Memristors

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강의자료 출처: 선형대수학 Express. 김대수 저

History of VLSI

- Shockley's semiconductor device concept (1945)
- Bardeen and Brattain's point-junction transistor (1947)
- Shockley's junction (sandwich) transistor (1950)
- Kahng and Attala's MOSFET (1960)

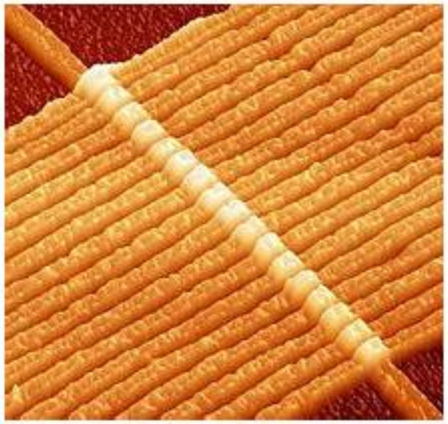
1956 Nobel Prize, Physics
(J. Bardeen, W. Shockley, and W. Brattain)

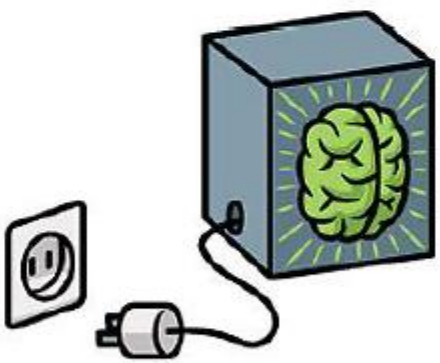
Dec. 16, 1947

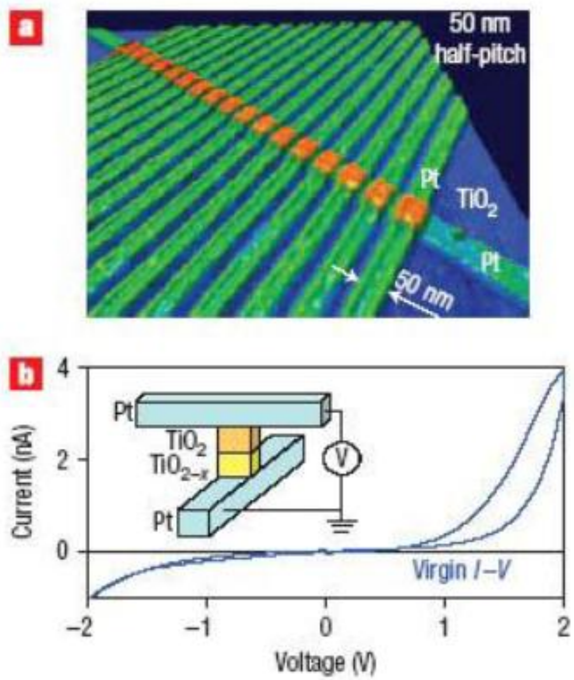
2000 Nobel Prize, Physics
(Jack Kilby)

Germanium,1T, 1C, 3R, Oscillator,
0.04 inch X 0.06 inch (Sept. 12, 1958)

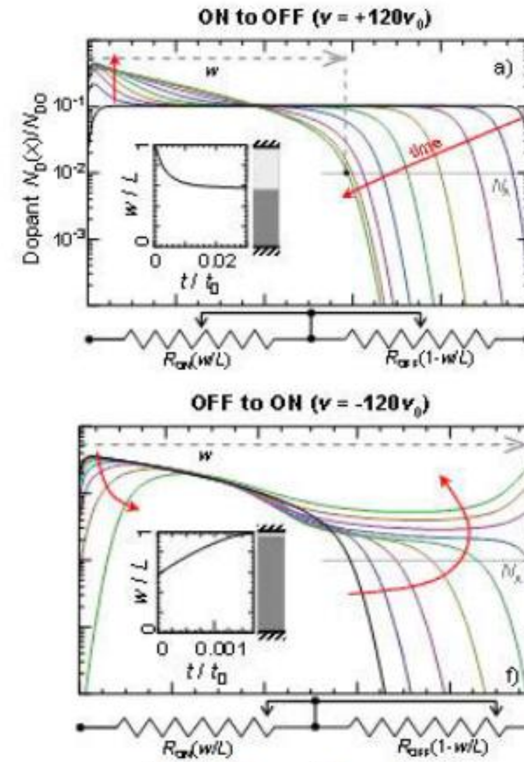
2008: Memristive device invented by HP







J. Yang, D. Pickett, X. Li, Ohlberg, D. Stewart, R. S. Williams, Nature Nanotech. (2008)



D. Strukov, J. Borghetti, R. S. Williams, Small (2008)

The missing link in constitutive relations

$V = R\,I$ (Resistor)

$Q = C\,V$ (Capacitor)

$\Phi = L\,I$ (Inductor)

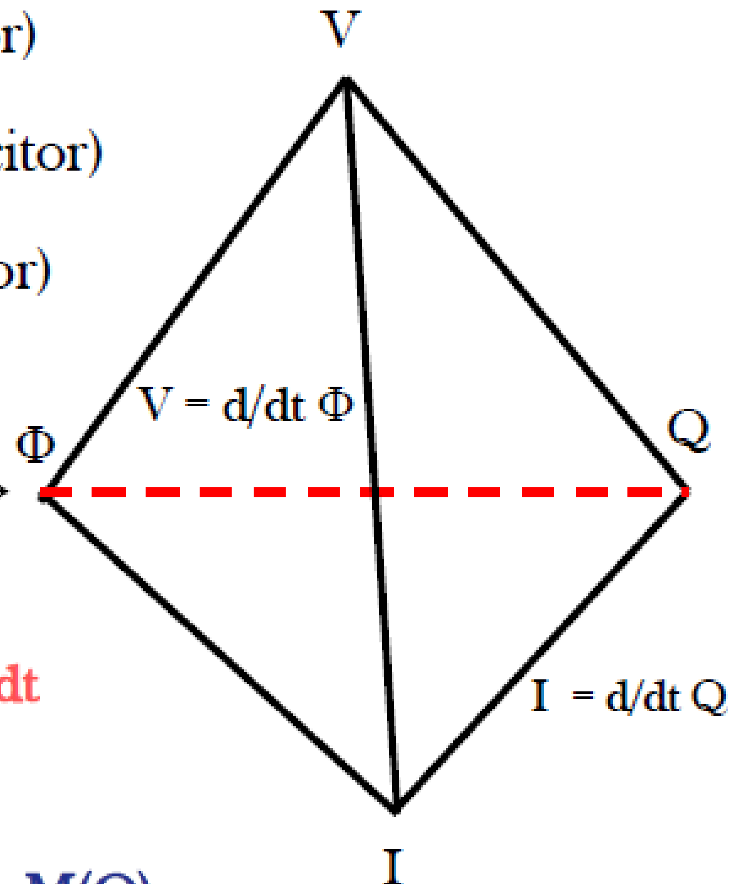
$\Phi = f(Q)$

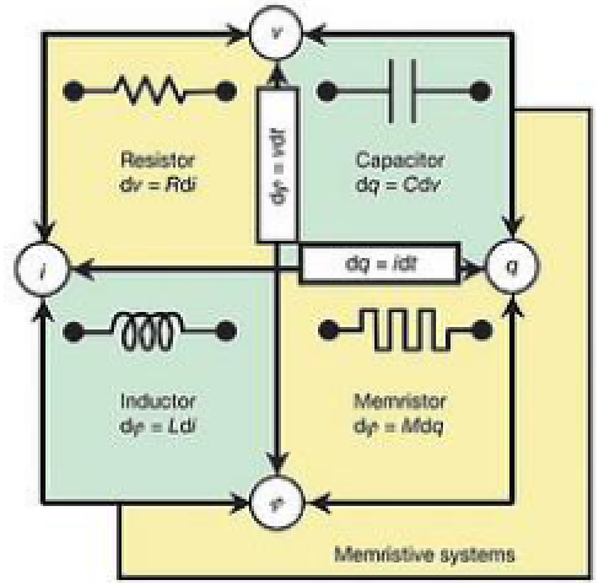
$d\Phi/dt = df(Q)/dt$

$= df(Q)/dQ.\ dQ/dt$

$V = M\,I$

Memristance $M=M(Q)$





Who are generalization of memristors

Memristor (1971 Chua)

$$\emptyset = f(q)$$

with property of

V = M(x) i

dx/dt = i

Memristive Device (1976 Chua and Kang)

V = R(x,i,t) i

dx/dt = f(x,i,t)

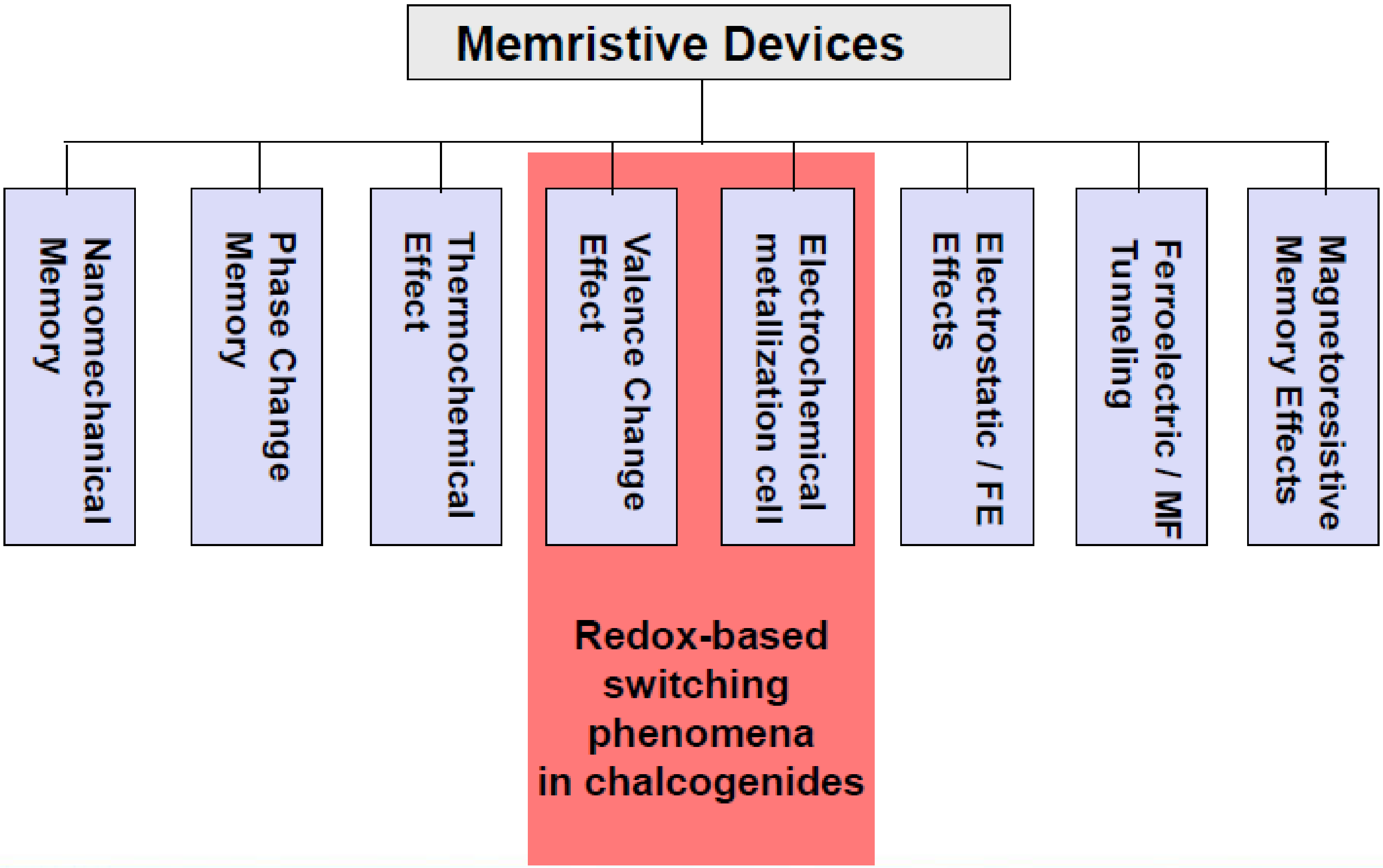
X is a much broader state variable.
When f(x,i,t)=i, R(x,I,t)= M(x),
then a memristor property.

Example:
•Thermistor
•Fluorescent Lamp
•Ionic channels in Hodgkin-Huxley model

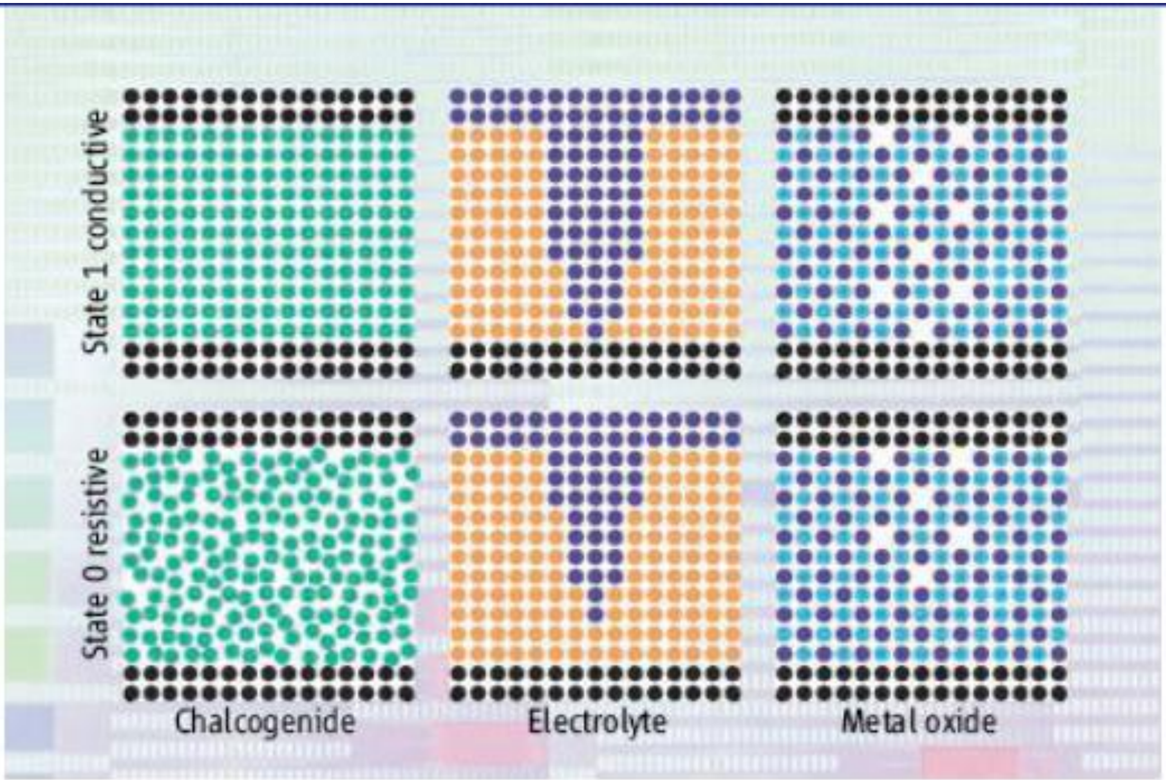
Recently," Memristor" and " Memristive Device" have been used interchangeably

Ref. L. O. Chua, Memristor-The Missing Circuit Element, IEEE Tarns. On Circuit Theory, CT-18 (5):505-517, 1971
L. O. Chua and S. M. Kang, Memristive Devices and Systems, Proceedings of the IEEE, vol. 64, pp. 209-223, Feb. 1976

Classification of the mechanism of memristor



Resistive switching materials

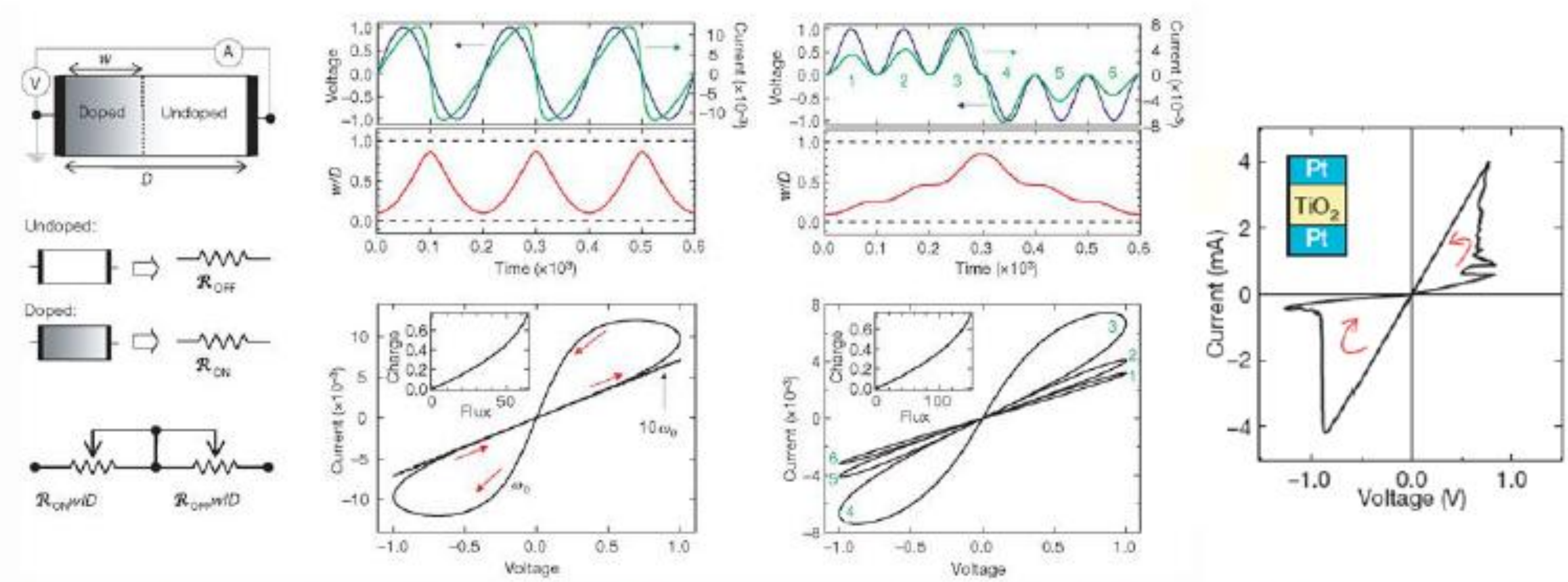


(Left) Phase change between a crystalline and an amorphous Ge2Sb2Te5 chalcogenide.
=> Phase-Change RAM (PCRAM), on the brink of mass-production
(Middle) Creation and annihilation of a metallic Ag protrusion in a GeSe solid electrolyte.
(Right) Creation and disruption of a pattern of missing oxygen atoms in a SrTiO3 transition-metal oxide. => RRAM (Resistive RAM) or Memristor, early stage in research

Ref: Science, March 2008

Memristor by HP

- Nanotechnology Enabled Memristive Devices
  - Typically formed in nano crossbar structures
    - Capable of ultra dense integration
  - Compatible with CMOS process
    - Enables hybrid CMOS/Nanodevices integration



Memristor by HP

$$V = \left[R_{on}\frac{W}{D} + R_{off}\left(1 - \frac{W}{D}\right)\right] i$$

$$\frac{dw}{dt} = \mu \frac{R_{on}}{D} i$$

with a boundary condition $0 \leq \frac{w}{D} \leq 1$

- A more accurate model should reflect non-constant memristance values when memristor is in high resistance and low resistance modes and their mode switching

Bipolar resistive switching in transition metal oxides

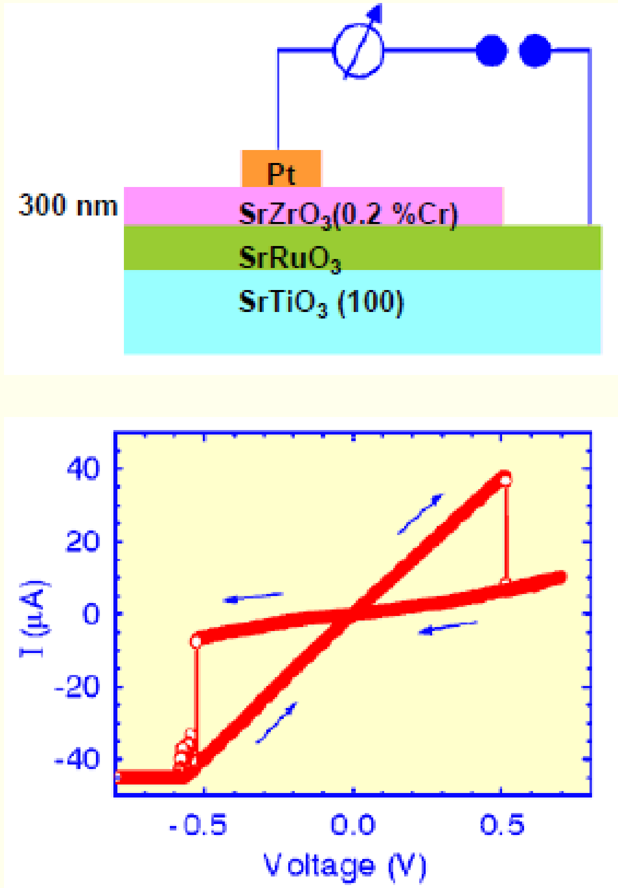
Examples

Capacitor-like structure with
- Cr-doped $SrZrO_3$ thin films
- PCMO thin films
- $(Ba,Sr)TiO_3$ thin films
- TiO_2 thin films
- $SrTiO_3$ single crystals

as resistive element

Characteristics

after forming process: reversible bipolar switching between stable impedance states



A. Beck, J. G. Bednorz, Ch. Gerber, C. Rossel and D. Widmer, Appl. Phys. Lett. 77, 139 (2000).

ZnO memristor

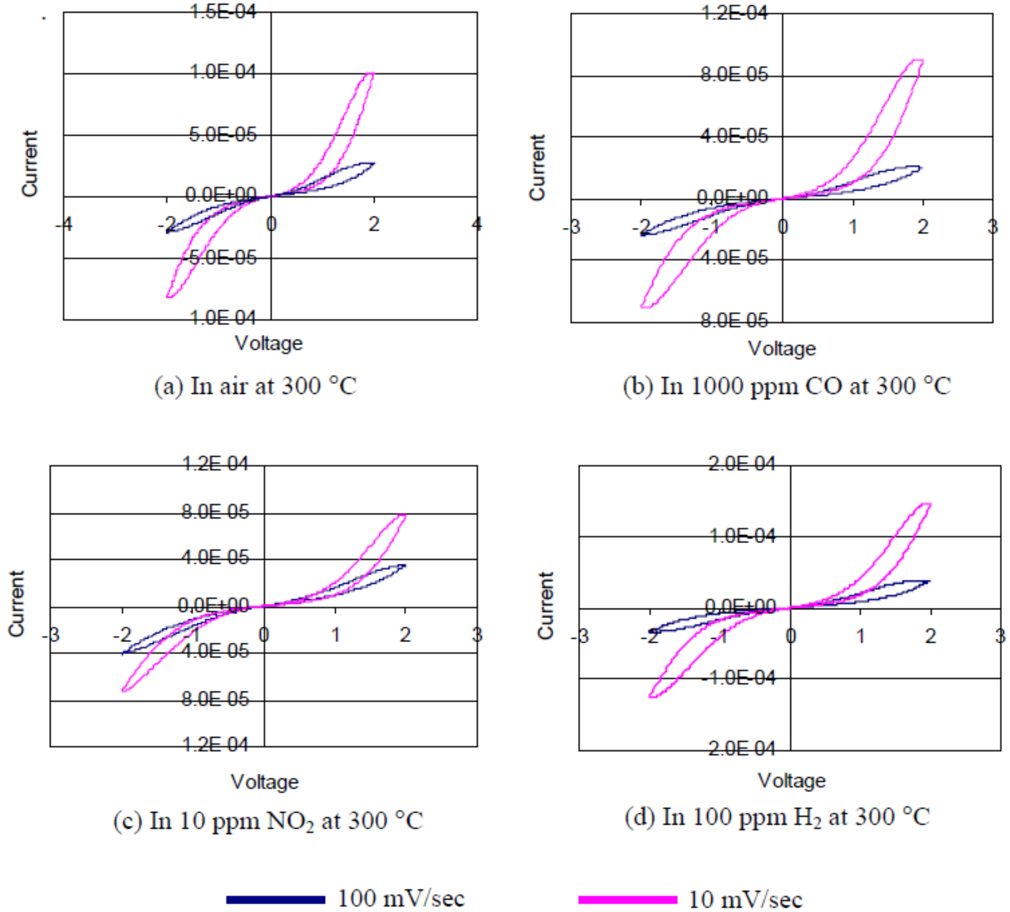
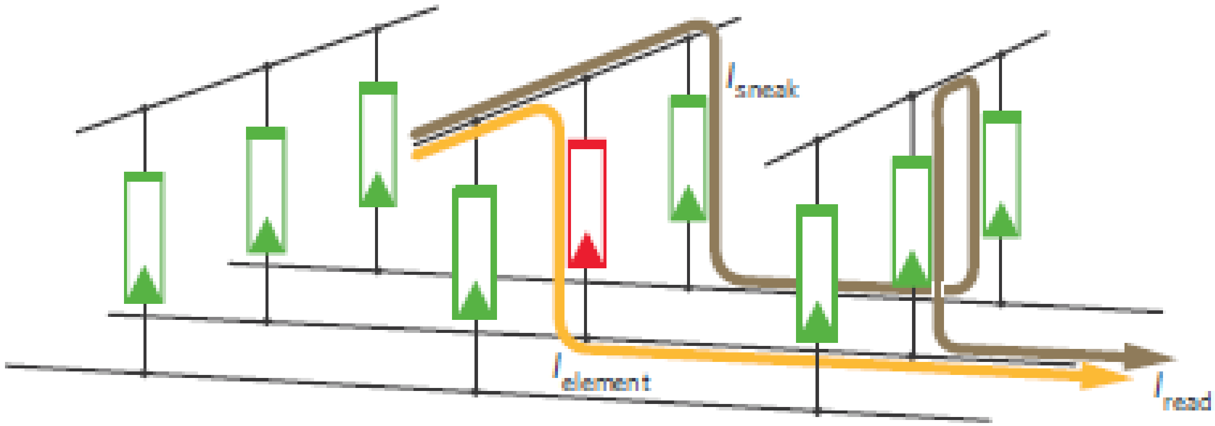


Figure 4.18 Current-voltage (I-V) curves of ZnO ($Ar:O_2$ = 7:3) micro array sensor measured at 300°C. I-V characteristics were observed from 0V to –2V, 0V, 2V to 0V with different sweep rates of 100 mV/sec and 10 mV/sec.

Memristor memory array (1)



Complementary resistive switches for passive nanocrossbar memories

Eike Linn[1,2], Roland Rosezin[2,3], Carsten Kügeler[2,3] and Rainer Waser[1,2,3]*

Memristor memory array (2)

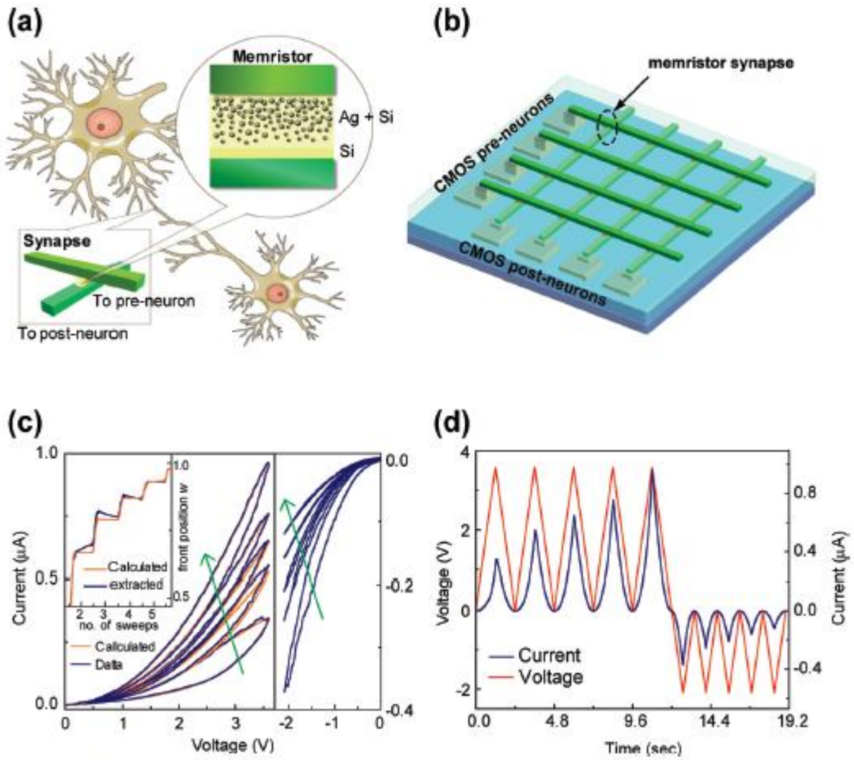


FIGURE 1. Nanoscale memristor characteristics and its application as a synapse. (a) Schematic illustration of the concept of using memristors as synapses between neurons. The insets show the schematics of the two-terminal device geometry and the layered structure of the memristor. (b) Schematic of a neuromorphic with CMOS neurons and memristor synapses in a crossbar configuration. (c) Measured (blue lines) and calculated (orange lines) $I-V$ characteristics of the memristor. Inset: calculated (orange lines) and extracted (blue lines) values of the normalized Ag front position w during positive DC sweeps. (d) The current and voltage data versus time for the device in (c) highlighting the change in current in sequential voltage sweeps.

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Nanoscale Memristor Device as Synapse in Neuromorphic Systems

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Memristor memory array (3)

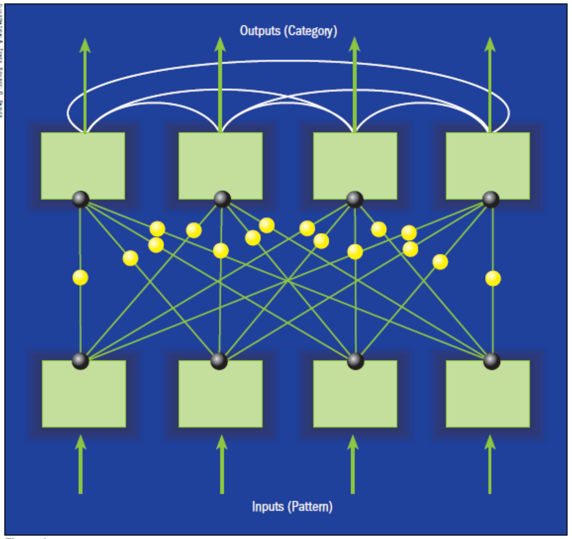
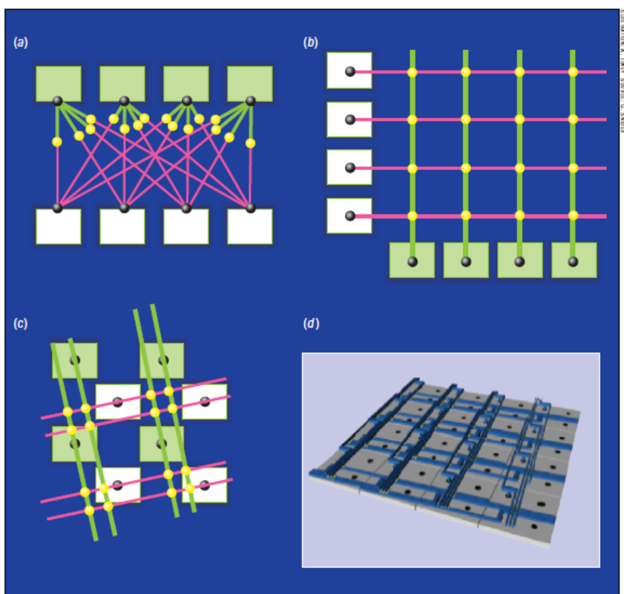


Figure 1. *Winner-take-all competitive network.*



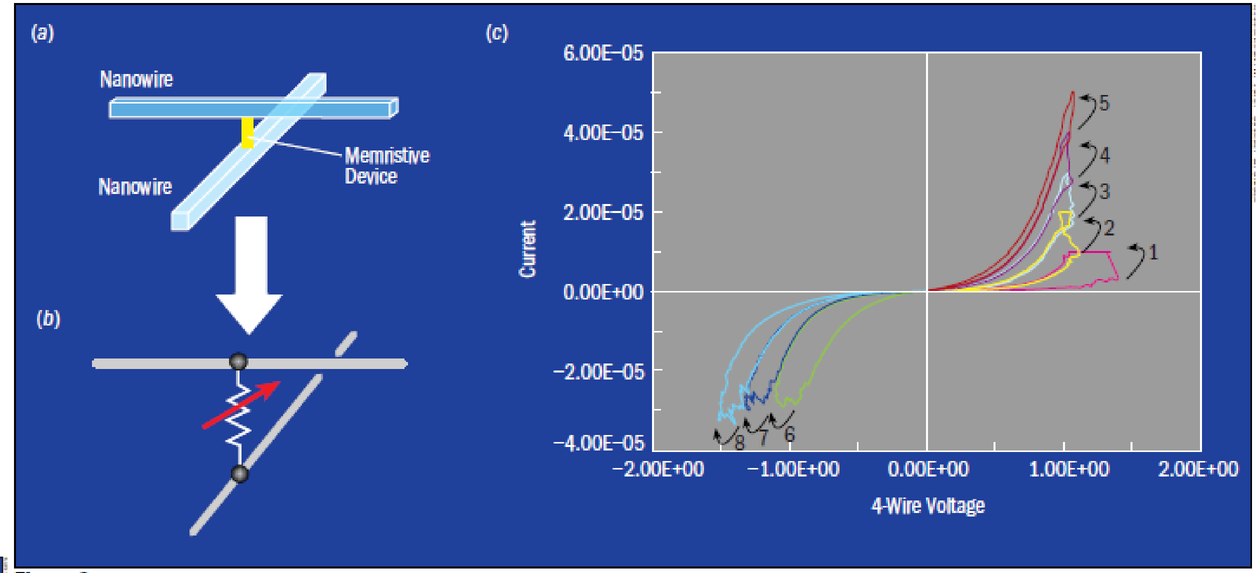


Figure 2. *Dynamical behavior of nanojunctions from experiments. Current–voltage curves are numbered sequentially and offset vertically for clarity. Positive voltage sweeps (1–5) are hysteresis loops of increasing conductivity; negative voltage sweeps (6–8) are hysteresis loops of decreasing conductivity.*