The missing memristor found

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Abstract

Anyone who ever took an electronics laboratory class will be familiar with the fundamental passive circuit elements: the resistor, the capacitor, and the inductor. However, in 1974 Leon Chua reasoned from symmetry arguments that there should be a fourth fundamental element, which he called a memristor (short for memory resistor).

Reference


- Memristor Fundamentals
- Memristor Modeling
- Dynamic Behavior of Interconnected Memristors
- Memristor-Based Logic Circuits
- Memristor Crossbar-based Nonvolatile Memory
- High-Density ALU-based on memristors, etc.
A model for transistor

\[ L = f(s) \]
\[ R_{e} = \frac{1}{n \rho_{e}} g(L) \]

\( T_{ox} \) = tunneling transmission coefficient
\( n \rho_{e} \) = effective density of electrons
\( L \) = tunnel barrier width
\( g(L) \) = voltage dependent parameter

A circuit model

\[ V_{th} = \text{initial value of } V \]
\[ L_{o} = \text{tunnel barrier width} \]
\[ V_{th}, V_{t} = \text{left, right threshold voltages} \]
\( a, \beta, \gamma \) = parameters to model nonlinear \( V_{th} \)
\( m, n_{p} \) = fitting parameters
\( m_{r} \) = smoothing function's parameter

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1. Set \( \text{model transistor plus minus} \) PARAMETERS:
2. \( \text{parameters values} \)
3. \( V_{th1} = 100 \quad V_{th2} = 10 \quad \text{threshold} = 1 \quad \text{voltage} = 1 \)
4. \( \beta \) = 10 \( \gamma \) = 1 \( \delta = 1 \) \( \gamma_{min} = 1 \quad \Delta = 1 \)
5. \( V_{th} = \alpha \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th1}) \}
6. \( \gamma \) = \( \gamma \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th2}) \}
7. \( \gamma_{min} \) = \( \gamma_{min} \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th2}) \}
8. \( \gamma_{max} \) = \( \gamma_{max} \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th1}) \}
9. \( \gamma_{max} \) = \( \gamma_{max} \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th2}) \}
10. \( \gamma_{min} \) = \( \gamma_{min} \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th1}) \}
11. \( \gamma_{max} \) = \( \gamma_{max} \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th2}) \}
12. \( \gamma_{min} \) = \( \gamma_{min} \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th1}) \}
13. \( \gamma_{max} \) = \( \gamma_{max} \text{ value} = \{ \text{at } \text{at } (V_{th} - V_{th2}) \}

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(Finalized)

14. \( \text{Func } \text{for nonlinear threshold behavior} \)
15. \( \text{Func } f_{x} = \{ -\alpha \star (x - \gamma) \} \)
16. \( \text{Func } f_{y} = \{ \gamma \star (x - \gamma) \} \)
17. \( \gamma \text{ for smoothing function} \)
18. \( \gamma \text{ for threshold} \)
19. \( \gamma \text{ for threshold} \)
20. \( \gamma \text{ for threshold} \)
21. \( \gamma \text{ for threshold} \)
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30. \( \gamma \text{ for threshold} \)
31. \( \gamma \text{ for threshold} \)
For example,

\[ p = 2 \]
\[ D = 3 \text{ nm} \]
\[ \text{m} = 1 \text{ pm} \]
\[ \varepsilon = 3 \times 10^6 \text{ V/m} \]
\[ \text{m} = \{ 1000, 75, 0.1, 50, 49, 50, 0.6, 1.7 [\text{V}] \} \]

\[ M(p) \text{ vs } V \]

With SPICE or a process simulator, various combinations of parameters have been studied.
Operation Steps

1. Start up
2. Apply inputs
3. Initialize state
4. Update state according to inputs
5. Output state

CMOS/Memristor Threshold Logic

\[ f(x_1, x_2, \ldots, x_n) = \begin{cases} 1, & \text{if } \sum \frac{w_i}{\|w_i\|} \geq X_{\text{threshold}} \\ 0, & \text{otherwise} \end{cases} \]

Memristive Crossbar-Based Nonvolatile Memory

Advantages:
- Scalability
- Density
- Cost
- Compatibility
- Speed
- Energy Efficiency
- Anti-radiation hardness

D-RAM: FROM Flash (read) TO S-RAM (write)

DRAM Read Time: 80ns to 120ns

Write Time: 0.5ns to 1ns

Cell Times:
- Write: 1-10ns
- Read: 10ns to 20ns

Redox-based RAM (reduction-oxidation)

Anti-Fused memristive switch (AFM)

\[ \begin{align*}
\text{Write} & : V_{\text{write}} \rightarrow \text{Redox} \\
\text{Read} & : \text{Redox} \rightarrow V_{\text{read}} \\
\text{Reset} & : V_{\text{reset}} \rightarrow \text{Redox} \\
\text{Set} & : \text{Redox} \rightarrow V_{\text{set}} \\
\end{align*} \]
- Metal-Semiconductor junction.
- Lower forward turn-on voltage.
- Steeper I-V curve
- Majority-carrier (Electron) device. Not like p-n diode using minority-carrier charge-storage effects.
- Higher cutoff frequency, reproducibility and ease of fabrication.
- Extaaxial and ion-implantation.
- Rectifying or non-rectifying (ohmic-contact)

No minority carrier storage!