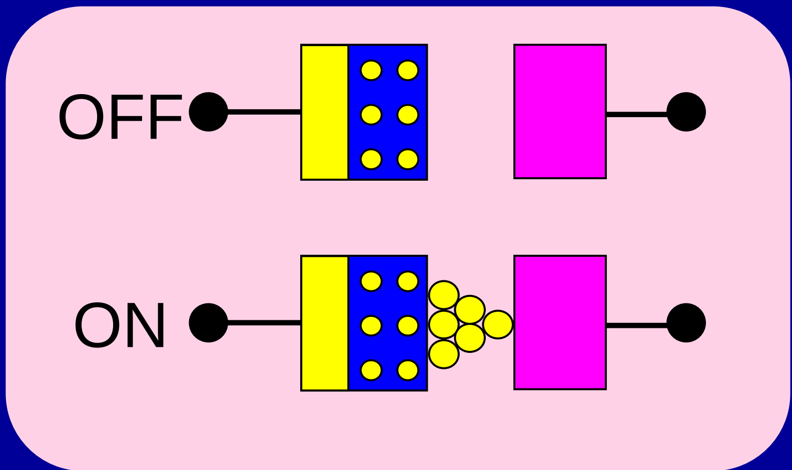
Atomic Switch



D. M. Eigler *et al.*, Nature **352** (1991) 600.

Atomic movement was achieved by electrical field.

ON/OFF : 10



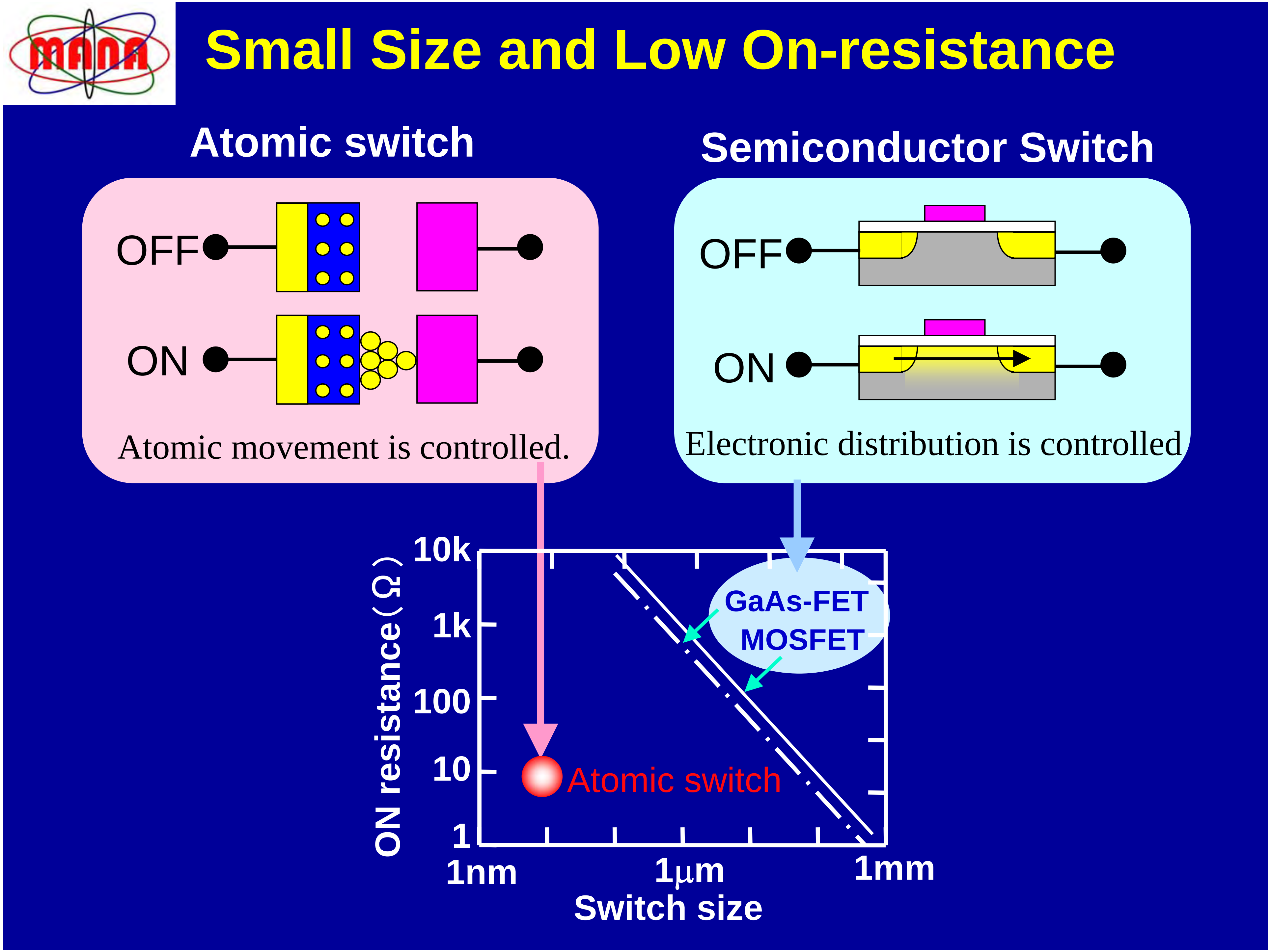
K. Terabe *et al.*, Nature 433 (2005) 47.

Atomic movement was achieved by solid electrochemical reaction.

ON/OFF : $>10^3$

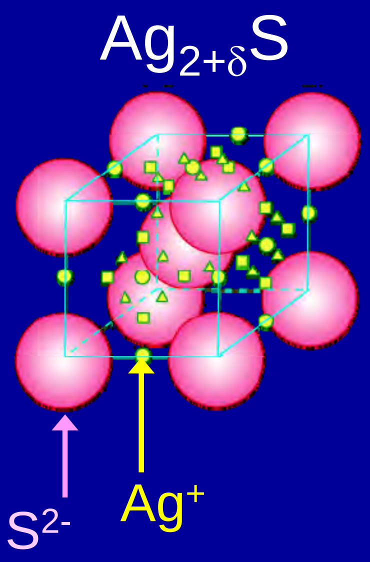
OUTLINE

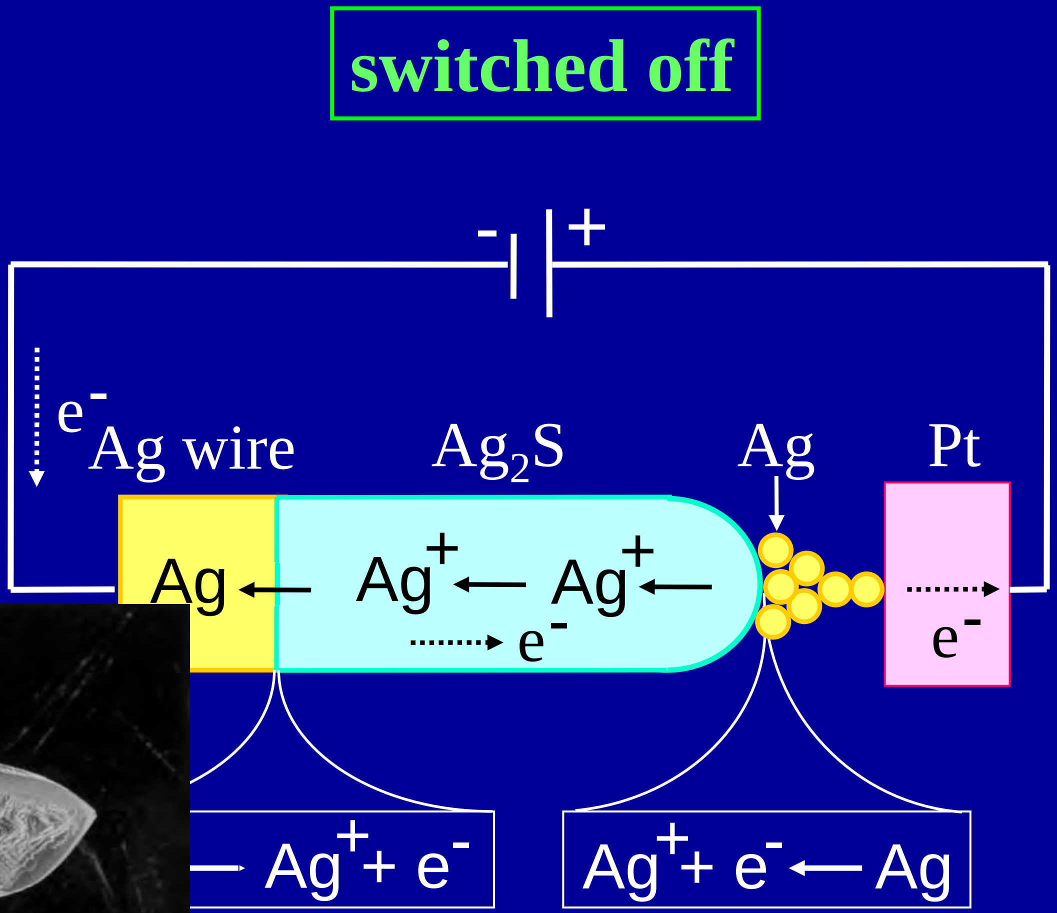
1. Mechanism and Characteristics
2. Application for Commercial Devices
3. New Type of Atomic Switch



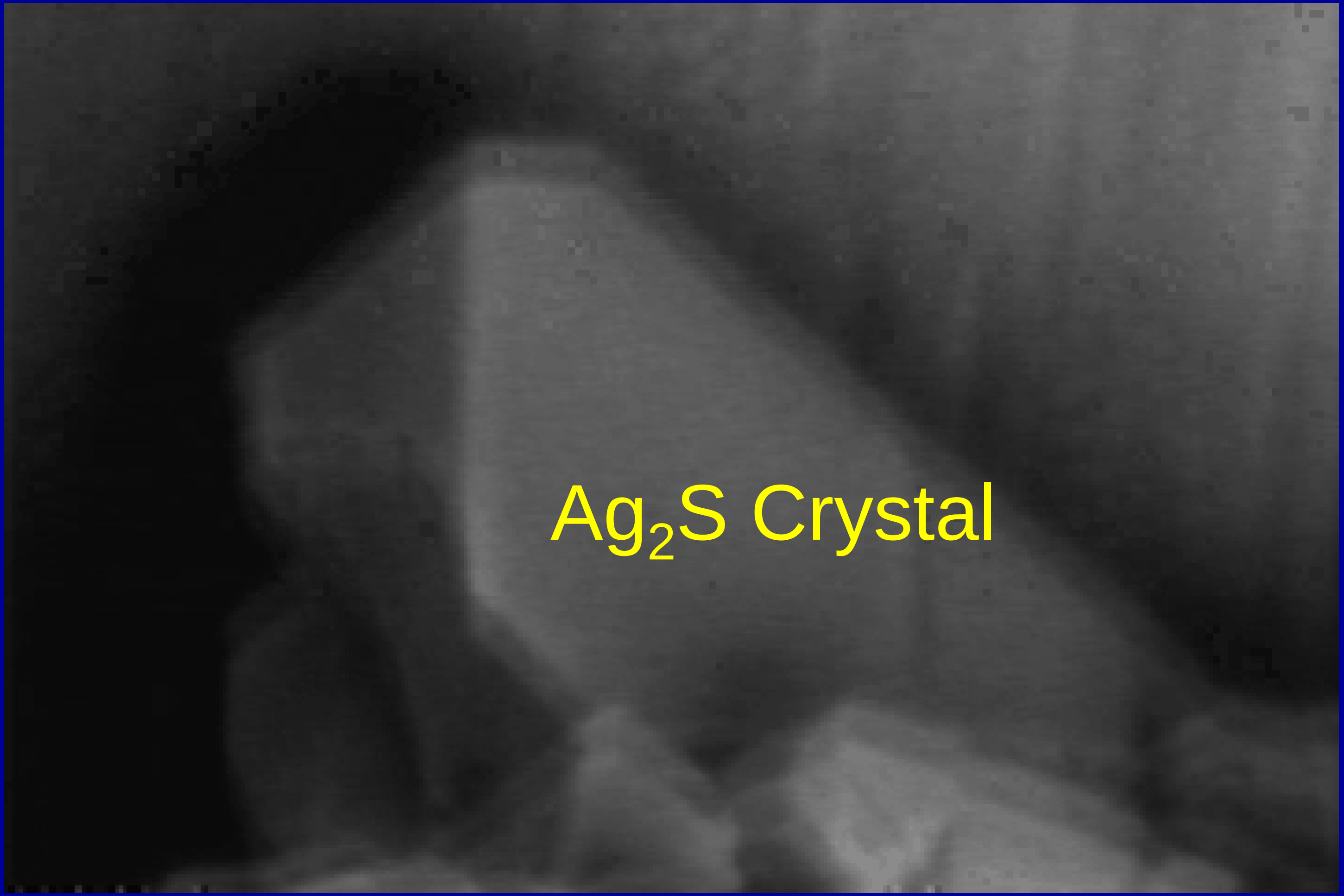
Small Size and Low On-resistance
Atomic switch
Semiconductor Switch
OFF
ON
OFF
ON
Atomic movement is controlled.
Electronic distribution is controlled
10k
1k
100
10
1
ON resistance (Ω)
1nm
1µm
1mm
Switch size
GaAs-FET
MOSFET
Atomic switch

Operating Mechanism

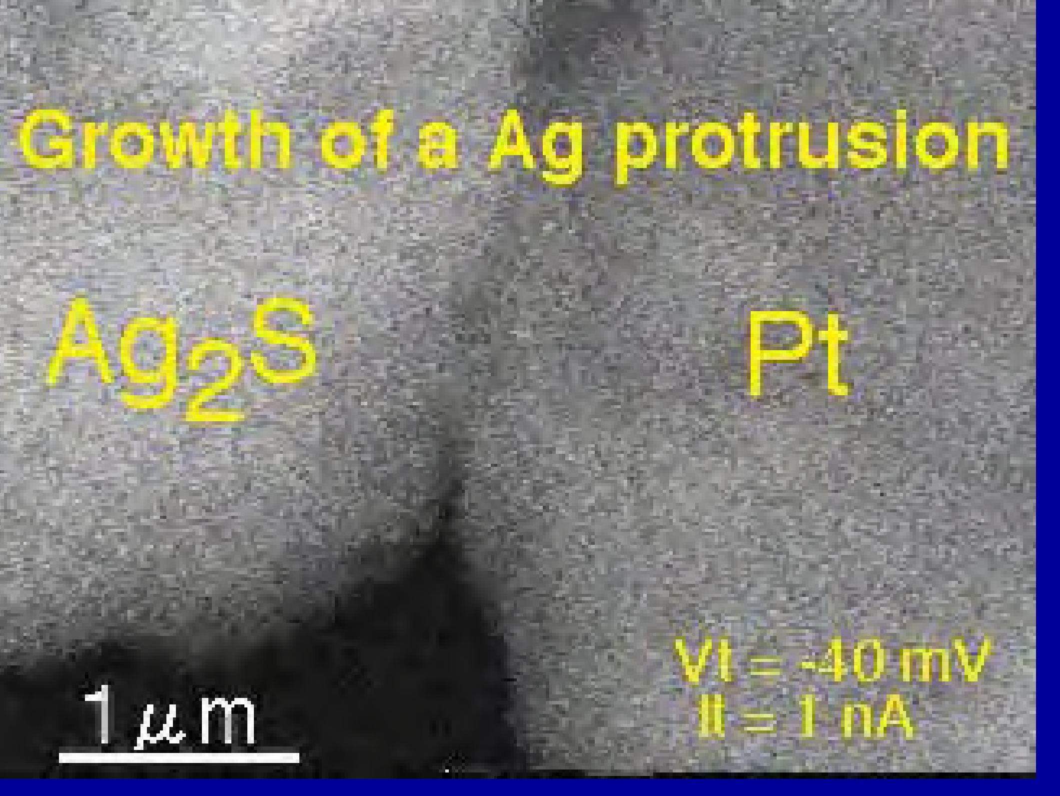




Ag nanowire growth by e-beam

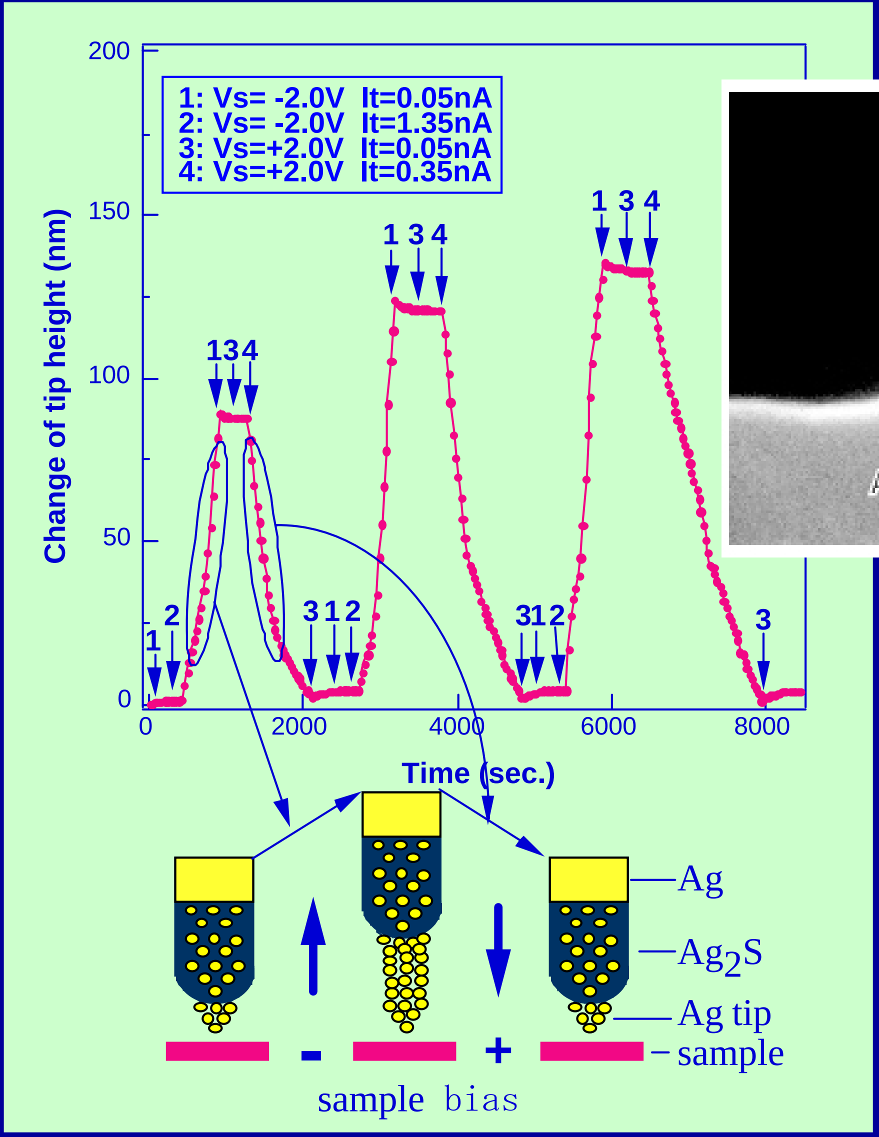


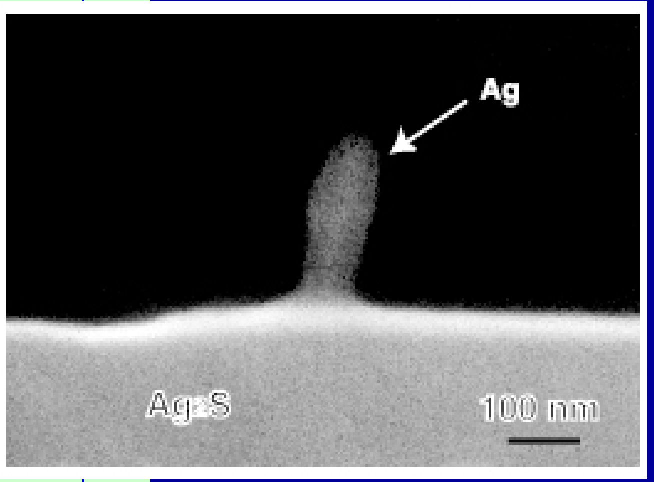
Single Ag protrusion growth by STM



The two electrodes are fixed in the case of atomic switch operation.

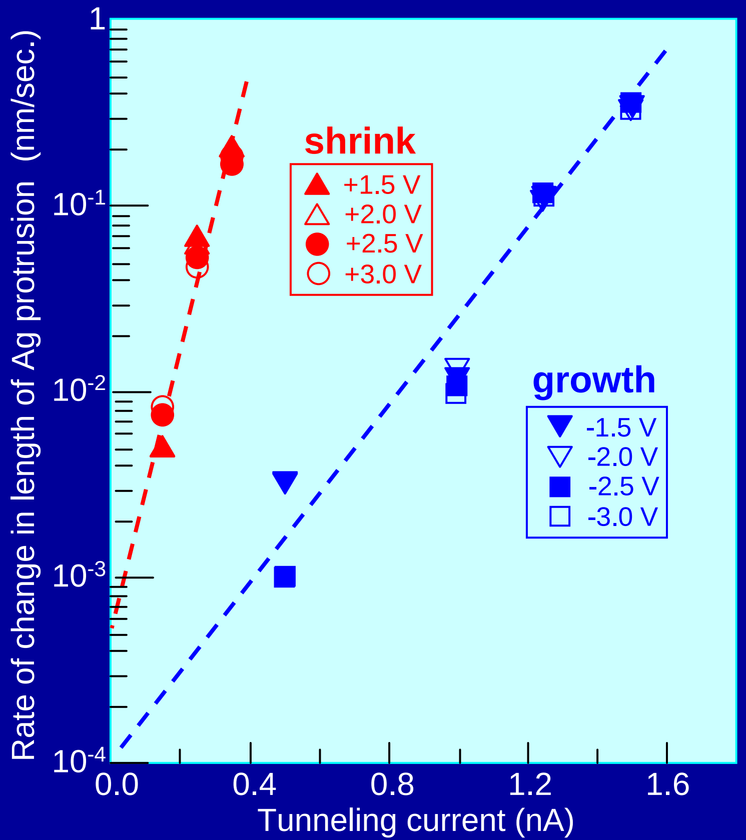
Controlled growth and shrinkage

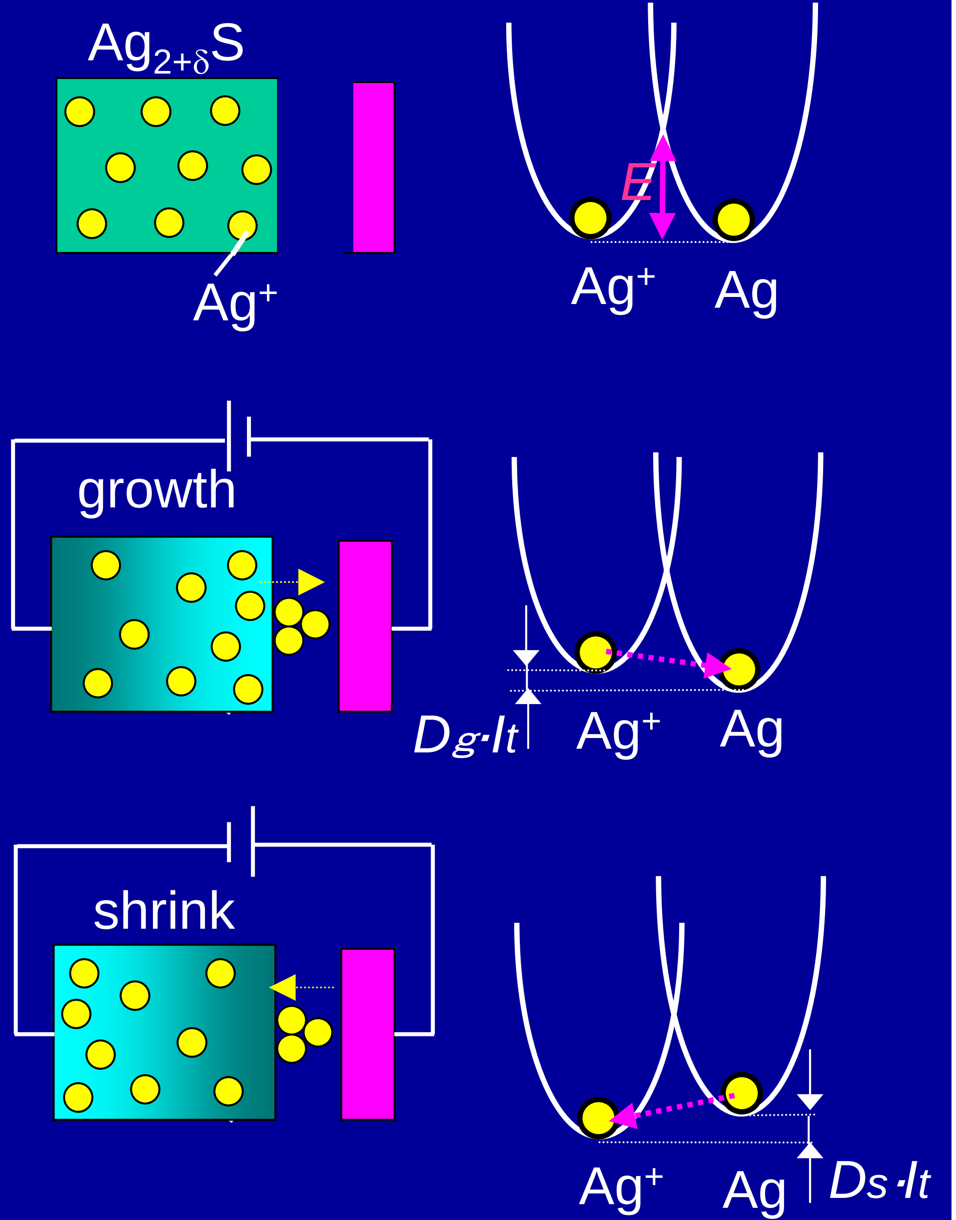




K. Terabe, T. Nakayama, T. Hasegawa and M. Aono, J. Appl. Phys., 91 (2002) 10110.

Growth and Shrinkage speed of Ag

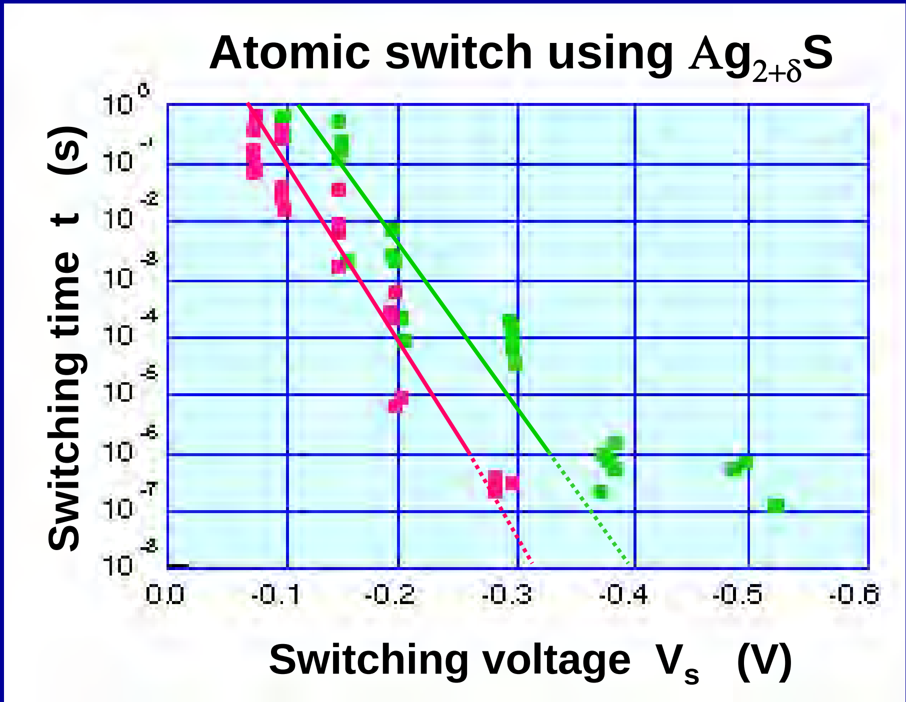


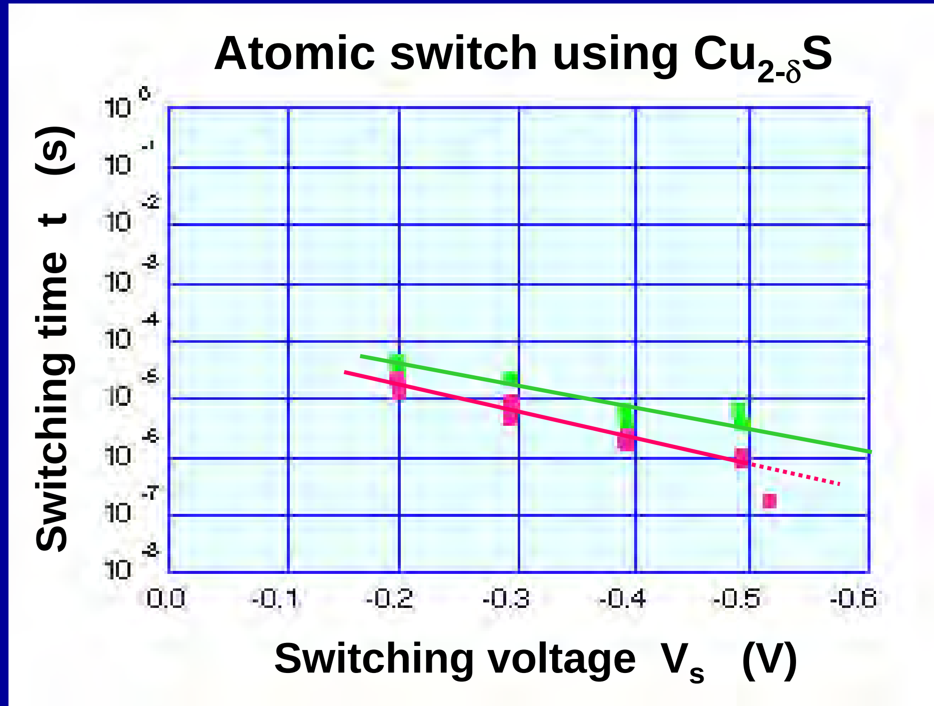


$$\frac{dN}{dt} = A \cdot exp\left(\frac{E - D \cdot It}{kT}\right)$$

Switching time vs. switching voltage

Switching characteristics depend on the materials.



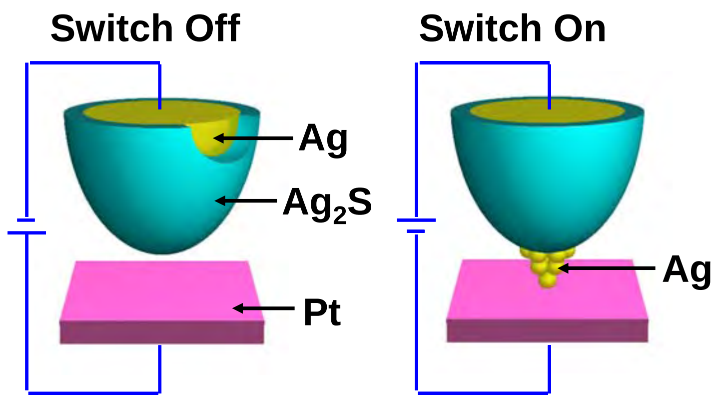


■ : 1MΩ to 12.9 kΩ
■ : 100 k Ω to 12.9 kΩ

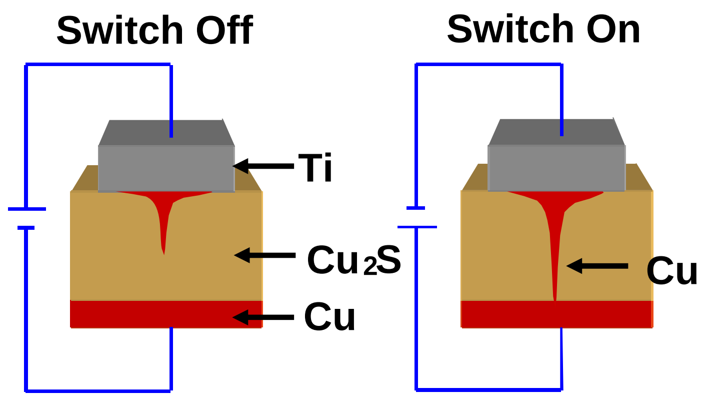
T. Tamura, T. Hasegawa, K. Terabe, T. Nakayama, T. Sakamoto, H. Sunamura, H. Kawaura, S. Hosaka and M. Aono, Jpn. J. Appl. Phys. 45 (2006) L364.

Two types of atomic switch

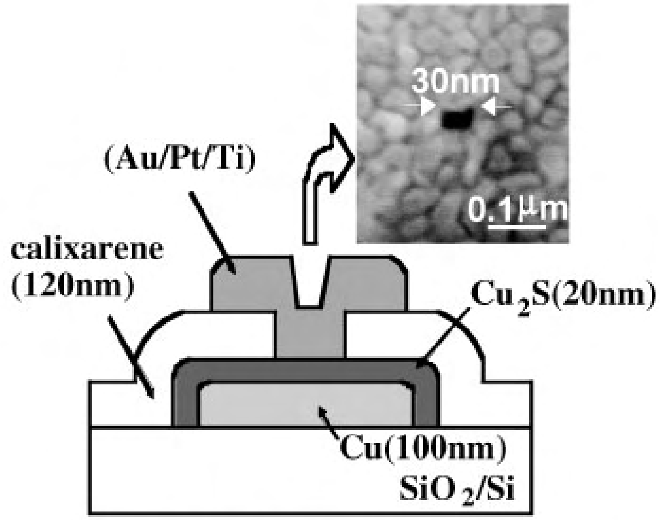
'with gap' and 'without dap'



Initial type of Atomic switch



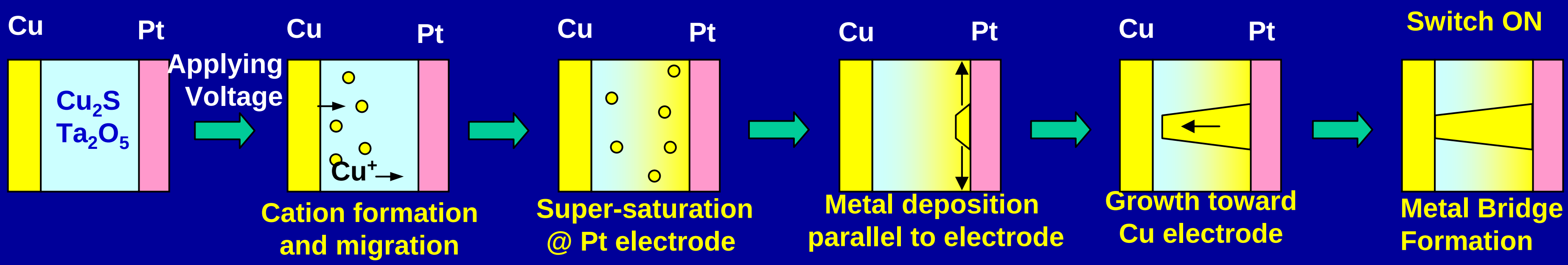
Gapless atomic switch (NanoBridge™)



Cross-section of NanoBridge

Switching Mechanism of gapless atomic switch

Operating Model



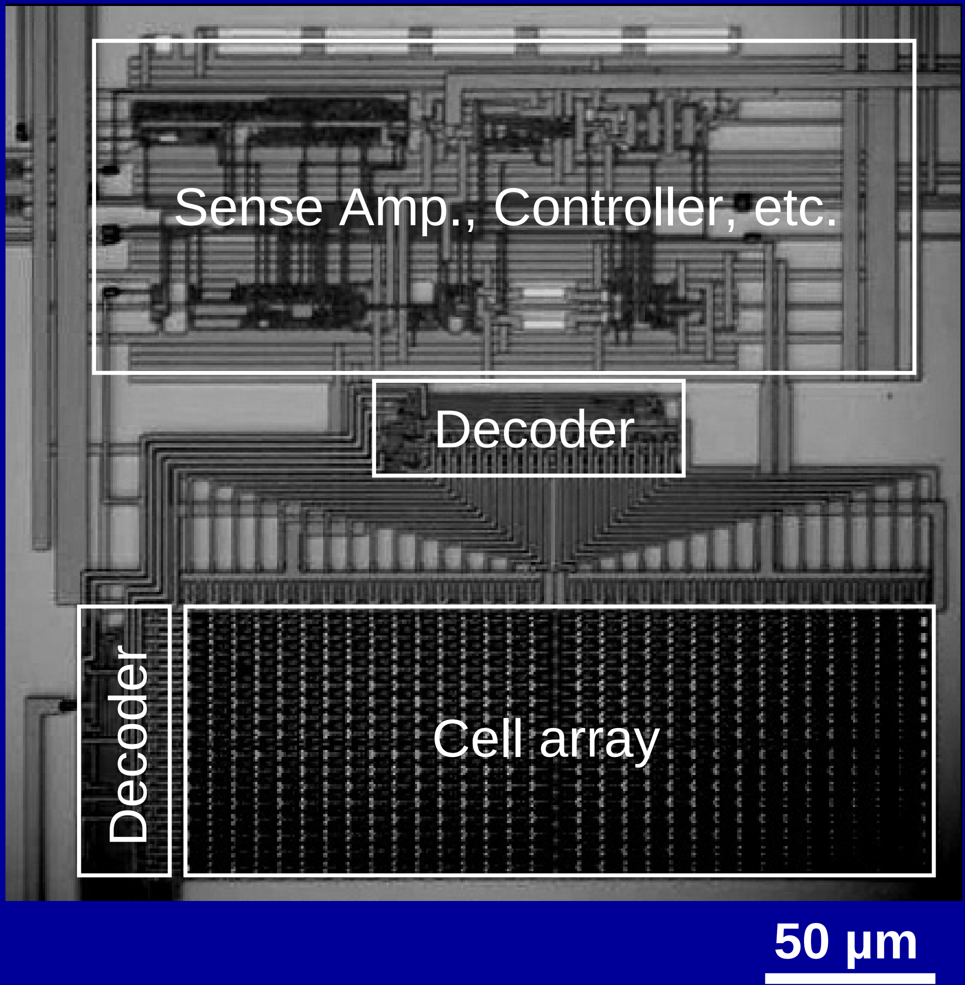
OUTLINE

1. Mechanism and Characteristics

2. Application for Commercial Devices

3. New Type of Atomic Switch

1k-bit nonvolatile memory

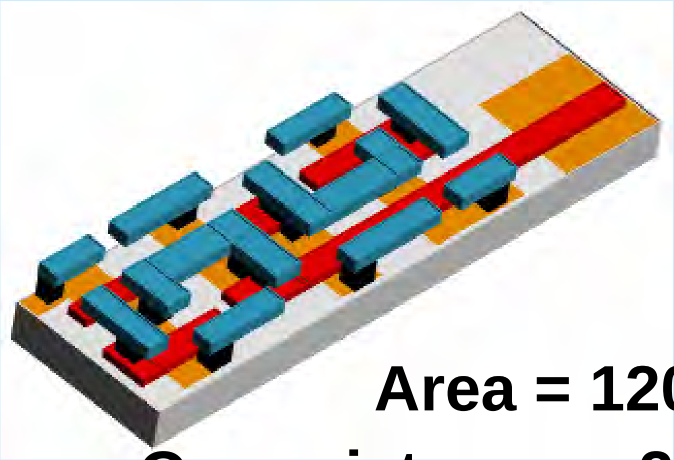


T. Sakamoto, H. Sunamura, M. Mizuno, H. Kawaura, T. Hasegawa, K. Terabe, T. Nakayama and M. Aono, IEEE J. Solid-State Circuits 40 (2005) 168.

Apply to Programmable Devices

Switch size reduces to 1/30, On-resistance reduces to 1/40.

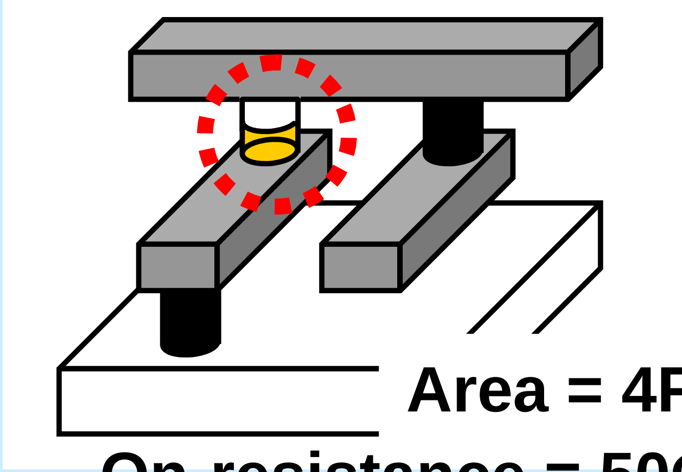
Nowadays Switch



Area = $120F^2$

On-resistance = 2kΩ

Atomic Switch



Area = $4F^2$

On-resistance = 50Ω

F: minimum feature size

New device "Programmable CBIC" is proposed.

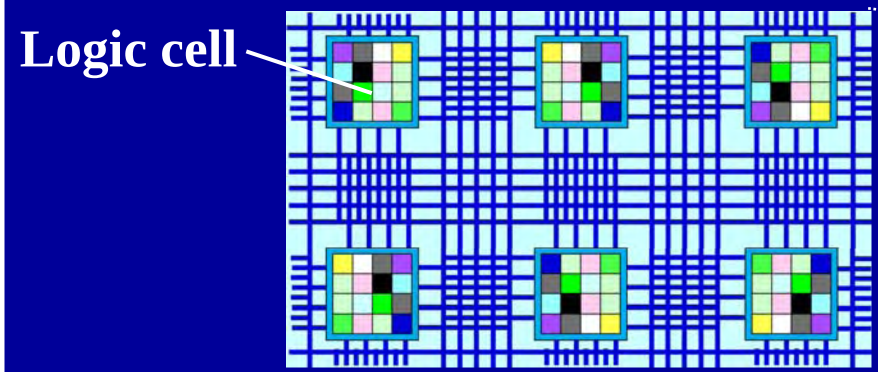
T. Sakamoto, H. Sunamura, M. Mizuno, H. Kawaura, T. Hasegawa, K. Terabe, T. Nakayama and M. Aono, IEEE J. Solid-State Circuits 40 (2005) 168.

Programmable CBIC

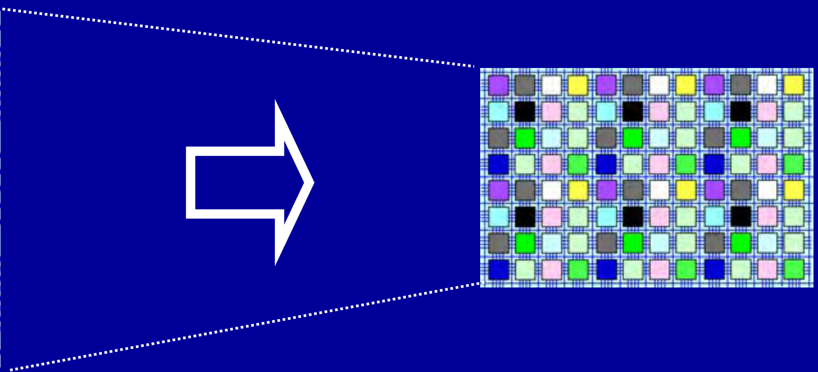
It enables many functions by a single chip

- Larger number of fine-grain logic cells
- Size reduction due to the small switches

Chip size: 1/10th, or 10 times larger application
Number of programs increases vastly.

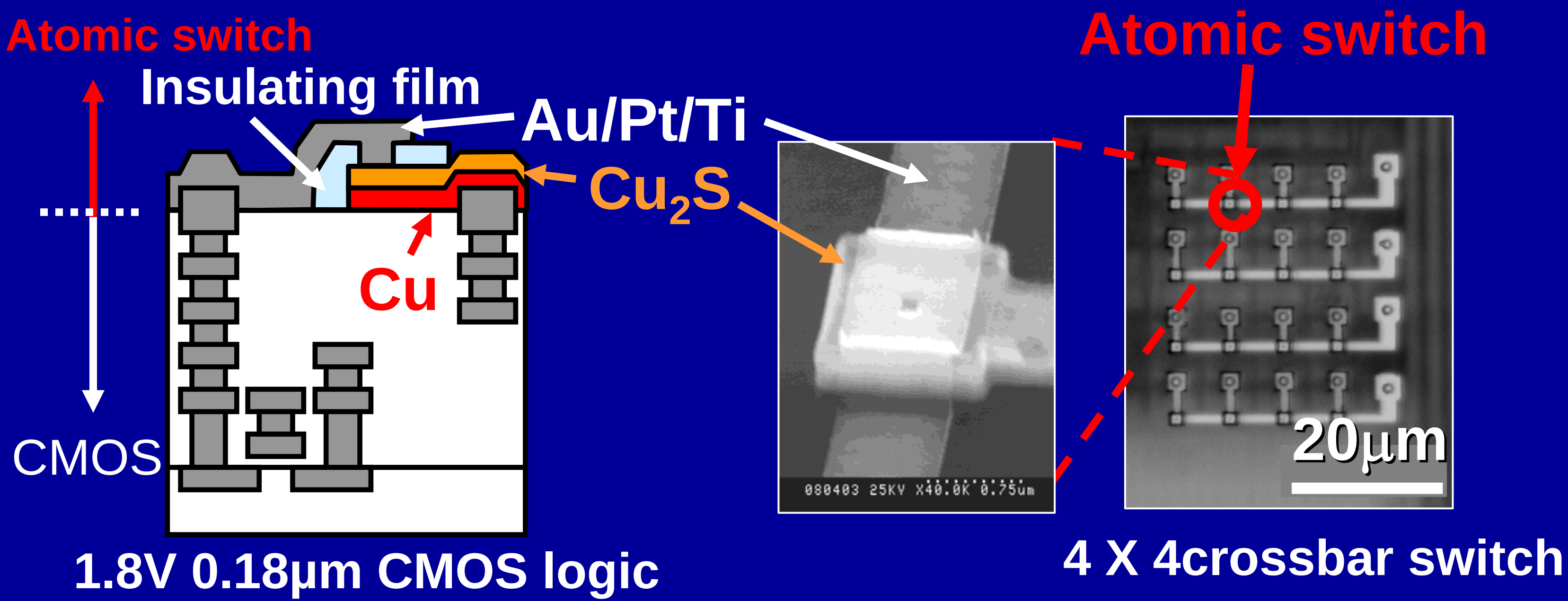


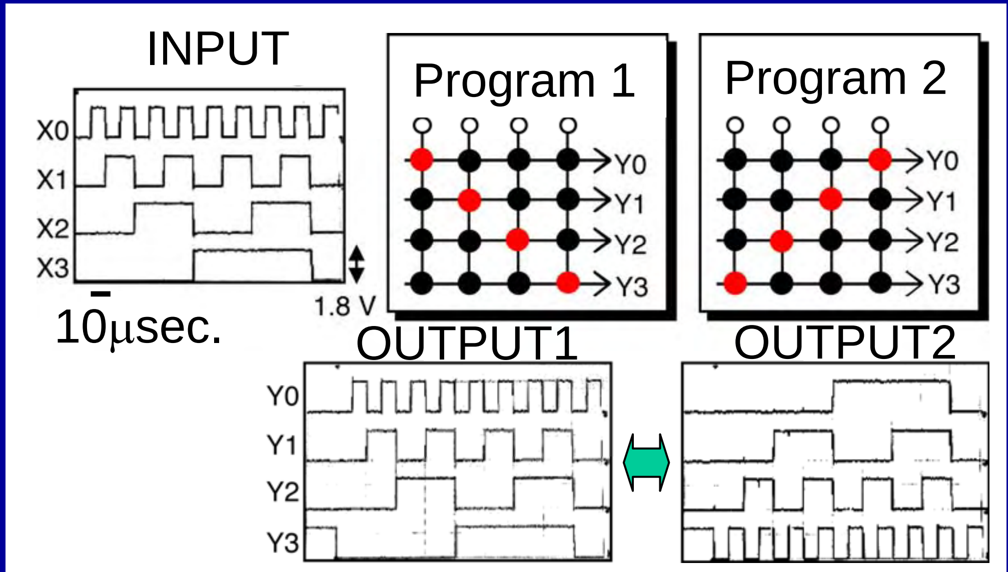
Conventional FPGA
FPGA: Field Programmable Gate Array



Programmable CBIC
CBIC: Cell Based Integrated Circuit

4x4 crossbar circuit





T. Sakamoto, et al.,
IEEE J. Solid-State Circuits
40 (2005) 168.

OUTLINE

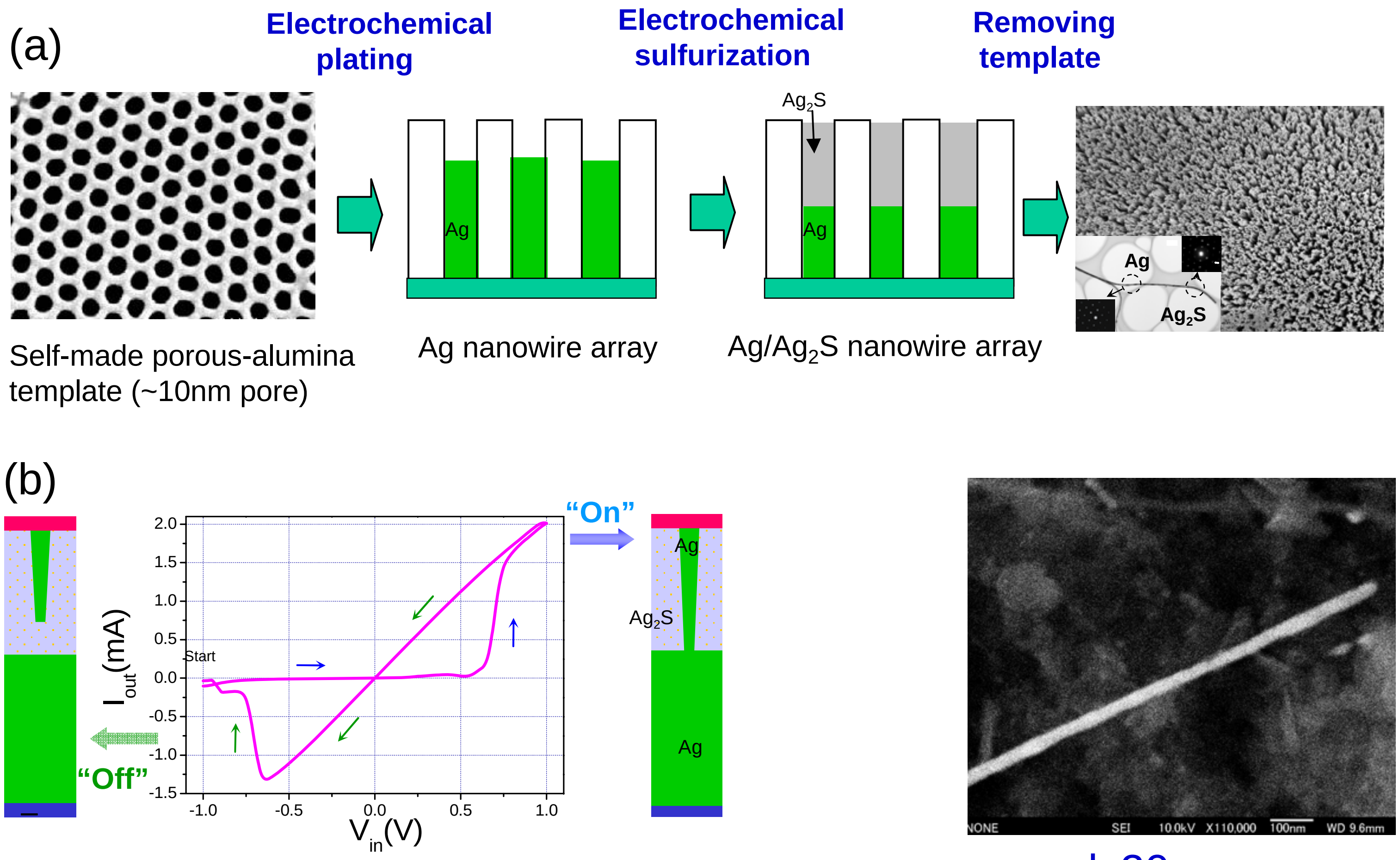
1. **Mechanism and Characteristics**

2. **Application for Commercial Devices**

3. **New Type of Atomic Switch**
   1) Atomic Switch Array using AAO Template
   2) Three terminal Atomic Switch
   3) Photon-assisted Atomic Switch

Atomic switch array using AAO

Ag_2S/Ag nanorod and its switching property

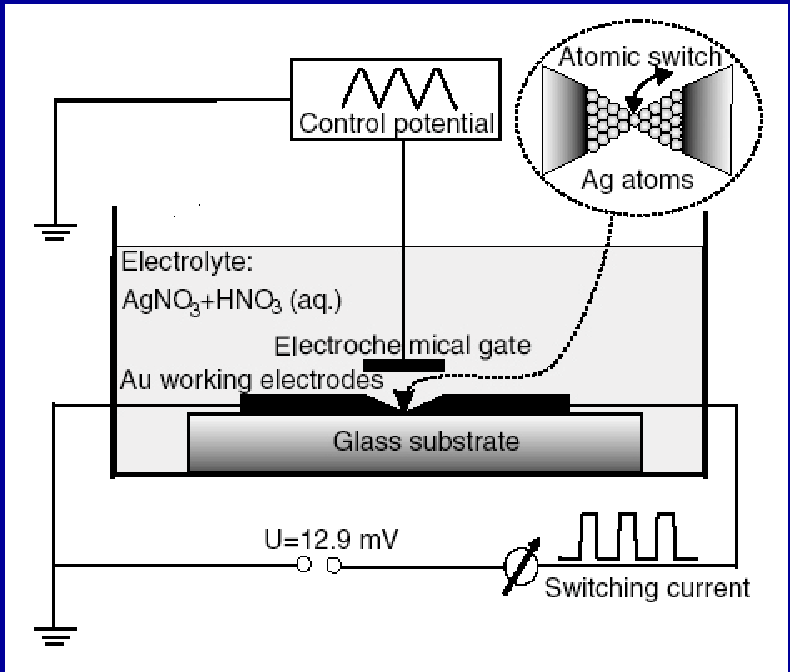


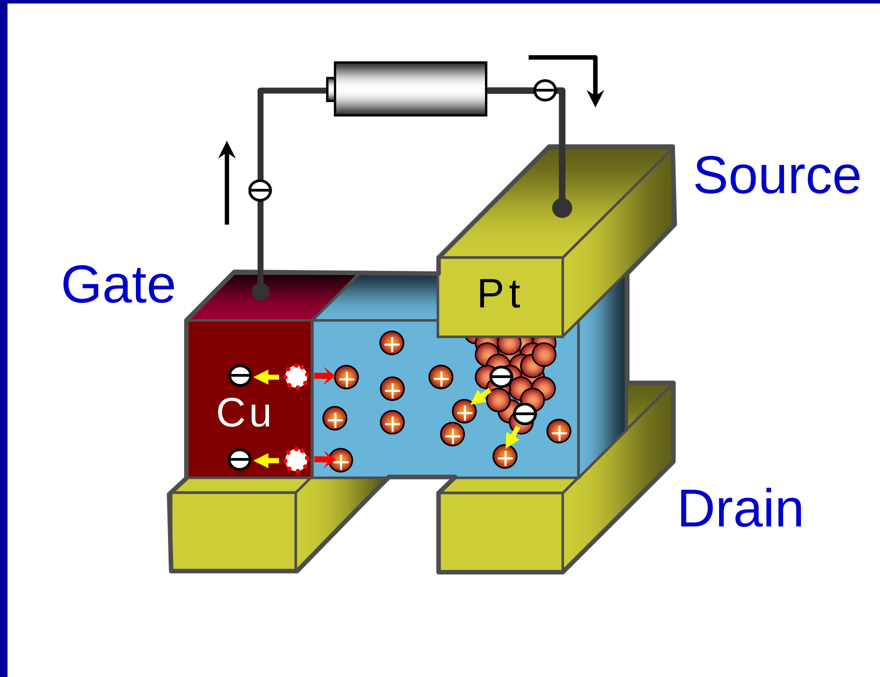
d：20 nm

Ch. Liang, K. Terabe, T. Hasegawa, R. Negishi, T. Tamura and M. Aono, Small 10 (2005) 971.

3-terminal Atomic Switch

For more controllability, large current, etc.

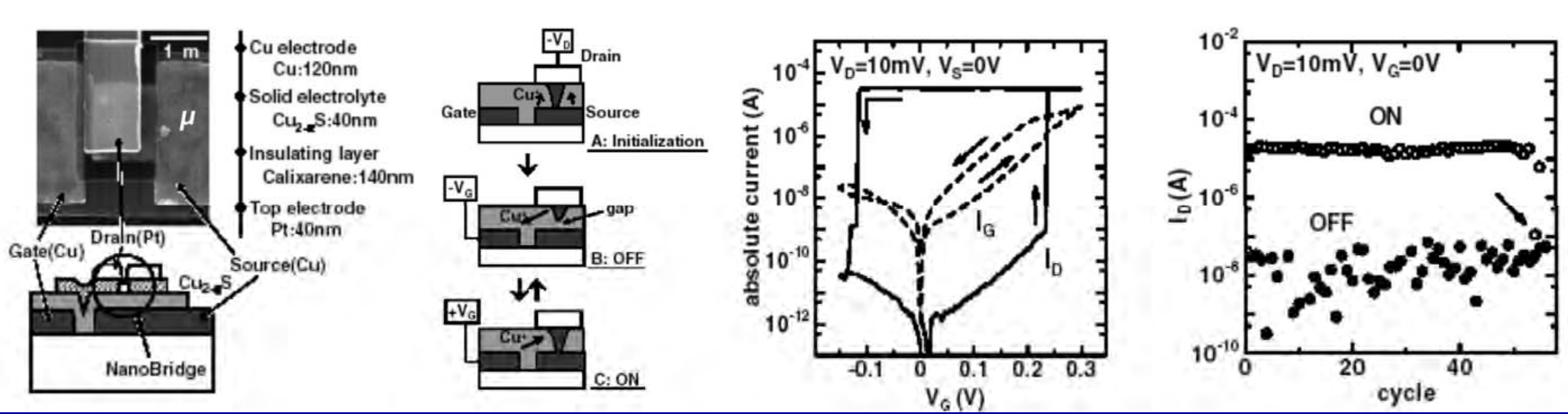




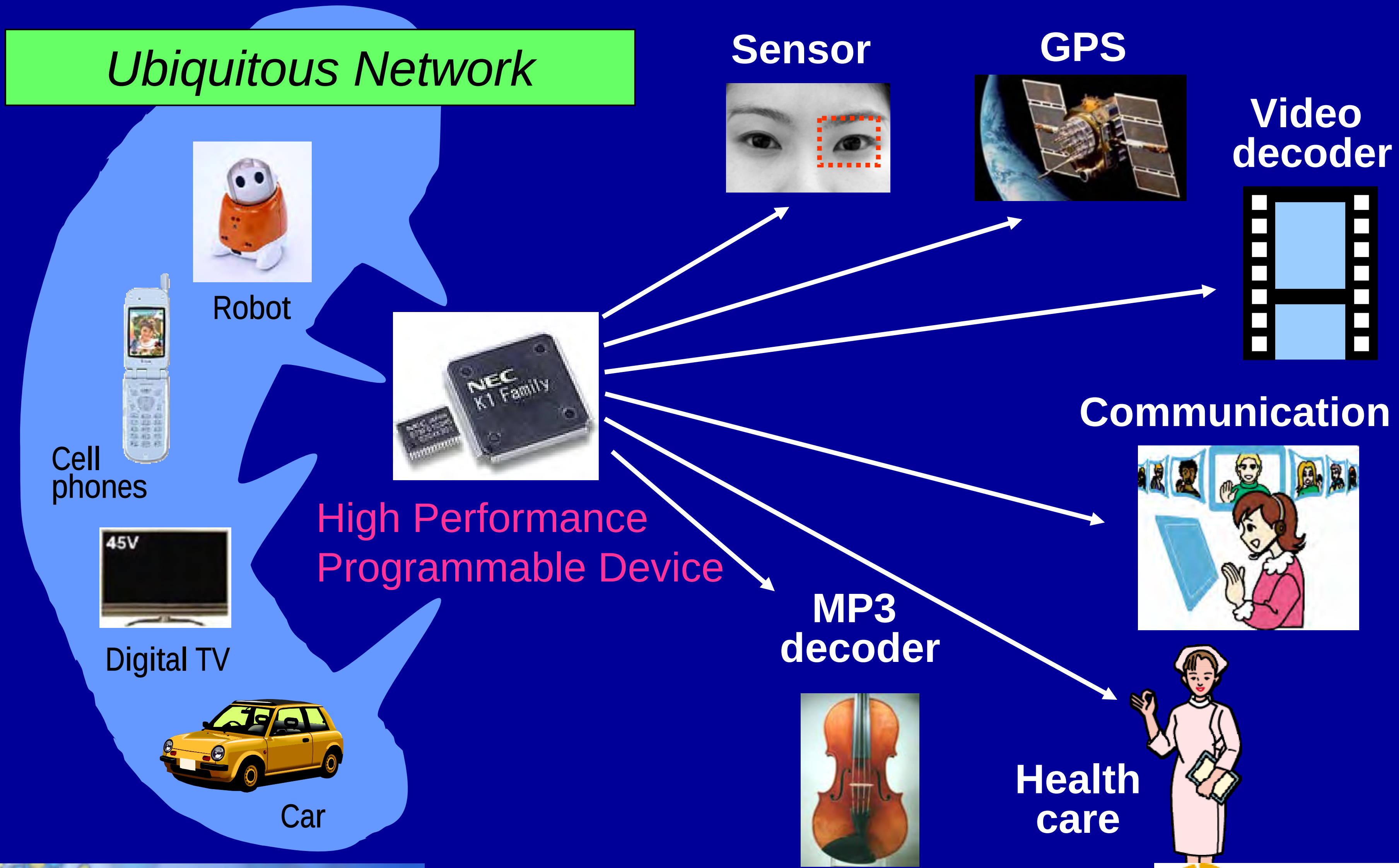
F. Xie et al., Phys. Rev. Lett., 93, 128303 (2004).

3-terminal Atomic Switch

For more controllability, large current, etc.



All functions enabled by a single chip using Atomic Switch



分子科学研究所
INSTITUTE FOR MOLECULAR SCIENCE
東京大学
THE UNIVERSITY OF TOKYO

1. Mechanism and Characteristics

1) Atomic Switch with 1 nm gap

2) Gapless Atomic Switch (Nano Bridge^{TM})

2. Application for Commercial Devices

1) Nonvolatile Memory

2) Programmable Logic Device

3. New Type of Atomic Switch

1) Atomic Switch Array using AAO Template

2) Three terminal Atomic Switch

3) Photon-assisted Atomic Switch