Studies in Memristor-Based Digital Circuits

Mini-Project II (Fourth Semester)

Computer Science and Technology Department
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4th Semester
Computer Science & Technology

What will we discuss today?

Brief on Memristor

Models of Memristor

IMPLY & Memristor Aided Logic (MAGIC)

Simulations on Logic Gates

More about Memristors

What is Memristor?

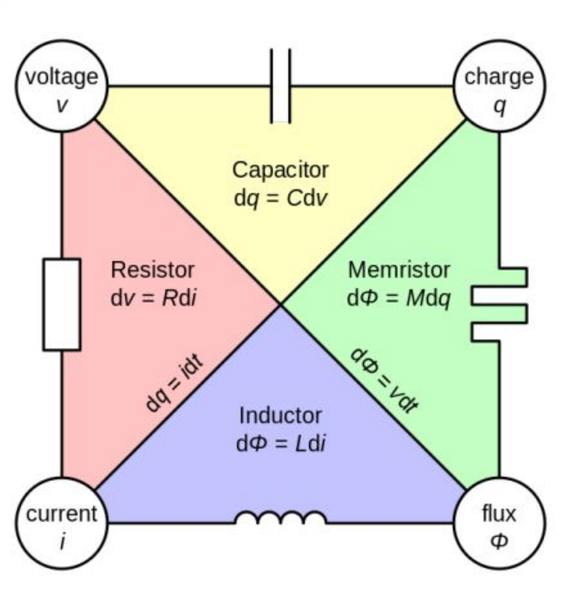
***Memristor*, the contraction of memory resistor, is a passive device that provides a functional relation between charge and flux.**

All of them follow Ohm's law in its own way.

The resistance of the element is varied with the applied potential and its polarity.

It is the property of the memristor that once the applied potential is removed the resistance state is stored and for the next applied potential the memristor starts to work from the last stored resistance.

This is observed from the hysteresis curve obtained on application of potential.



Relationship Diagram

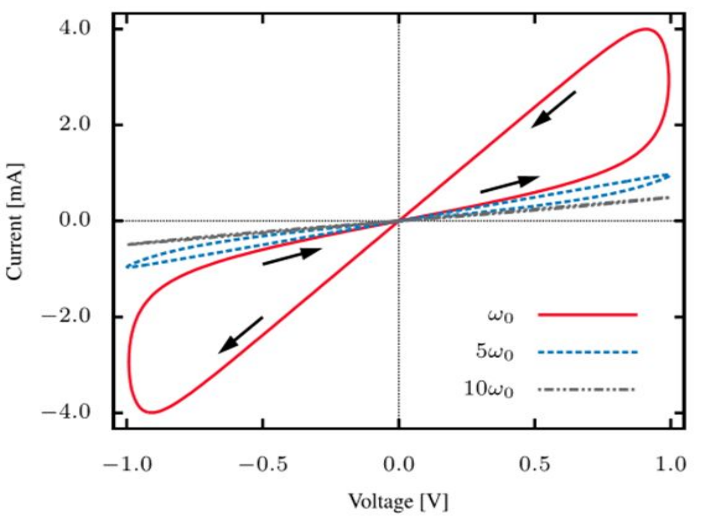
The memristor has varying resistance (also named memristance). Formally, a current-controlled time invariant memristive system is represented by

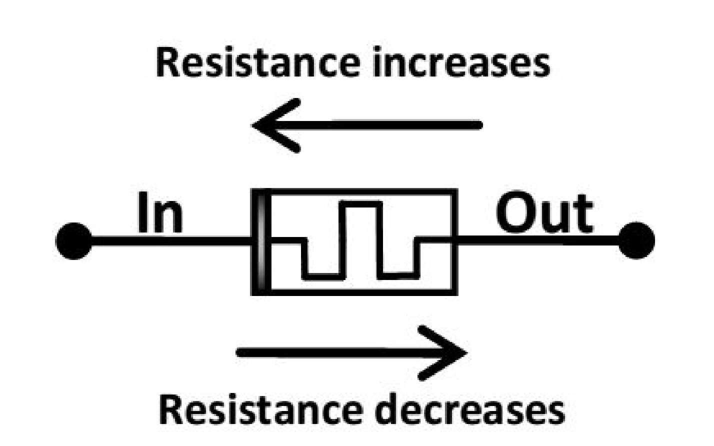
$$\mathbf{d\phi = M\ dq}$$

If each side is divided by dt, it can be converted to

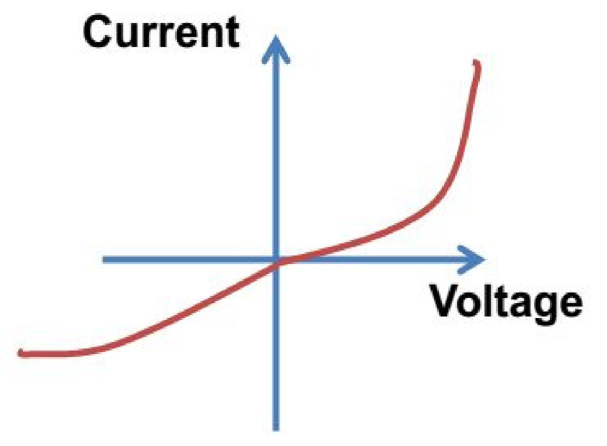
$$\mathbf{d/dt = M\ dq/dt}$$
$$\mathbf{V = M\ I}$$

This can be compared to **V = IR**. That is why this memory based device is compared to resistors and named as memristor.



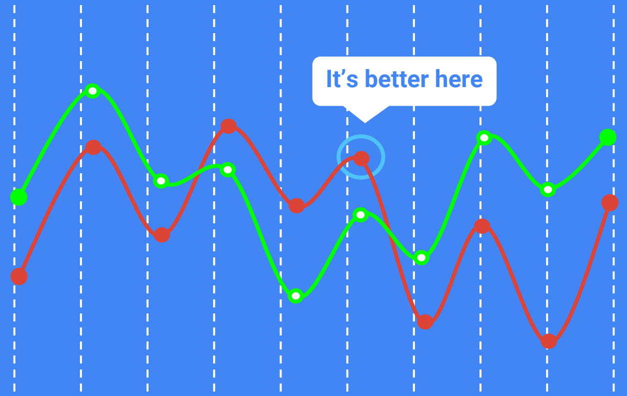


Memristor symbol. The polarity of the memristor is represented by a thick black line. When current flows into the device (the upper arrow), the resistance of the device increases. When current flows out of the device (the lower arrow), the resistance of the device decreases.



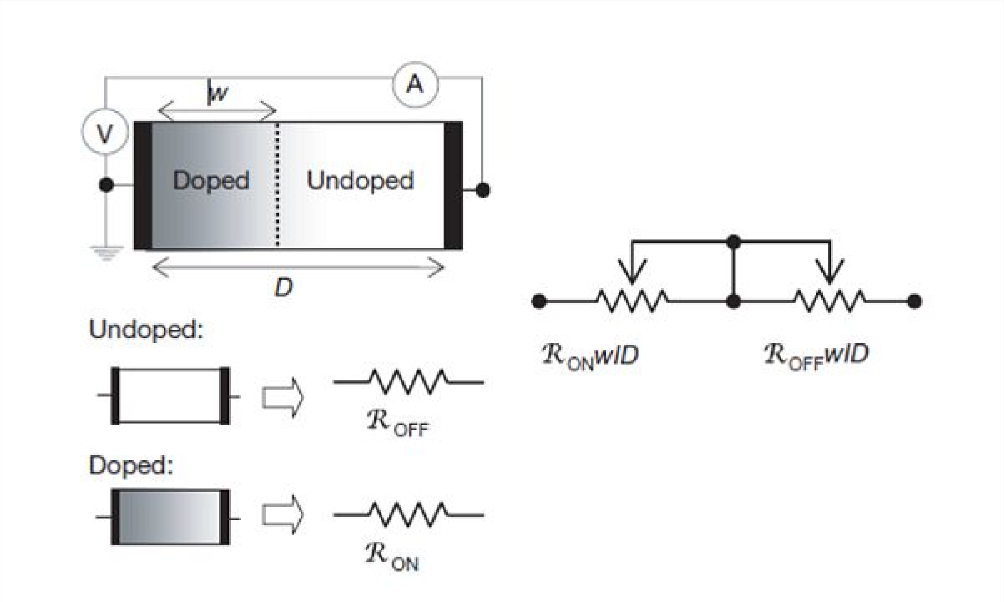
Polarity of Memristor Graph

Physical Models of Memristor

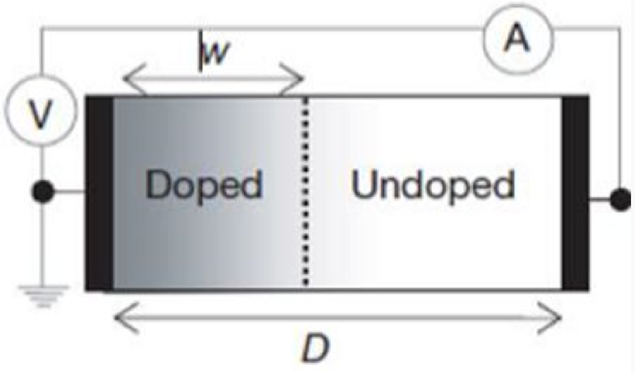


- ★ Linear Model
- ★ Non - Linear Model

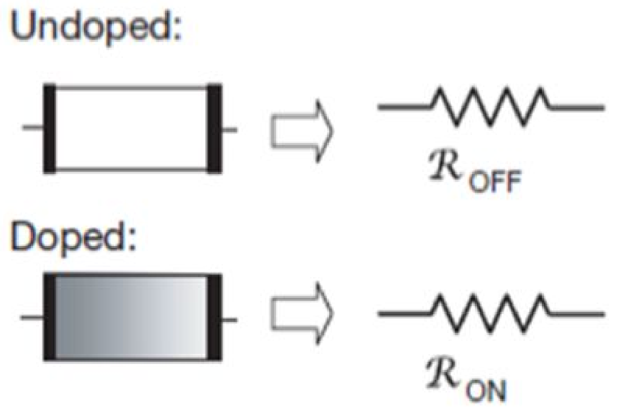
Linear Model



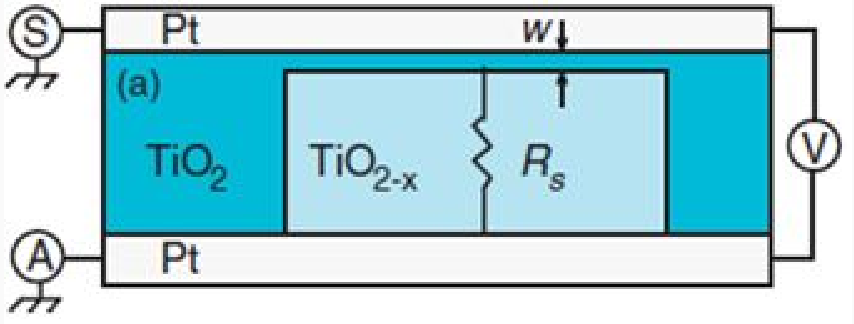
- Developed by HP labs upon production of the first memristor
- Very simplistic model
- Doping of TiO_2 is done here
- The model assumes that charged ions are free to move under the influence of large field, this movement changes the conductance of the media



- Two regions – Doped (having width w) & Un-doped (having width d-w)
- Un-doped region → $Roff$ state(high resistance)
- Doped region → Ron state(low resistance)
- Behaves as two resistor connected in series connection

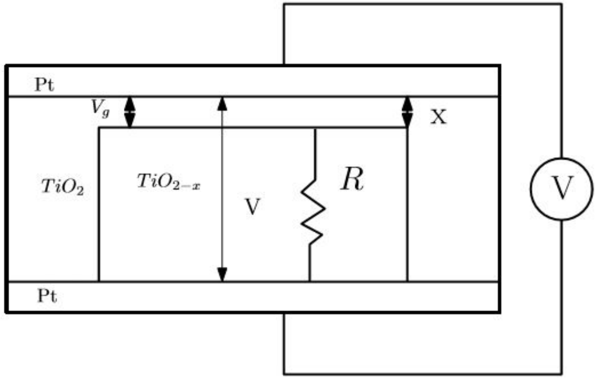


Non - Linear Model



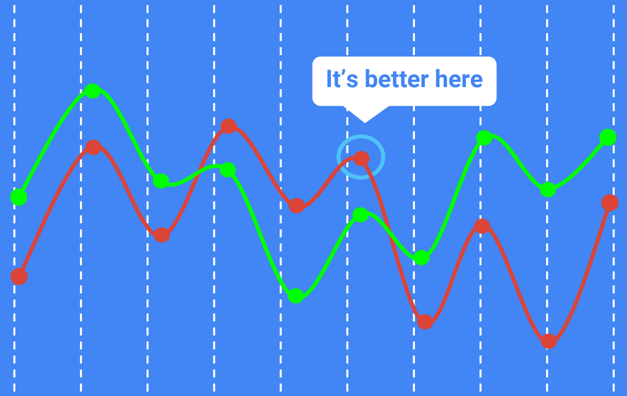
Non-Linear Model of Memristor

- HP's Simmons tunnel barrier model is presented



- TiO_2works as a semiconductor and it is auto-dopped
- Pure TiO_2 is highly resistive but $TiO_{2-x}$is conductive
- When +ve voltage applied
  - Boundery of TiO_2 & TiO_{2-x} is shifted upwards
  - conductivity of the devices increases
- When -ve voltage applied
  - boundary of TiO_2 & TiO_{2-x} is shifted downwards
  - conductivity of the devices increases

Methods for Memristor Based Logic



★ IMPLY (Using IMPLY Logic)
★ MAGIC(Using Memristor Aided Logic)

Determines the logic state either by voltage or resistance across memristor

IMPLY
Using IMPLY Logic

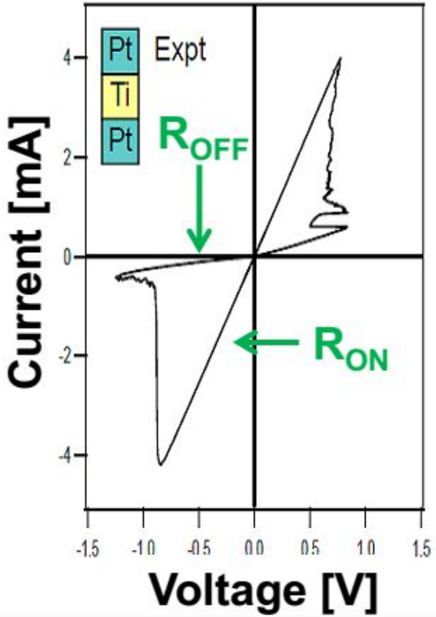
IMPLY logic is the digital logic. It is defined by the theorem. If P is TRUE then output follows Q, otherwise it is TRUE. It stands for if P then Q and is denoted by p) q. By classical logic we say IMPLY gate function is equivalent to ((NOT of P) OR Q). IMPLY logic is said to be functionally complete with which any logic functions can be implemented.

P	Q	$P \rightarrow Q$	$\neg P \vee Q$
0	0	1	1
0	1	1	1
1	0	0	0
1	1	1	1

Output of the IMPLY gate is $P \rightarrow Q$

Logical State as Resistance

- R_{ON} → logical '1', R_{OFF} → logical '0'
- The **input** of the logic gate is the memristor-based cells value
- The **result** is stored into the memory



MAGIC
Memristor Aided Logic

MAGIC, a novel method for memristor-based logic. *Five basic logic functions:*

- NOT
- AND
- NAND
- NOR, and
- OR

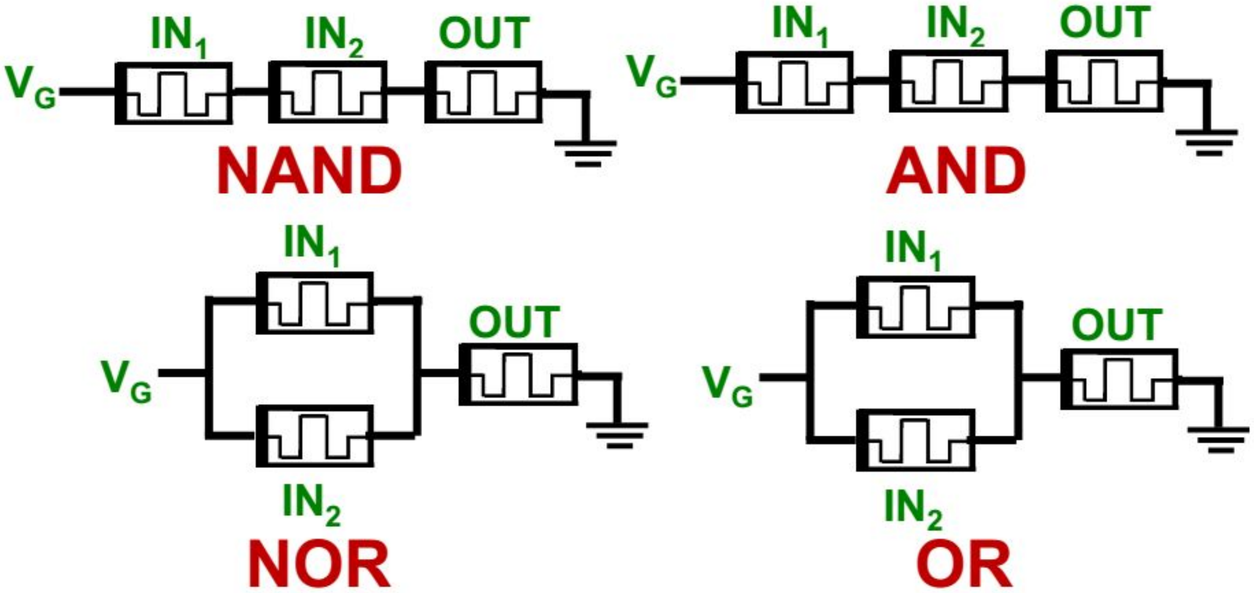
Uses simple connections among memristors, where the number of memristors is equal to the number of inputs plus one additional memristor at the output.

Only one applied voltage controls these logic gates, different than other memristor-based stateful logic.

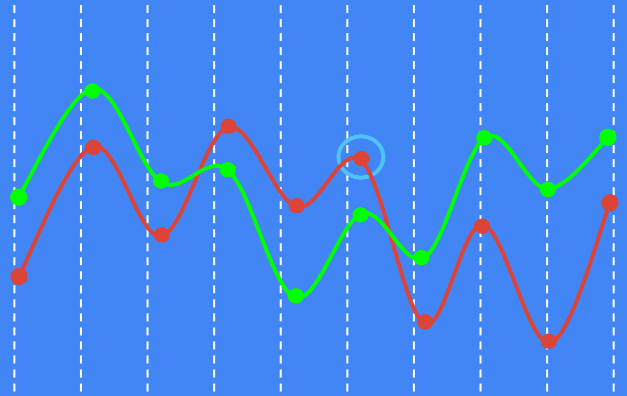
Unlike the *IMPLY gate*, the input and output in *MAGIC* are separated, and the output is written to a dedicated memristor.

MAGIC – Memristor Aided LoGIC

- One applied voltage V_G
- Separate input and output memristors



What we have simulated?

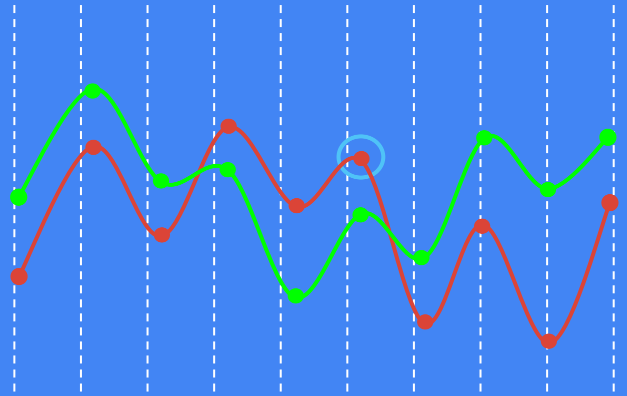


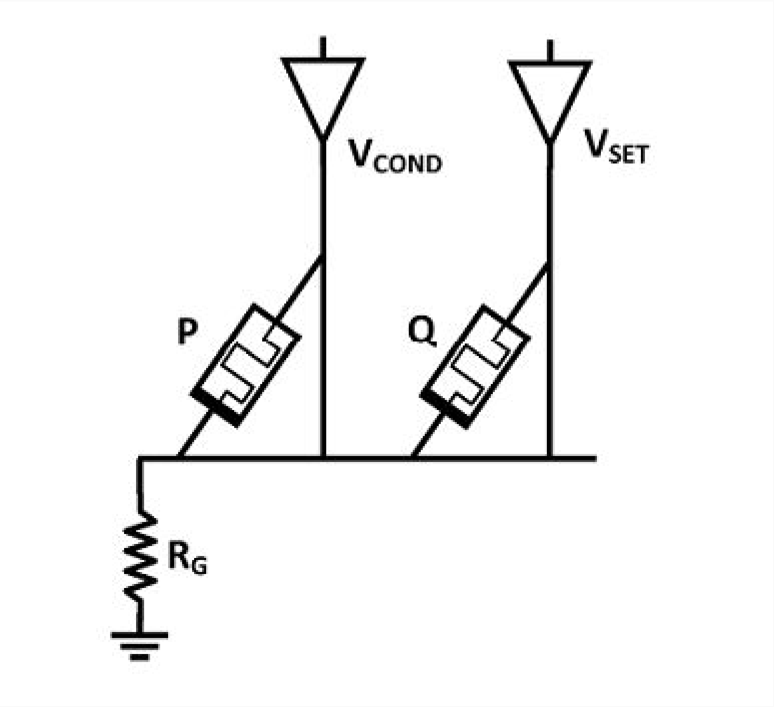
- ★ MEMRISTOR'S STATE & PINCHED HYSTERESIS LOOP
- ★ IMPLY
- ★ MAGIC NOT
- ★ MAGIC AND
- ★ MAGIC OR

What we will simulate today?

- Basic Characteristics (Pinched Hysteresis Loop) of Memristor
- IMPLY GATE
- MAGIC NOT
- MAGIC AND

IMPLY LOGIC





P and Q are memristors, R_G is the resistor, V_{cond} and V_{set} are 0.5V and 1V

IMPLY Logic with Memristors

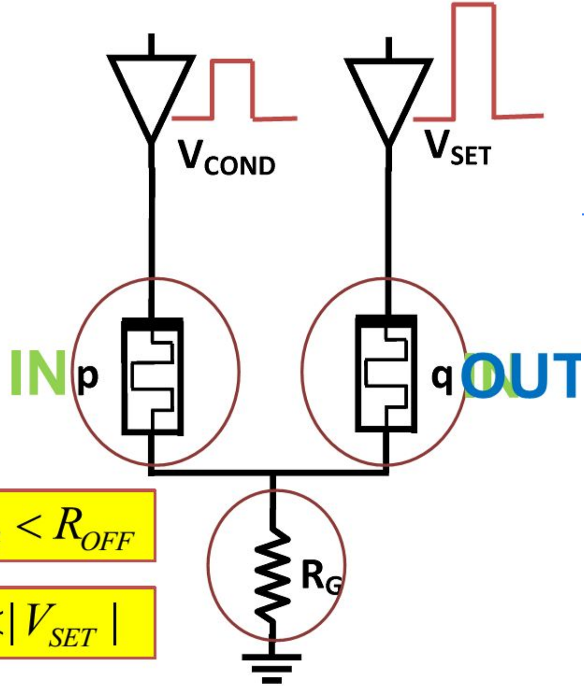
Logic 0 $\rightarrow R_{OFF}$

Logic 1 $\rightarrow R_{ON}$

p	q	*p IMP q*
0	0	1
0	1	1
1	0	0
1	1	1

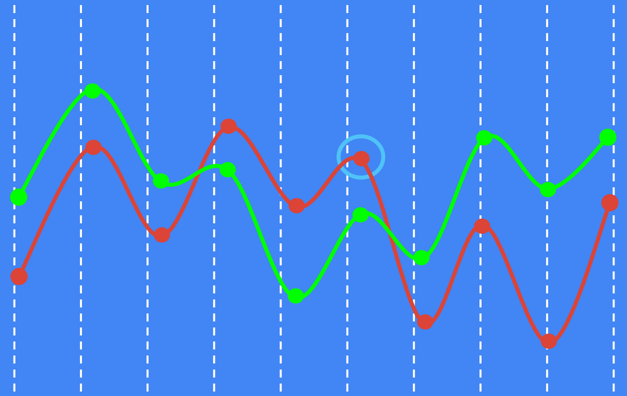
$$R_{ON} < R_G < R_{OFF}$$

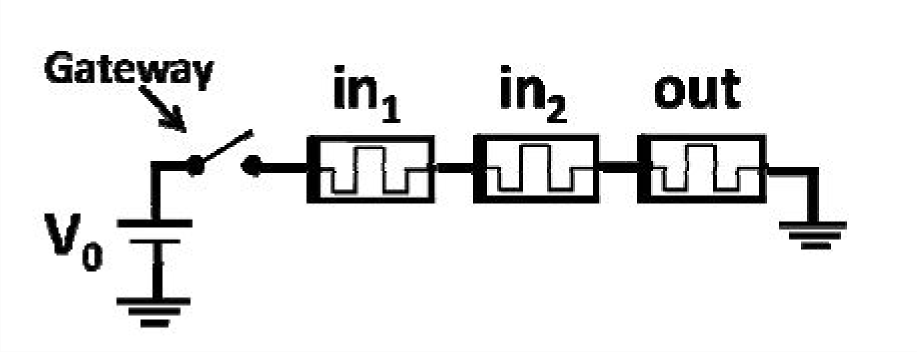
$$|V_{COND}| < |V_{SET}|$$



A	B	~A+B
0	0	1
0	1	1
1	0	0
1	1	1

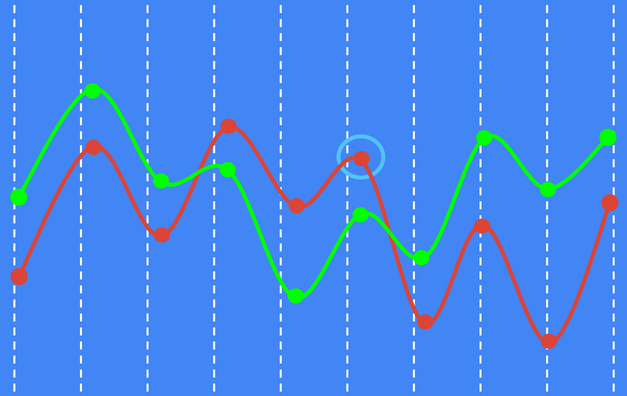
MAGIC AND

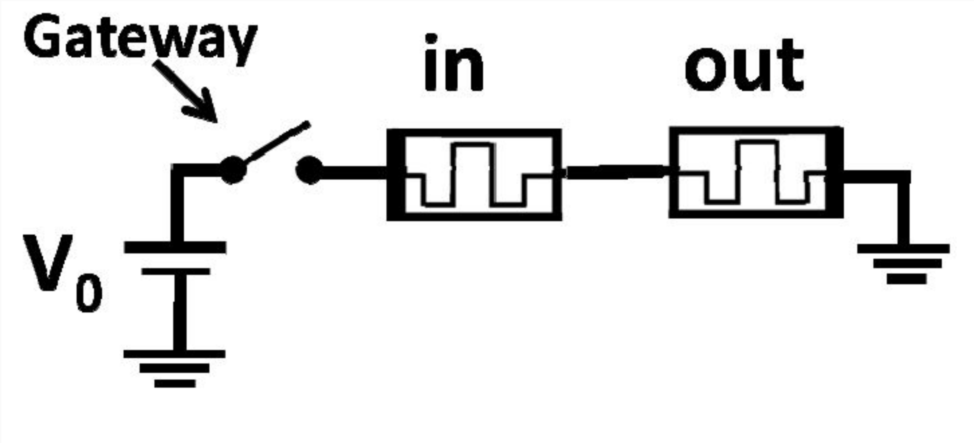




A	B	A.B
0	0	0
0	1	0
1	0	0
1	1	1

MAGIC NOT





A	**~A**
0	1
1	0

Advantages & Disadvantages

- Memristor can hold the value between ‘0‘ and ‘1‘, i.e., values other than digital levels.
- Capable of replacing both DRAM and hard drives
- Smaller than transistors while generating less heat
- Works better as it gets smaller which is the opposite of transistors
- Devices storing 100 gigabytes in a square centimeter have been created using memristors
- Quicker boot-ups
- Requires less voltage (and thus less overall power required)

Advantages

- The major challenges in the application of the memristor are its relatively low speed
- Major changes in the characteristics at high frequency and the need for designers to learn how to build circuits with this new element
- Since the memristor is not yet manufactured commercially, the research remains at the laboratory level only.
- Also there is urgent need for a standard memristor model which can be acceptable for fabrication and simulation purpose.

Future Scope

- Memristor is proposed to be manufactured at nano scale. Hence the device density reduction is main goal in the manufacturing process.

- Since it is at nano scale, the issues arising at nano level need to be studied and tackled.

- The research is in progress on how to model the memristor as a solid state device.

- The memory holding capacity of the memristor needs to be improved in terms of longevity and accuracy.

- Speed increase will add major advantage to memristor technology regarding its use in Crossbar devices.

- The use of memristor in non-volatile Random Access Memory (NVRAM) will bring about ultimate change in the memory storage systems.

- Also use of memristor in the neural network systems may unfold important information about the working of human brain.

Thank You