



Memristive Memory: a fundamental shift



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Nanoelectronics Research Group, Hewlett Packard Laboratories
Flash Memory Summit , August 10, 2011

The Memristor: Predicted

Fourth Fundamental Two Terminal Circuit Element

Leon Chua
U.C. Berkeley

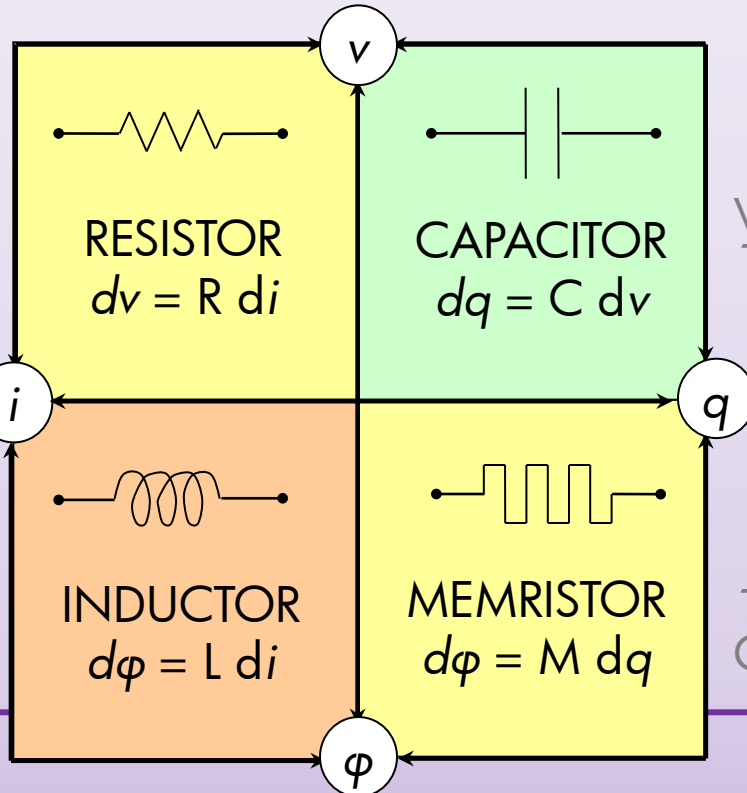
ϕ	v	q	i
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$$d\phi/dt \equiv v$$

$$dq/dt \equiv i$$



Ohm
1827



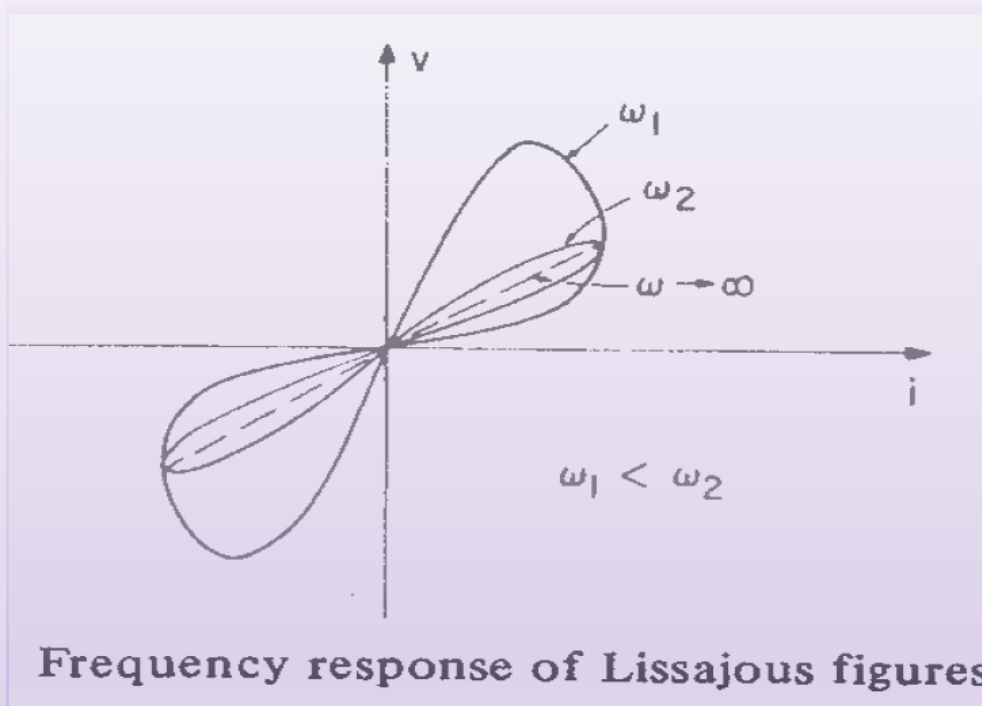
Von Kleist
1745

1831
Faraday

1971
Chua

The Memristor: Fundamentally Different

Dynamical Non-Linear Behavior



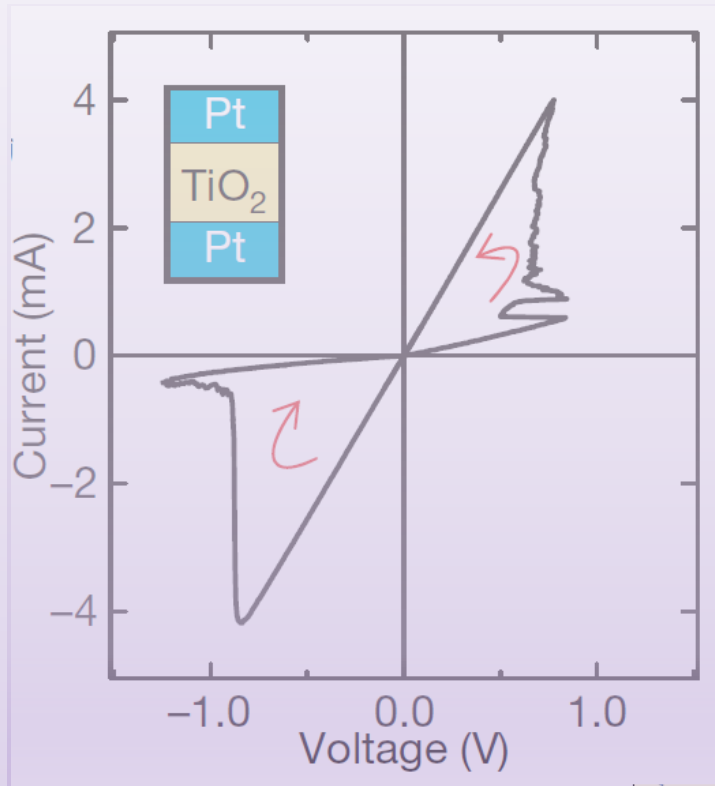
Generalized Memristor
(Memristive system):

$$v = M(w, i)i$$

$$\frac{dw}{dt} = f(w, i)$$

The Memristor: Found

Reduced to Practice in 2008

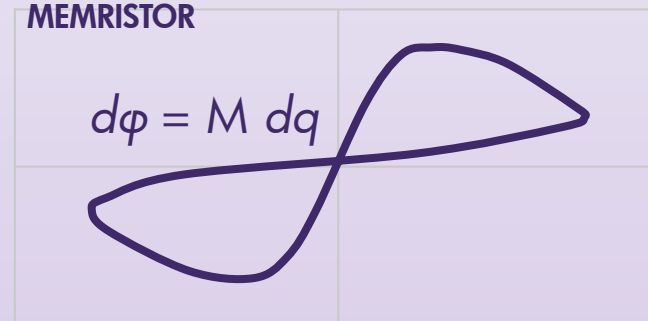
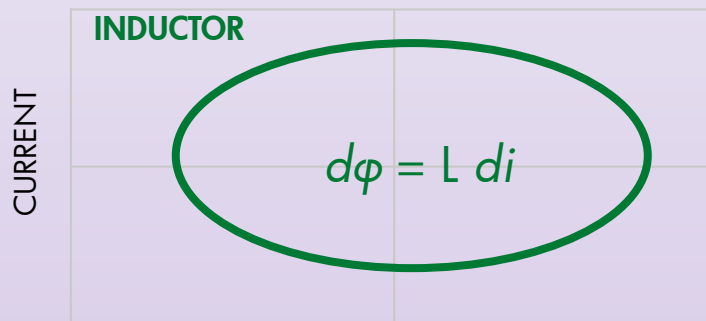
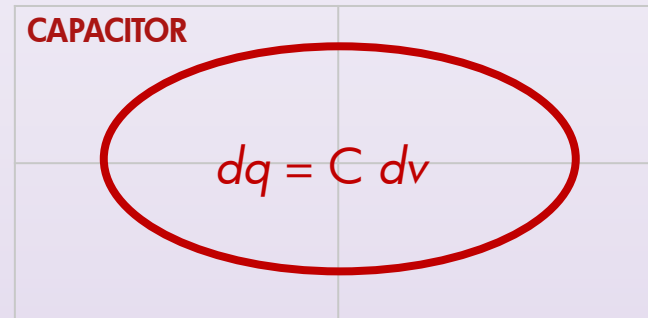
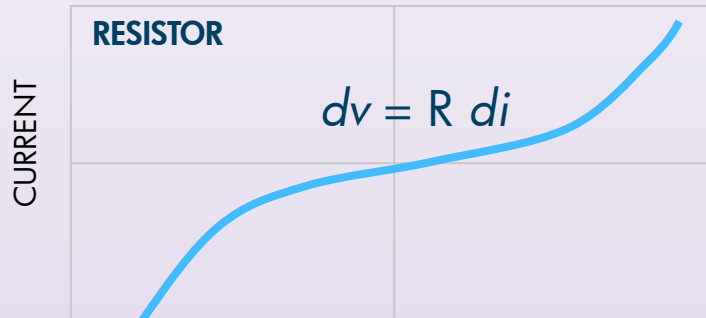
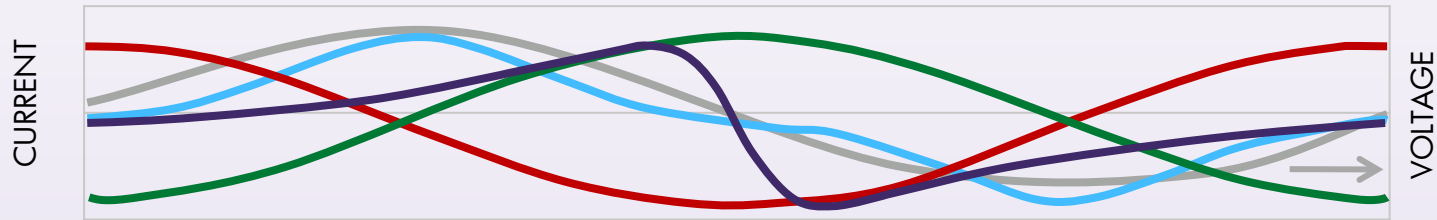


R. Stanley Williams
HP Laboratories

D. B. Strukov, et al., vol 453, 1 May 2008, doi:10.1038/nature06932

What makes a memristor “fundamental”?

Inability to duplicate properties with the other passive circuit elements

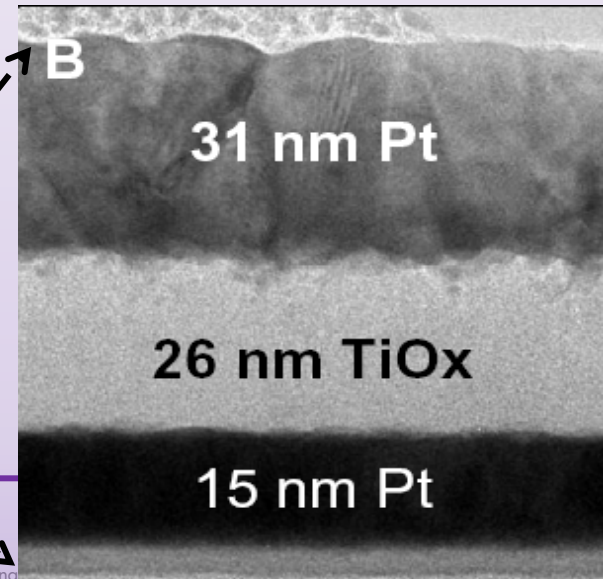
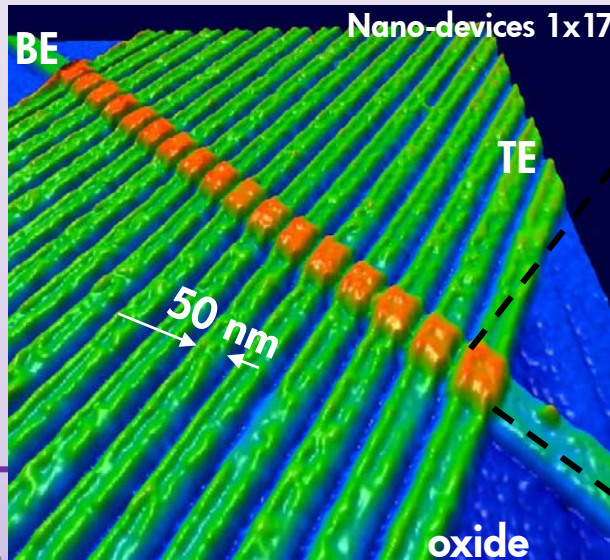
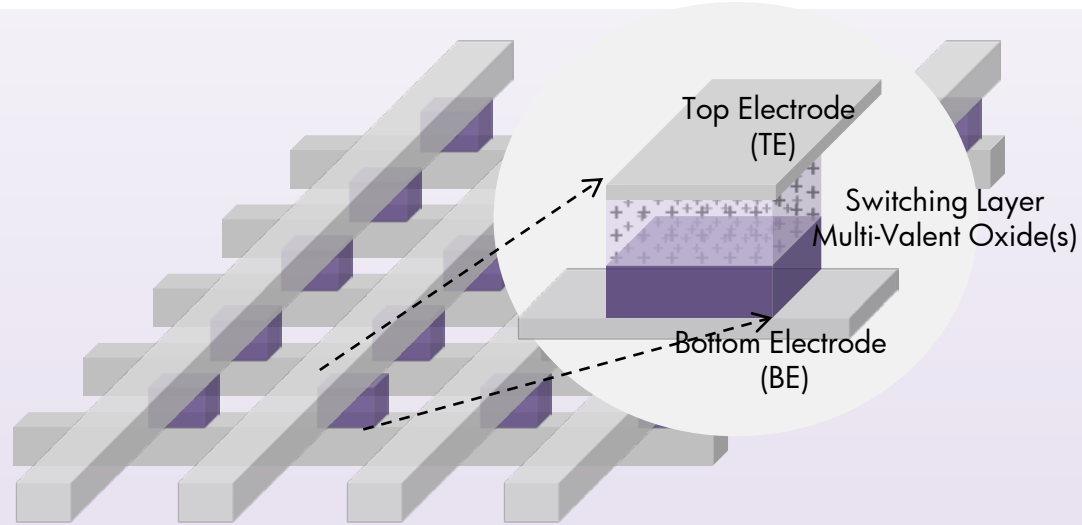


VOLTAGE

VOLTAGE

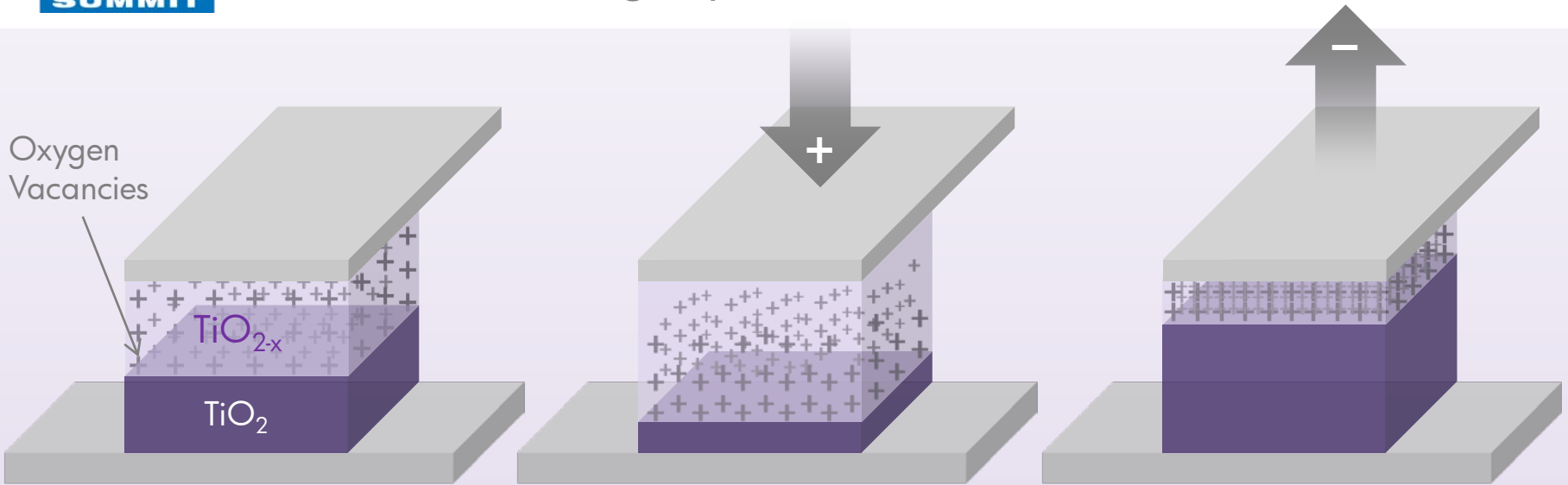
What exactly is it?

Cross-bar device with multi-valent oxide



How does it work?

Semiconducting Bipolar Switch



- highly resistive TiO_2 region
- a conductive TiO_{2-x} region contains positively charged O^+ vacancies
- specific electrodes

- Under positive bias voltage:
- O vacancies drift to the BE
 - Narrows the tunneling gap
 - Reduces resistance.

- Under negative bias voltage:
- O vacancies to drift to the TE
 - Increases tunneling gap
 - Increases resistance

Previously:

Fixed semiconductor structure and only electronic motion

Now:

Ionic motion dynamically modulates the semiconductor structure controlling the electronic current.

Endurance of Memristors over Time

Moore's type increase in endurance





How does it stand up as a memory?

Dynamical and Non-Linear – Enables True Cross-point

	Memristor	PCM	STTRAM	DRAM	Flash	HDD
Density (F ²)	4	8–16	14–64	6–10	4–6	2/3
Energy per bit [†] (pJ)	1–3	2–27	0.1	2	10000	1–10x10 ⁹
Read time (ns)	<10	20–70	10–30	10–50	25000	5–8x10 ⁶
Write time (ns)	~.20	50–500	13–95	10–50	200000	5–8x10 ⁶
Retention	years	years	weeks?	<<second	years	years
Endurance (cycles)	>10 ¹²	10 ⁷	10 ¹⁵	10 ¹⁶	10 ³ - 10 ⁶	10 ¹⁵



Thank you

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