

Memristor: Theory and Implementations

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Theory

- Memory Resistor
- Thought up in 1971 by Leon Chua.
- Non-linear, passive, two-terminal electrical component.
- “Missing” compliment to resistor, capacitor and inductor.

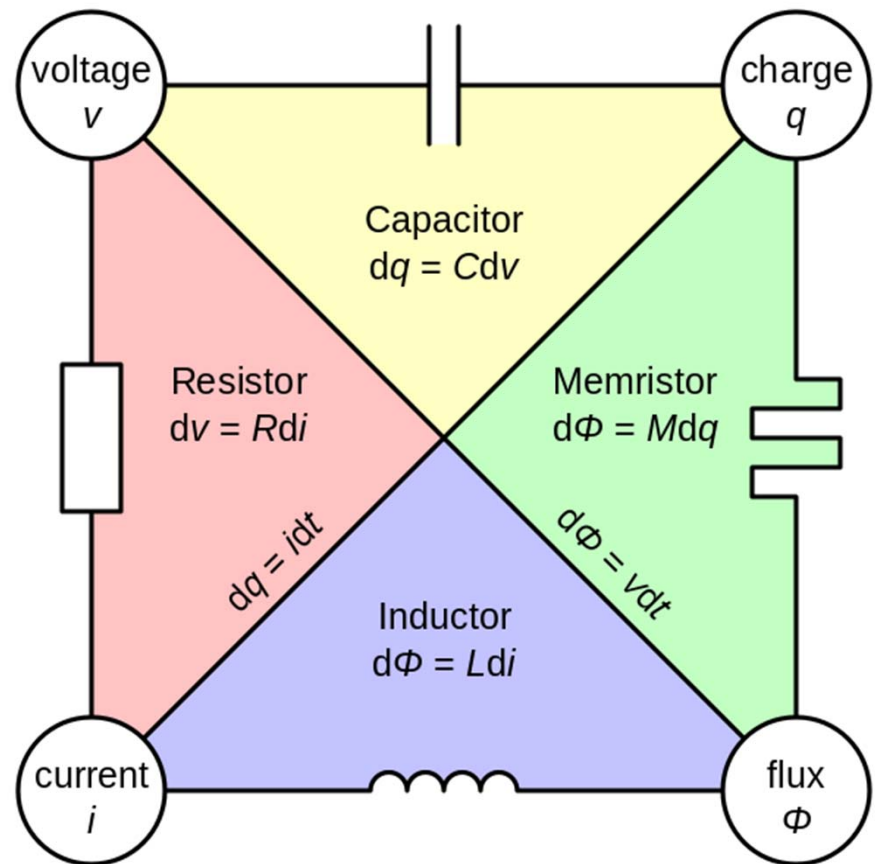


Image Credit: Jeremy Tan Jie Rui

Parameter Relationships

- Resistor: $dv = Rdi$
- Capacitor: $dq = Cdv$
- Inductor: $d\phi = Ldi$
- **Memristor: $d\phi = Mdq$**

Memristor Specific Equations

- $M(q) = \frac{d\phi_m}{dq}$
- $M(q(t)) = \frac{d\phi_m/dt}{dq/dt}$
- $M(q(t)) = \frac{V(t)}{I(t)}$

Aside: Linearity

- (Ideal inductors, capacitors, resistors are linear circuit elements)
- The math for a “linear” Memresistor collapses to a resistor
- $M(q(t)) = \frac{V(t)}{I(t)}$
- $M = \frac{V}{I} = R$

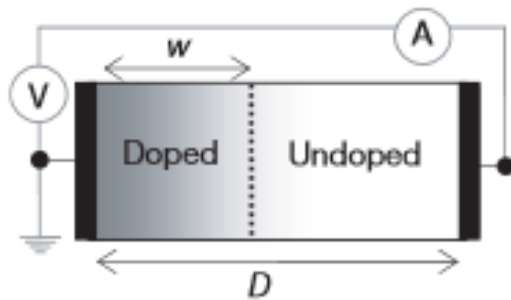
Implementations

- Titanium Dioxide
- Polymeric
- Layered
- Ferroelectric
- Spin memristive systems

Titanium Dioxide Memristor

- R. Stanley Williams, HP, 2008
- Solid state, nanoscale thin film.
- Key differences from theoretical memristor
- Works off the principle of fast ion conductors

Titanium Dioxide Memristor

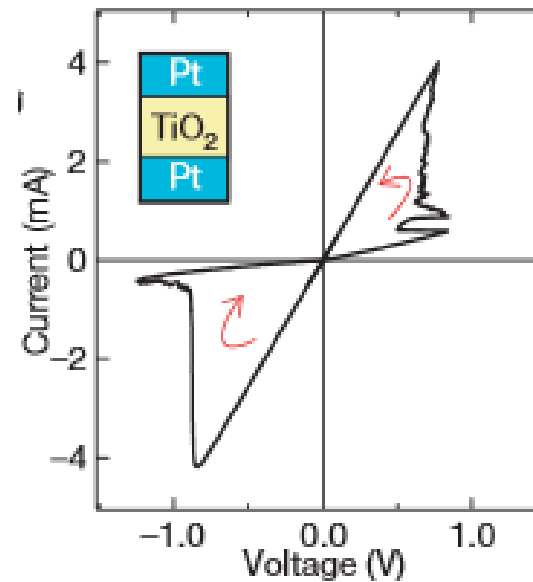
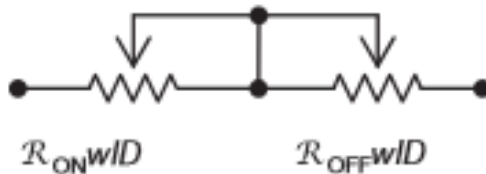


$$v(t) = \left(\mathcal{R}_{\text{ON}} \frac{w(t)}{D} + \mathcal{R}_{\text{OFF}} \left(1 - \frac{w(t)}{D} \right) \right) i(t)$$

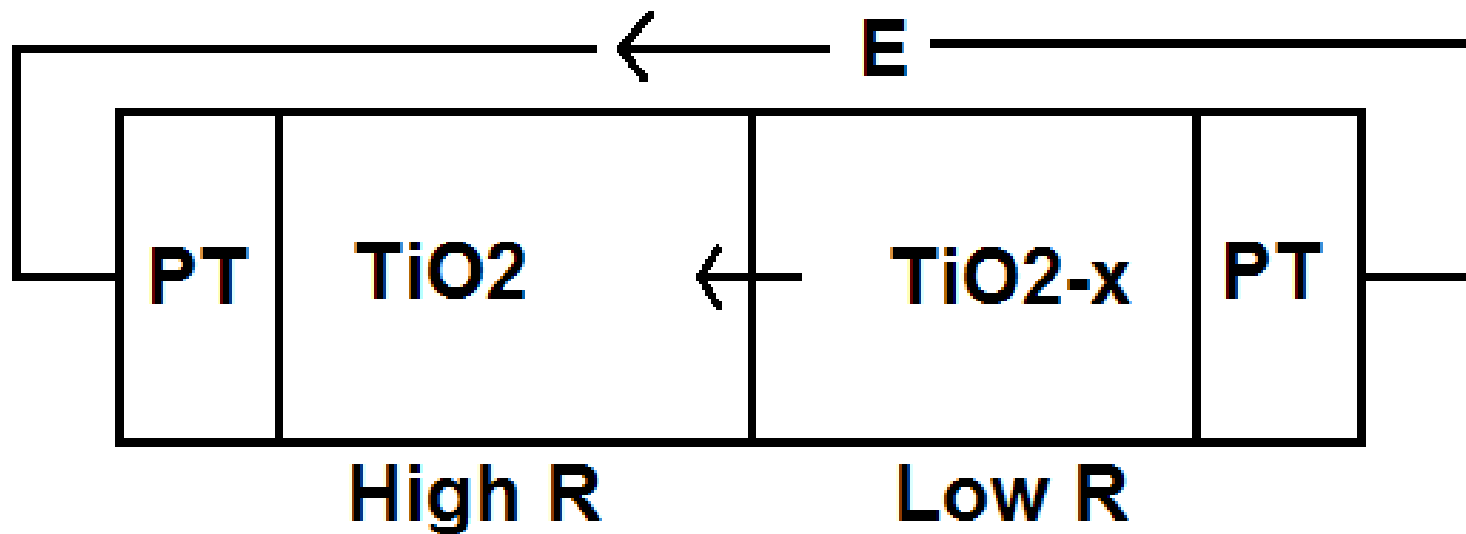
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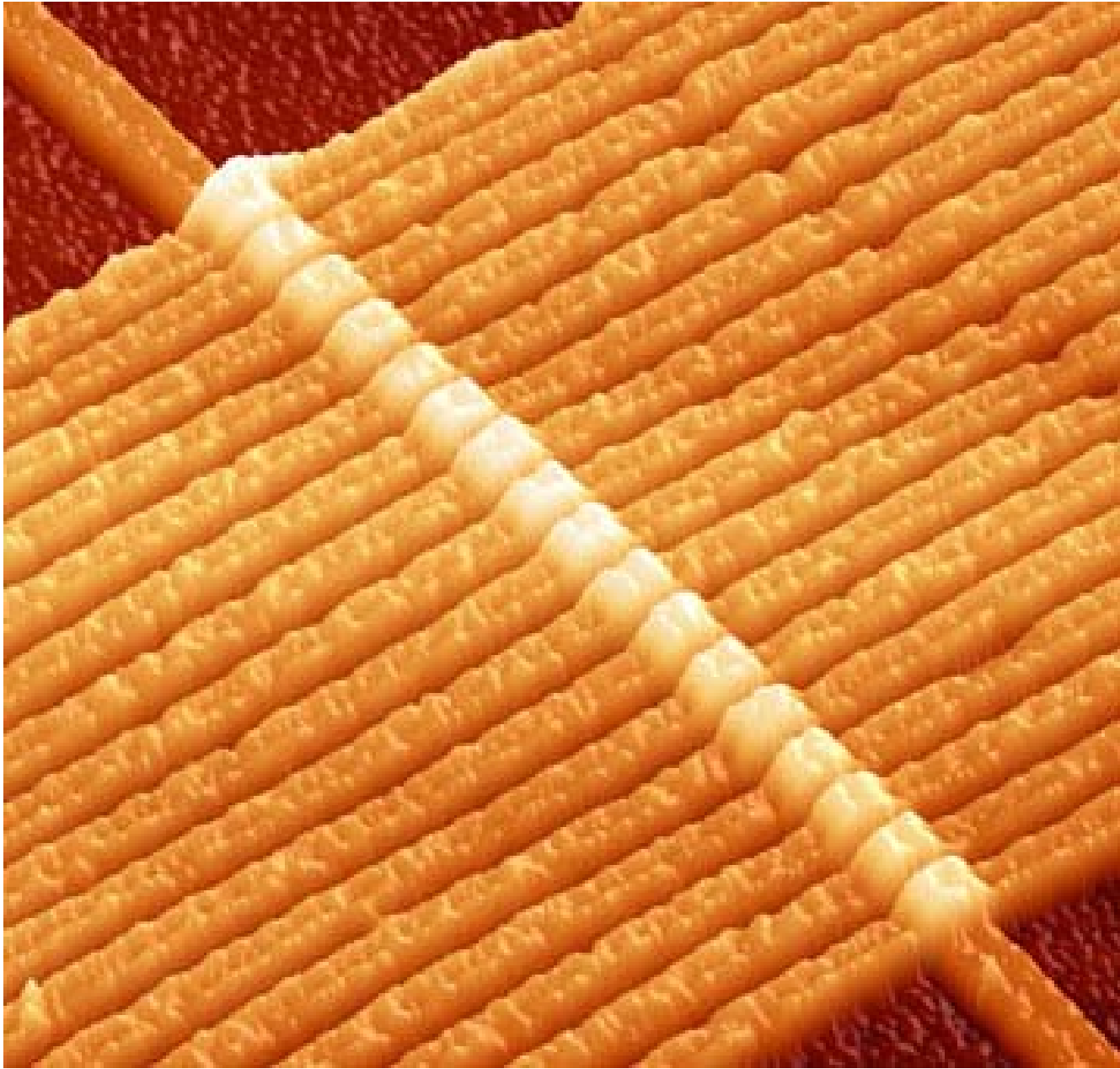


Doped:



Titanium Dioxide Memristor

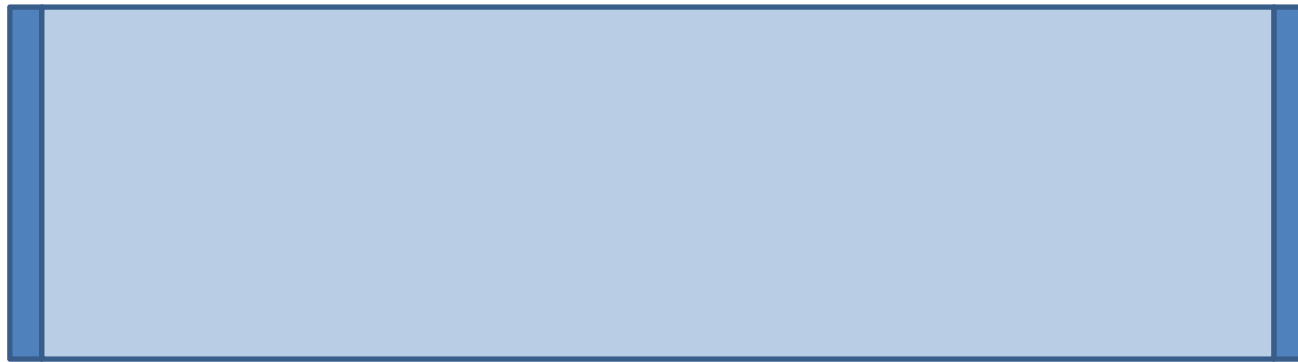




Polymeric Memristor

- Krieger and Spitzer, 2004.
- Didn't call it a memristor.
- Makes use of fast ion conductors and the formation of conductive bridges.

Polymeric Memristor



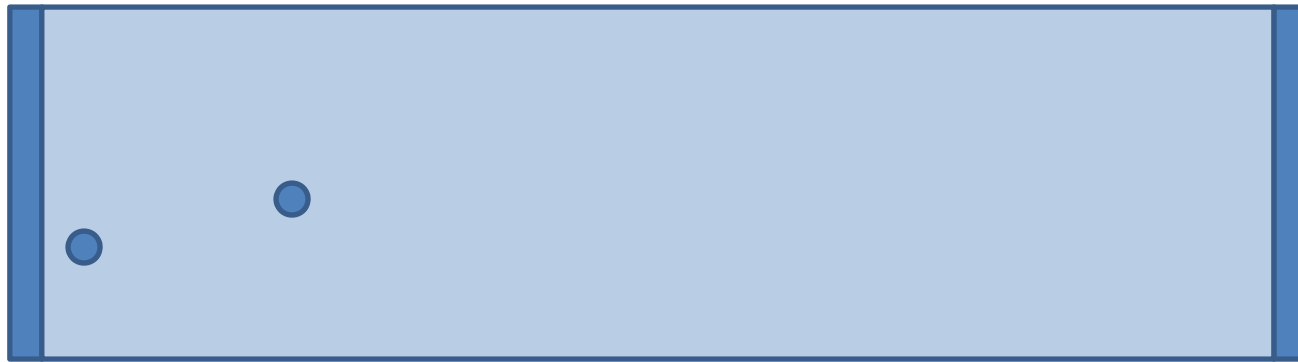
High Resistance State

Polymeric Memristor



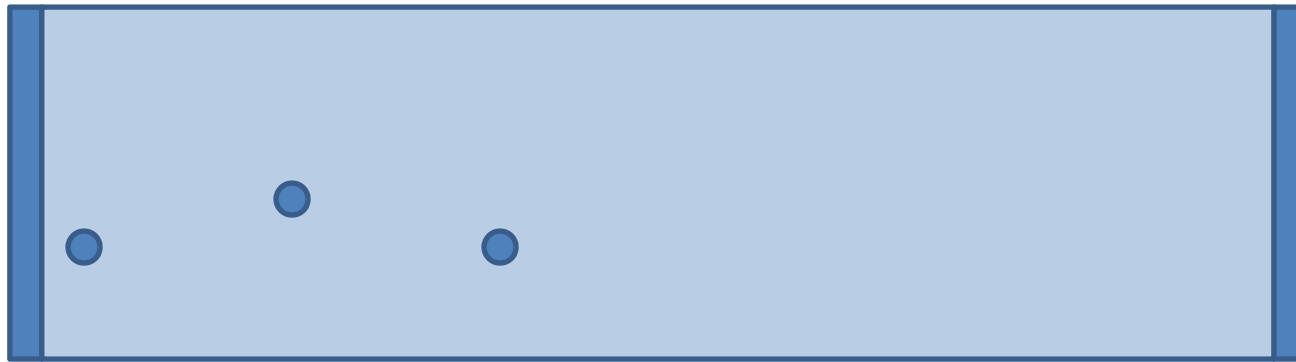
High Resistance State

Polymeric Memristor



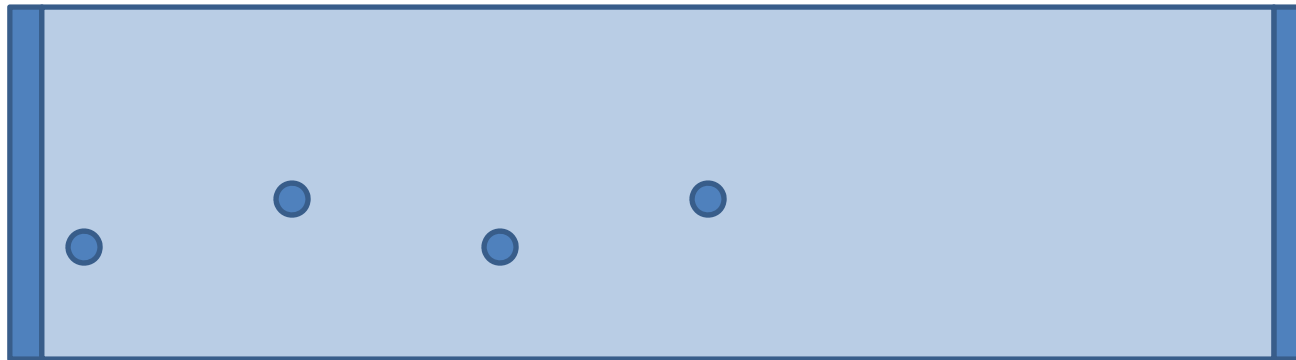
High Resistance State

Polymeric Memristor



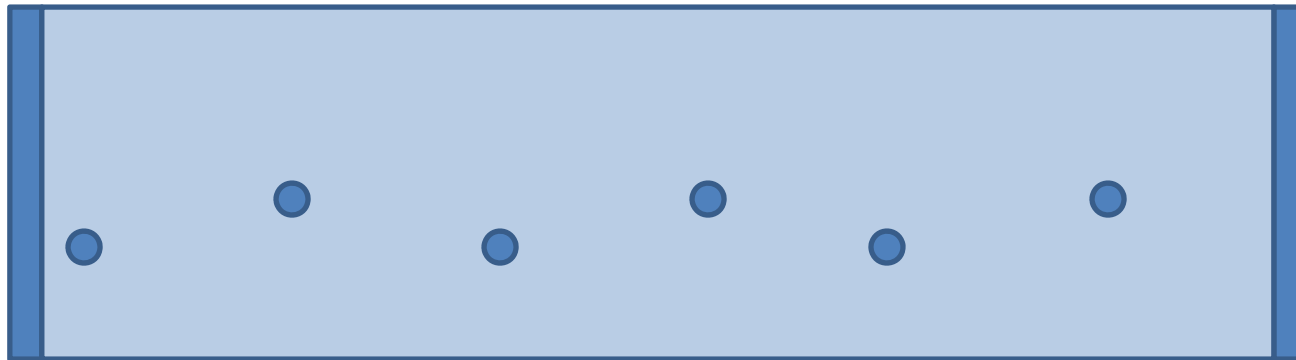
High Resistance State

Polymeric Memristor



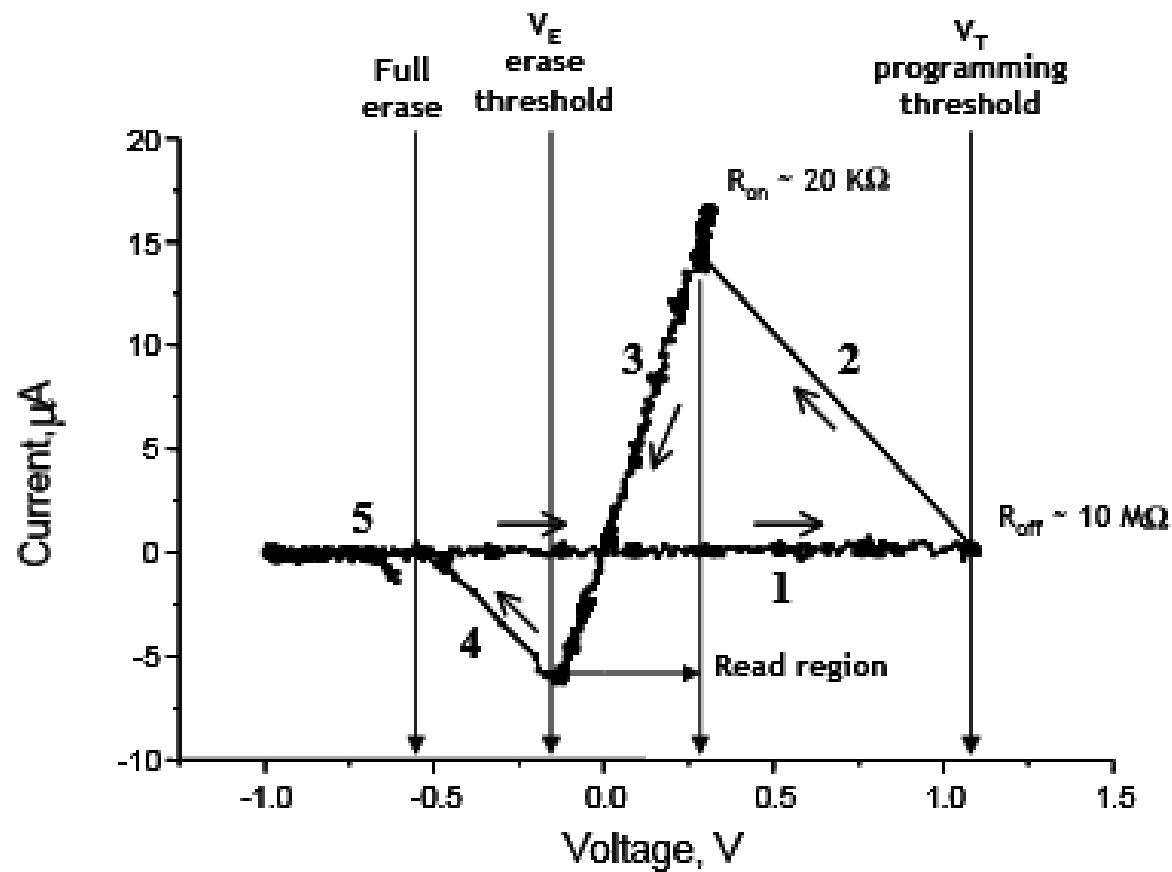
High Resistance State

Polymeric Memristor



Lower Resistance State

Polymeric Memristor

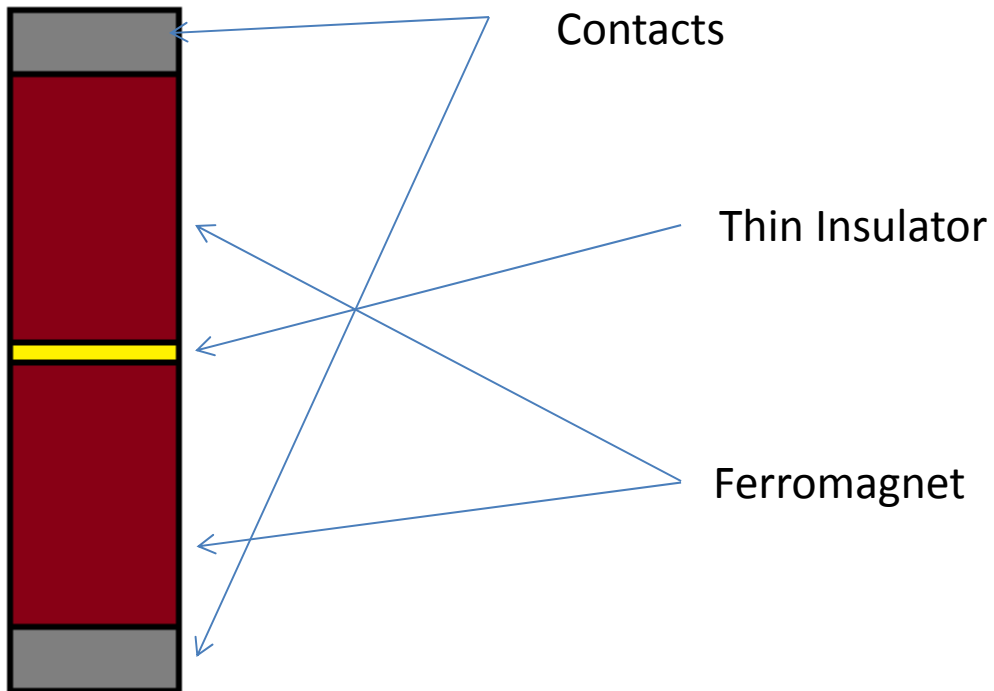


Krieger and Spitzer, 2004.

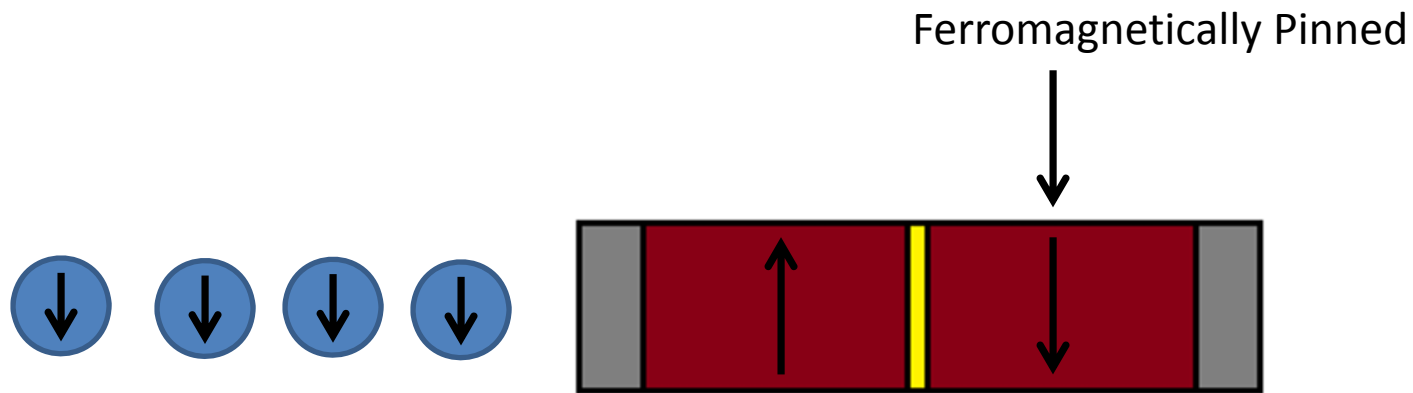
Spin Memristor Systems

- Spin Transfer Torque MRAM
- “Old” (1990s)
- Looser definition of memristor

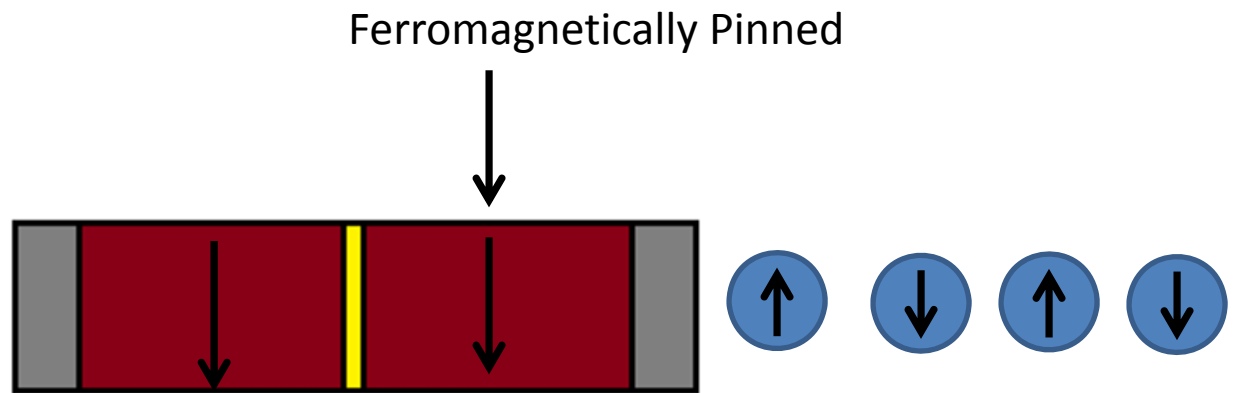
Magnetic Tunnel Junction



Spin Memristor



Spin Memristor



Memristor Applications

- Memory
- Programmable Logic
- Learning systems
- Neuromorphic Computing