Overview

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Background

Fundamental Circuit Elements
Leon Chua
Timeline of events
Scale
Fundamental Circuit Elements

- **Resistor**: $dv = Rdi$
- **Capacitor**: $dq = CdV$
- **Inductor**: $d\phi = Ldi$
Leon Chua

- In 1971, Chua argued symmetry dictated 4\textsuperscript{th} circuit element
- 6 mathematical relations connecting i, v, q, and \( \varphi \)

\[
\begin{align*}
\frac{dv}{dt} &= Ri \\
\frac{dq}{dt} &= Cdv \\
\frac{d\varphi}{dt} &= Ldi
\end{align*}
\]

- Charge is the time integral of the current: \( dq = idt \)
- Magnetic Flux if the time integral of the voltage: \( d\varphi = vdt \)
Fundamental Circuit Elements

Resistor: $\frac{dv}{dt} = Rdi$

Capacitor: $\frac{dq}{dt} = Cdv$

Inductor: $\frac{d\phi}{dt} = Ldi$

Memristor: $\frac{d\phi}{dq} = Mdq$
Timeline of Events

1971
Leon Chua

2008
HP Labs
What took so long?

- IT’S ALL ABOUT SCALE
- Memristance becomes the dominant effect on circuit components at nanoscale
- Hardly noticeable at even milliscale
- Only recently able to measure $M$
What is a Memristor?

Memristance
Hysteresis
What is a Memristor?

- “Memory Resistor”: remembers its history
- Nanoscale device
- Resistance depends on the magnitude and polarity of the voltage applied
- When the voltage is turned off, it remembers its most recent resistance until the voltage is reapplied

http://www.spectrum.ieee.org/print/7024
Hysteresis

- History dependence of physical systems
- Hysteresis loops occur when the system is altered back and forth

Side Note: no etymological link

http://www.thecdi.com/cdi/images/misc/hysteresis_loop.gif
Hysteresis Loop of a Memristor

- Leon Chua’s v-i plot for an ideal memristor
- Lower frequencies increase loop
- Higher frequencies flatten to linear response

http://www.spectrum.ieee.org/print/7024
Crossbar Array
Connection to Chua’s work
Long-term research group on Moore’s Law, 1995

Goal to create nanoscale computing architecture

Simplest abstraction of Teramac architecture

Crossbar Array allowed for defect-tolerance

http://www.spectrum.ieee.org/print/7024
Crossbar Array

- Storage system – open switch represents a zero, closed switch represents a one
- Array of perpendicular wires – Anywhere two wires cross is a switch
- Open and close switches by applying voltages to the ends of the wires

http://www.hpl.hp.com/research/about/images/nano1.jpg
Crossbar array yielded unpredictable results
- Unexpected hysteresis

Compared to Leon Chua’s i-v plot

Realized they had built a memristor
How Memristance Works

In a Crossbar Array
Crossbar Array

http://www.spectrum.ieee.org/print/7024
Memristor

- A change of 0.3nm will yield a change in R by factor of 1,000
- Cube (TiO$_2$)
  - Lower layer: 2:1 ratio, great insulator
  - Upper layer: oxygen deficiencies (+), conductive metallic material

http://www.spectrum.ieee.org/print/7024
Positive Voltage

- Positive Voltage Repels Oxygen Deficiencies
- Boundary between layers moves down
- Increases Conductivity

http://www.spectrum.ieee.org/print/7024
Negative Voltage

- Negative Voltage Attracts Oxygen Deficiencies
- Boundary between layers moves upwards
- Decreases Conductivity

http://www.spectrum.ieee.org/print/7024
In other words...
Applications
Potential Effect on Moore’s Law

- Currently projected to end with in the decade
- Devices need to be increasing in capability, not just scalability
- Memristor-Transistors hybrid expected to improve circuit performance
- Uses transistors more efficiently,
- Potentially extend Moore’s Law by another decade

http://home.fnal.gov/~carrigan/pillars/Moores_law.png
Instant On computers

- The key feature of a memristor: device remembers previous resistance
- Very appealing for computer memory
- Could be used as nonvolatile memory
- If memory using memristors were to loose power...
  - Remove lengthy boot-up times or unintentional loss of memory due to power failure
Brain Circuits

- Mimic processes of human brain (decade)
- Emulate, not simulate
- Simulate a mouse brain using transistors:
  - astronomical number of PDEs
  - size of a small city
  - several dedicated power plants.
- Using memristors:
  - small enough to fit in a shoebox,
The Future of the Memristor
Conclusions

- The next step:
  - reliable design and manufacture of electrode contacts interconnects and the active region of the memristor must be possible
  - research needs to be put into creating a high resistance ratio between the ON and OFF states.
  - Most manufacturers will embrace this technology only after a well-functioning, large-scale array is clearly demonstrated. When that demonstration occurs, there will surely be a rejuvenated race towards smaller devices.
References

QUESTIONS?