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Computation Aspect of Memristor Memories

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Headline

- **Introduction**
- Our Approach
- Summary
- Future Work

Introduction

- Demand in Memory
- Memristor

Demand in Memory

- Semiconductor industry has long looking for high-density, high speed, low power memory device that retains its data even the power is interrupted (nonvolatile).
- DRAM (Dynamic Radom Access Memory) used in today's computer must be continuously powered to keep its memory state.
- Flash memory, is nonvolatile, but with slow writing speed and limited number of write/erase cycles.
- Traditional memory are rapidly approaching miniaturization limits as processing technologies limitation.

Universal Memories

1. Ferroelectric RAM (FRAM)

1. Phase Change Memory (PCM)

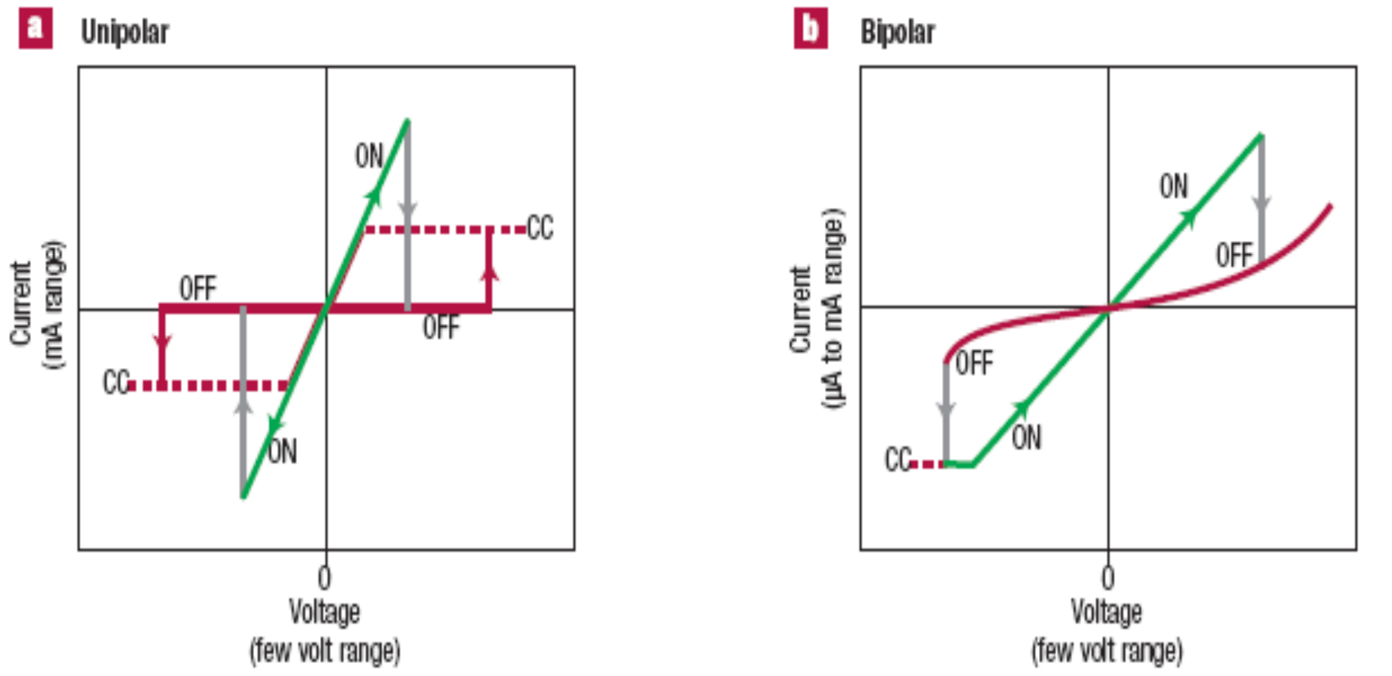
2. Magnetoresistive RAM (MRAM)

3. **Resistance Change Memory (ReRAM)**

ReRAM: Resistance Change Memory

- Two-terminal device, often has a metal insulator metal (MIM) sandwich structure (example $Pt/TiO_2/Pt$).
- Two resistance states: High resistance state (HRS) & Low resistance state (LRS).
- Two basic switching behaviors: Unipolar and Bipolar.

Classification of Switching Mechanisms



R.Waser and M.Aono, Nature Material, Vol.6, p.833, (2007)

Switching is called bipolar when the turn-on and the turn-off processes happen at controversial voltage polarities. On the other hand, switching is called unipolar when both the set and the reset procedures can occur at the same voltage polarity. Unipolar or bipolar: depend on structure/process temp.

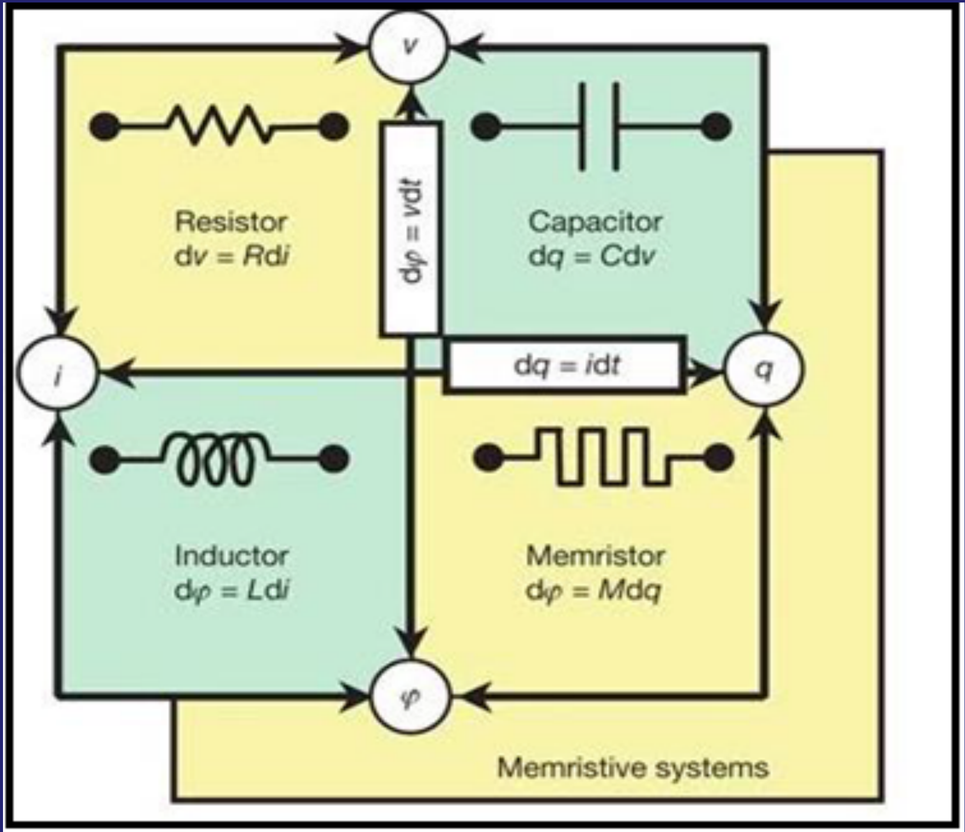
Memristor

- Memristors are resistances with memory.
- Memristors can store data even when power is turned off.
- Leon Chua invented and named memristor in 1971 [1].
- William's team at HP Labs fabricated the first memristor successfully in 2008 with speed only 1/10th of DRAM[2].
- Memristors are intended for use in nano-electronic memories and computer logic among others.

Some important work

- **2008**, Williams published an article in Nature identifying a link between the 2-terminal resistance switching behavior found in nanoscale systems and memristors.
- **2009**, Di Venta, Pershin, and Chua extended the notion of memristive systems to capacitive and inductive elements,
  namely capacitors and inductors, whose properties depend on the state and history of the system.
- **2015**, Knowm Inc announced Self Directed Channel (SDC) memristors commercially.
- **2018**, MemSat (Memristor Satellite) was launched to fly a memristor evaluation payload.

Featured Photo



Fundamental circuit elements

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Our Approach

1. Computer Simulation and Analysis of conduction mechanism
   Computer simulation of the memristor that based on a Verilog A model were conducted. Verilog A model works well in predicting the behavior of the memristor [3].
2. Matlab and Simulink programming explored the various dimensions of crossbar structure impact on the behavior of memory[4].

Model for Verilog A

The voltage across a charge-controlled memristor can be specified as:

$$v(t) = M\big(q(t)\big) \cdot i(t)$$

$$M(q) = \frac{d\varphi(q)}{dq}$$

For voltage-controlled memristor:

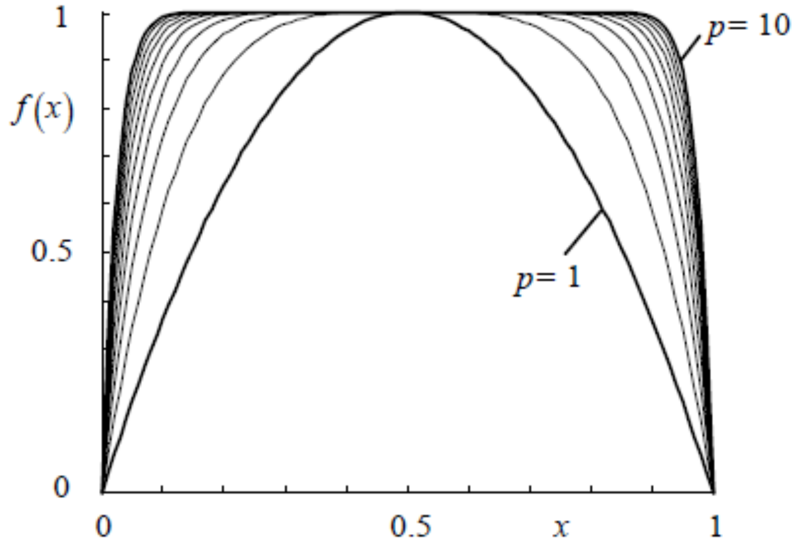
$$i(t) = W\big(\varphi(t)\big) \cdot v(t)$$

$$W(\varphi) = \frac{dq(\varphi)}{d\varphi}$$

Window Function used

Nonlinear effect: $\frac{dx}{dt} = ki(t)f(x)$ $k = \mu R_s / D^2$ $x = W/D$

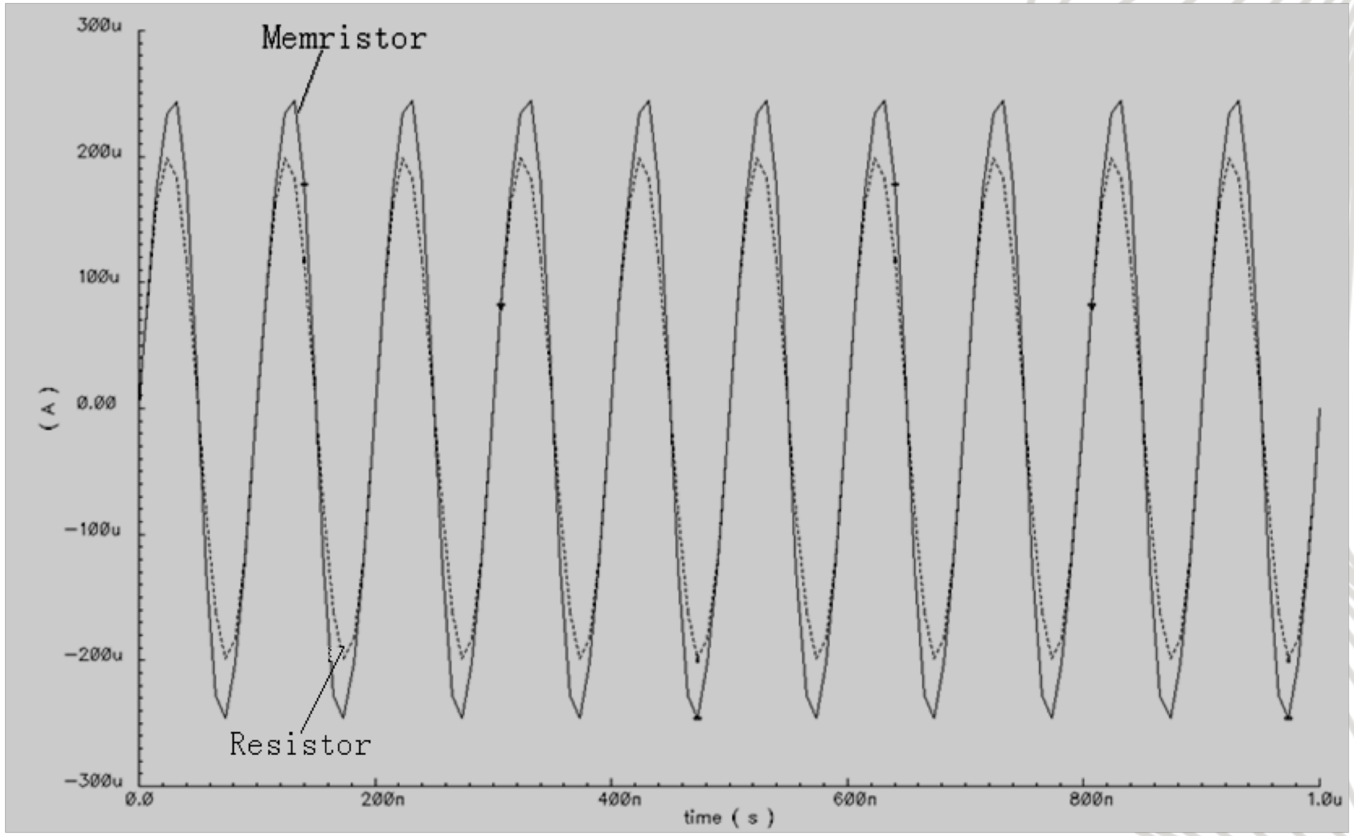
Window Function : $f(x) = 1 - (2x - 1)^{2p}$



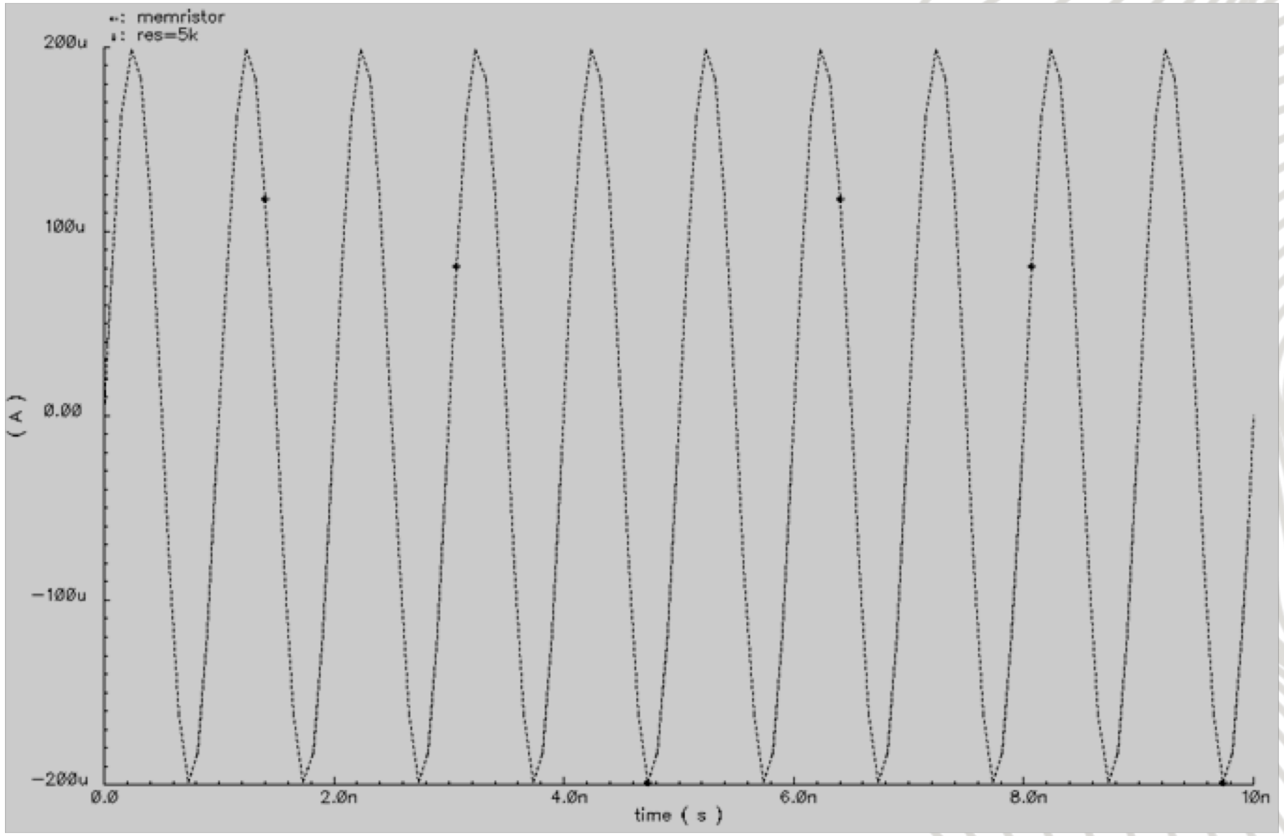
Biolek, D., Biolek, Z., & Biolkova, V. (2009)

Biolek, D., Biolek, Z., & Biolkova, V. (2009)

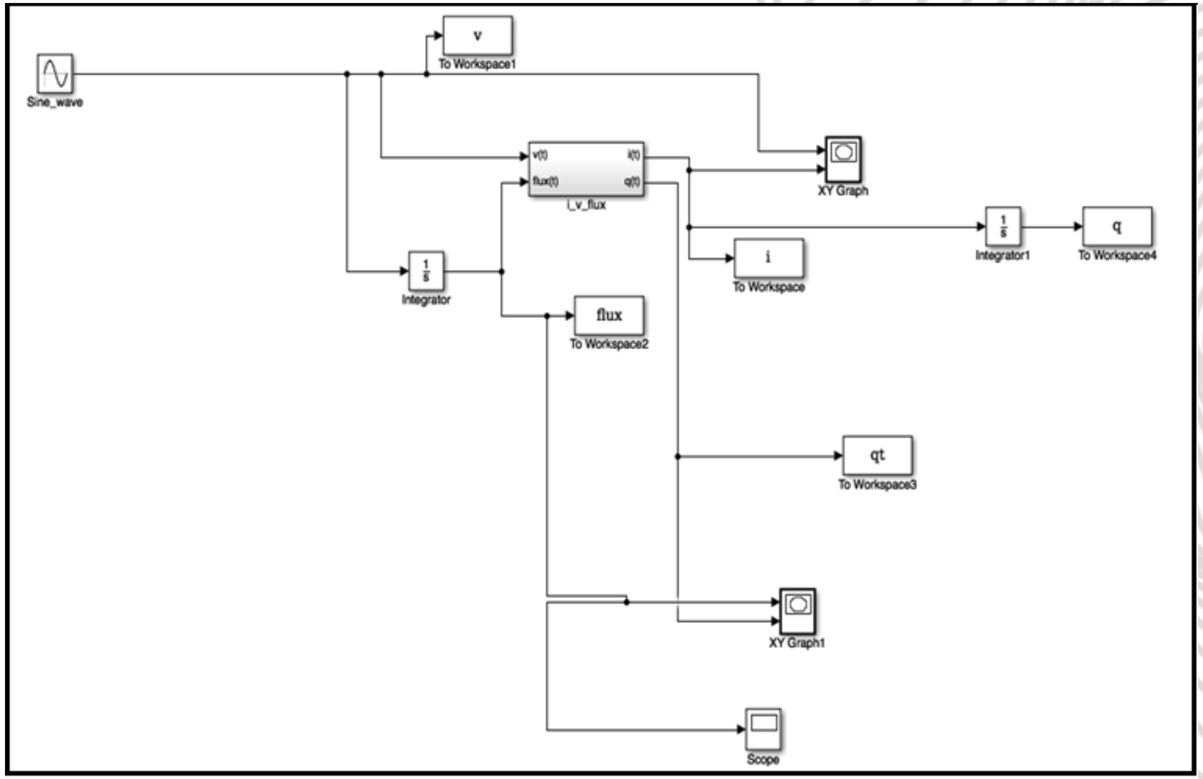
Frequency Response @ 10 MHz



Frequency Response @ 1GHz



Cross Bar Simulation Mathematic model

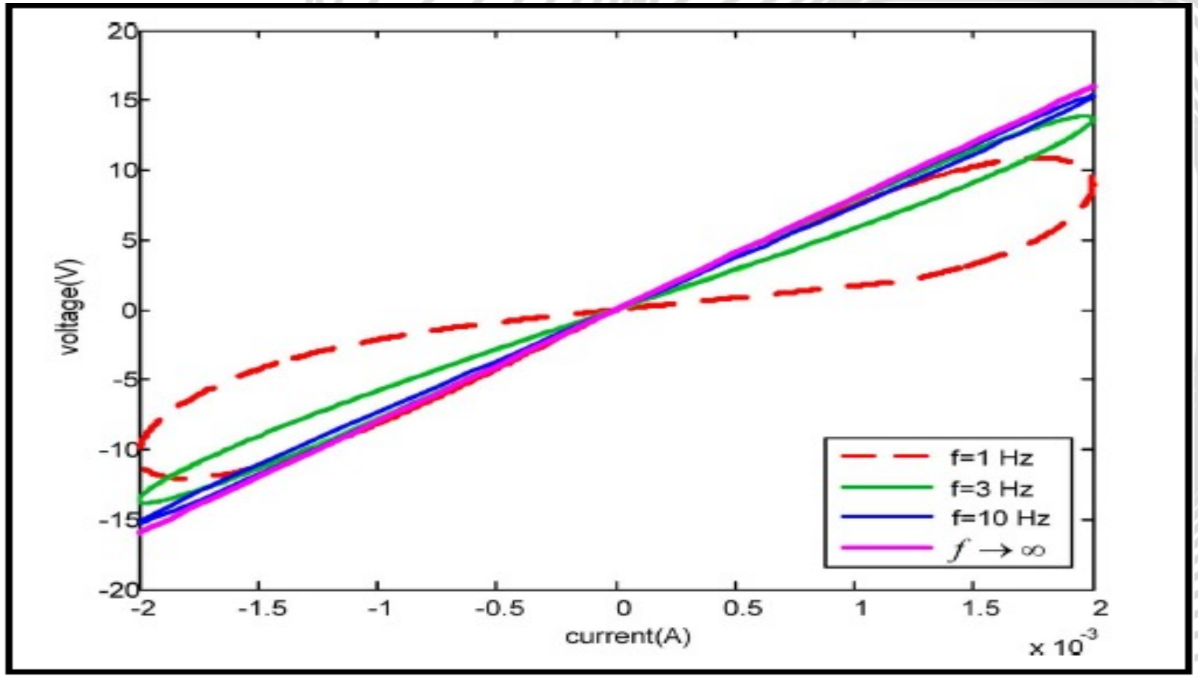


Mathematic Model of Memristor

Methodology

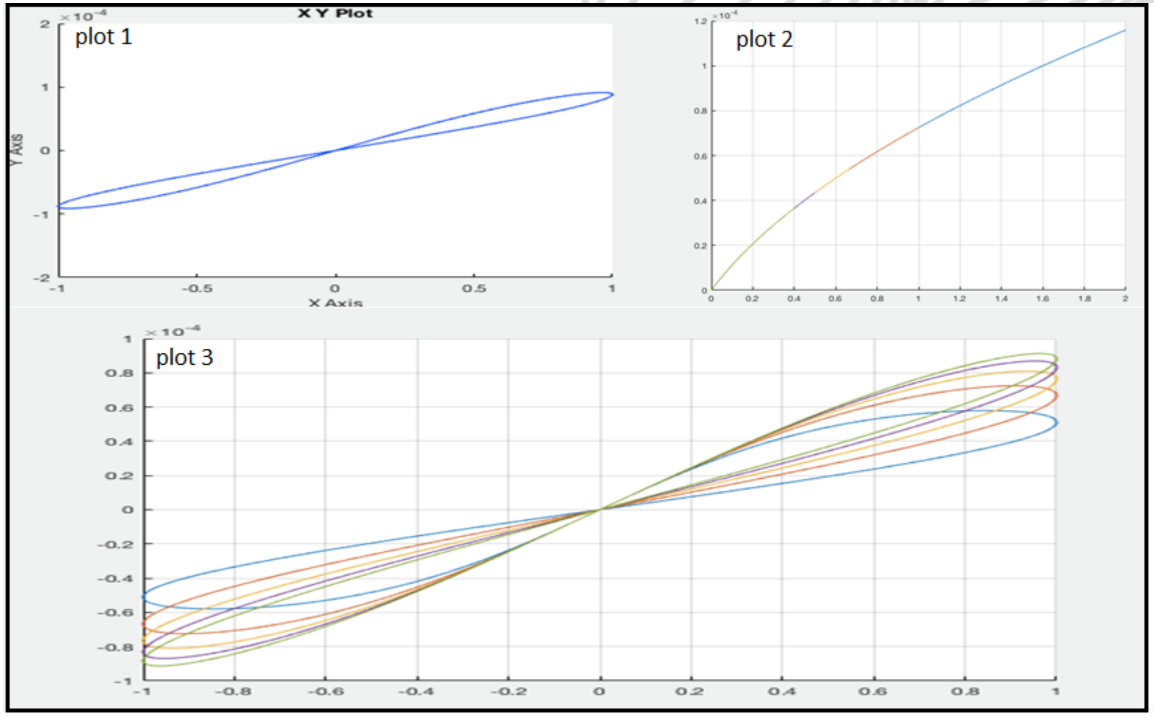
- The charge axis is the input charge to the composite device and does not represent the charge of the individual memristors.
- The charge of the individual memristors corresponding to the flux is obtained by adding its corresponding initial charge to

  the horizontal-axis value of the charge.



Hysteresis plot for at different frequencies

Case of simulation: when the width of doped region was considered to be half of the total thickness.→ W = D/2. This case is considered to be the ideal case for simulation of a memristive system.



plot 1: Voltage versus Current ; plot 2: Charge versus Flux; plot 3: Hysterisis curve

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Summary

- Various memory is in urgent need of today's circuit.
- Memristor based RRAM has great potential in future application.
- Computer simulation is great tool for researcher of novel memories by memristor: performance, behavior prediction, conduction mechanism analysis, design optimization, et al.

Future Work

- Continue in computer simulation and analysis for memristor;
- Computation in various novel structure memristor design optimization; and in memory implementation;
- Fabrication and characterization are essential for continued success.

References

- [1] L. O. Chua, "Memristor—the missing circuit element," IEEE Trans. Circuit Theory, Vols. CT-18, no. 5, pp. 507-519, September 1971.
- [2] D. B. Strukov, G. S. Snider, D. R. Stewart, and R. S. Williams, "The missing memristor found," Nature, vol. 453, no. 7191, pp. 80-83, May 2008.
- [3] D. Xia, and L. He, “Verilog A modeling of the memristor for circuit applications”, Nanotech Conference and Expo 2011, June 13-16, 2011, Boston, MA
- [4] M. Negi, S. Srinivasan, and L. He, S. Hamedi-Hagh, “Crossbar Architecture for Memristor Based Memory Design”, Nanotech France, June 26-28, 2019, Paris, France