SPIN-TORQUE TRANSFER RANDOM ACCESS MEMORY

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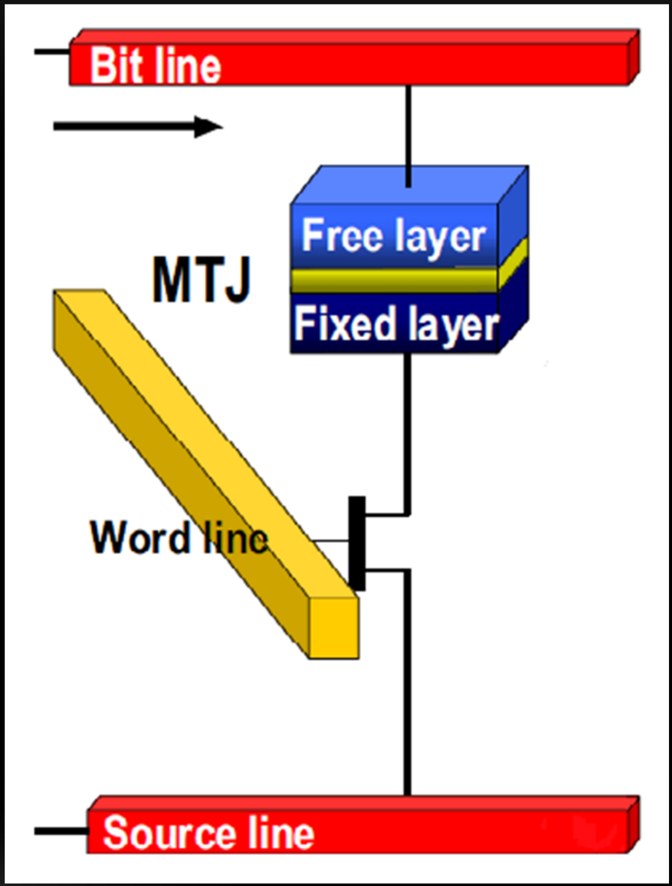
WHAT IS STTRAM?

- A type of Magnetic RAM (MRAM)
- Advantages over traditional memory types:
  - Non-volatile MRAM
  - Speed of SRAM
  - High density (Single Transistor Cell)
  - Scalable beyond 90nm node
  - Zero leakage power

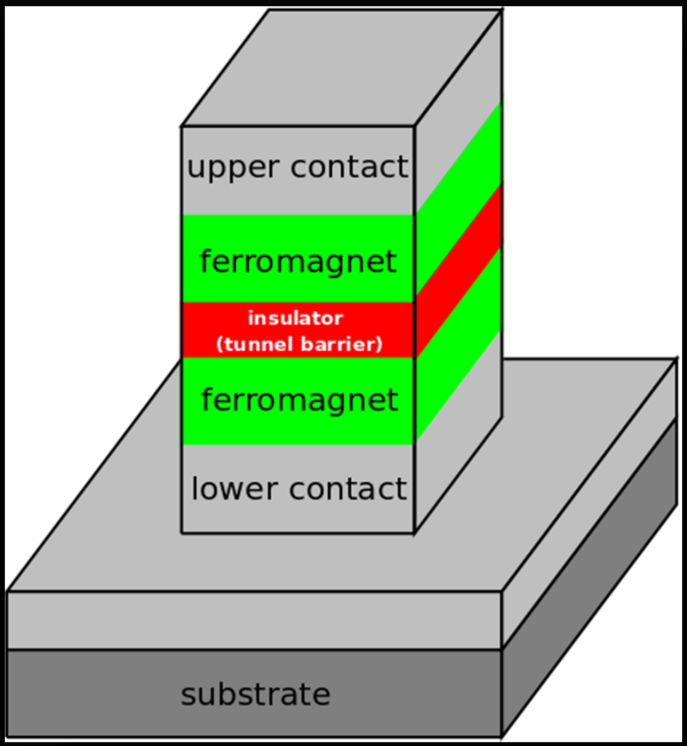
CELL STRUCTURE

- Magnetic Tunnel Junction (MTJ)
    - Two ferromagnetic layers separated by an insulating layer
- Single n-type MOSFET transistor
- Bit line, Source line, and Word line
- Cell bit is “stored” by the resistance of the MTJ



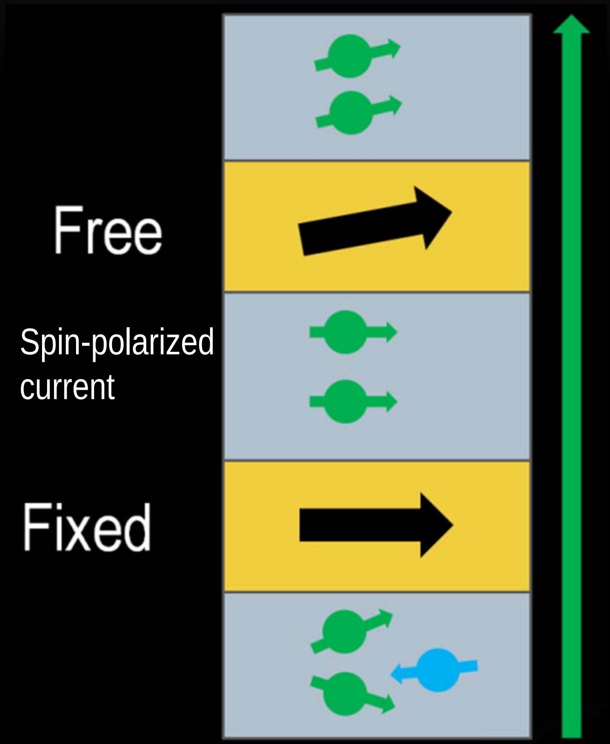
MAGNETIC TUNNEL JUNCTION

- Core of the STTRAM cell
- Two ferromagnets (FM) separated by a thin insulating layer
  - Usually MgO
  - A few nanometers thick
  - Electrons can tunnel through this barrier
- One FM layer has fixed magnetization
- The other FM layer is “free” and can have its magnetization changed by spin-polarized current
  - This changes the resistance through the MTJ



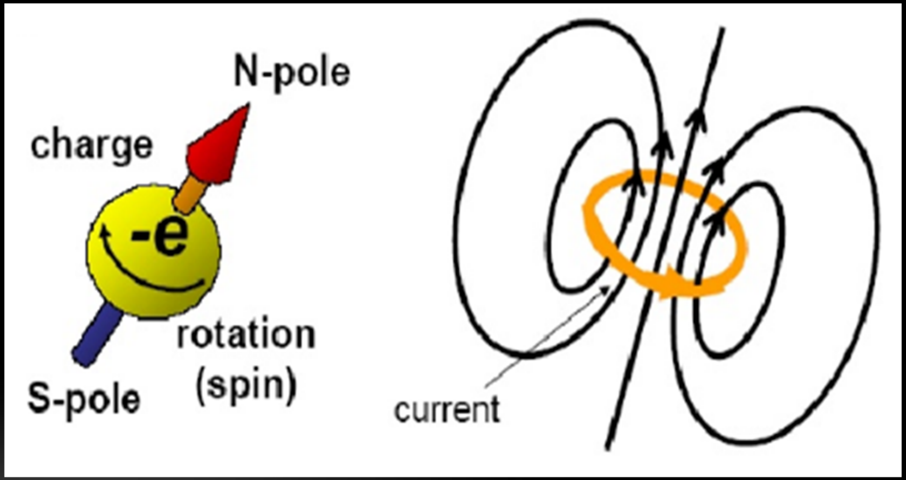
SPIN-POLARIZATION

- Current is passed through a thick magnetic layer, and the spin of the carrier electrons is polarized to a single spin state
- As the electrons move through the fixed layer, their magnetic moments become aligned to that of the fixed layer
- These spin-polarized electrons pass through the free layer and exert a torque on the magnetic moment of that layer
    - With enough current, the torque exerted can switch the free layer



SPIN-TORQUE TRANSFER

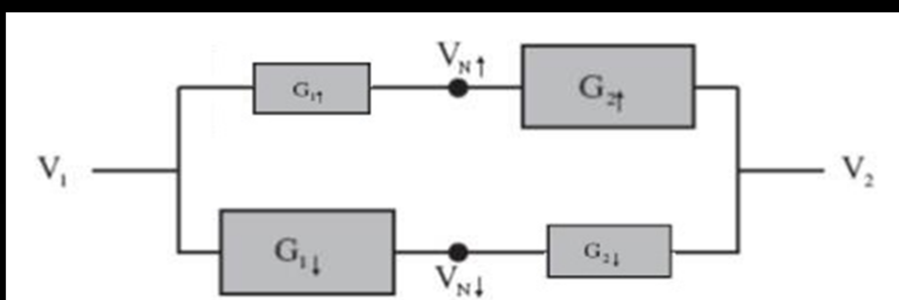
- When spin-polarized electrons pass through the free FM layer it exerts a torque on it
- When the spin-polarized electrons scatter, their angular momentum (spin) is transferred to electrons in the layer
- Total spin is still conserved



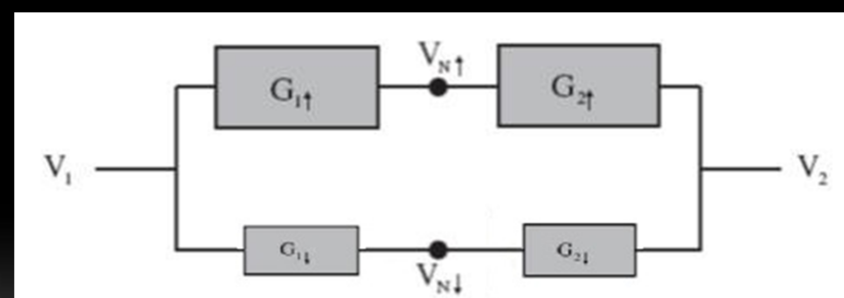
TUNNEL MAGNETORESISTANCE (TMR)

- Assume conservation of spin during tunneling
- Resistance is varied by the magnetization of FM layers in the MTJ
  - Magnetizations parallel => the electrical resistance is lower
  - Magnetizations anti-parallel => the electrical resistance is higher
- Two current model

Anti-Parallel



Parallel



TMR CONTINUED

- TMR Formula:

$$TMR = \frac{R_{ap} - R_p}{R_p} \times 100$$

- Current TMR around 500% or more
- Alternative expression in terms of Polarizations:

$$TMR = \frac{2P_1P_2}{1 - P_1P_2}$$

- Full spin-polarization of both layers (P = 1) results in infinite TMR
  - Has not been experimentally confirmed yet

WRITE OPERATION

- Write '1' (Parallel to AntiParallel): Positive voltage applied to Source Line, current from SL to BL

$$V_{GS} = V_{DD} \qquad V_{DS} = V_{DD} - IR$$

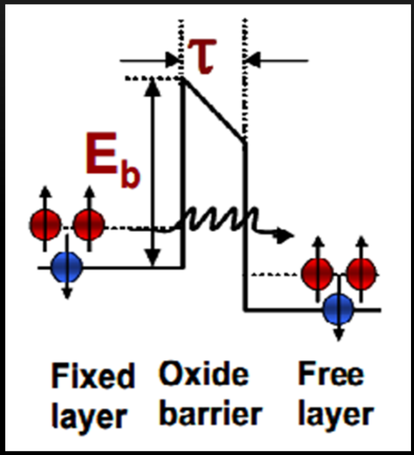
$$I_{DS} = K\frac{W}{L}\left((V_{GS} - V_{TH})V_{DS} - \frac{{V_{DS}}^2}{2}\right)$$

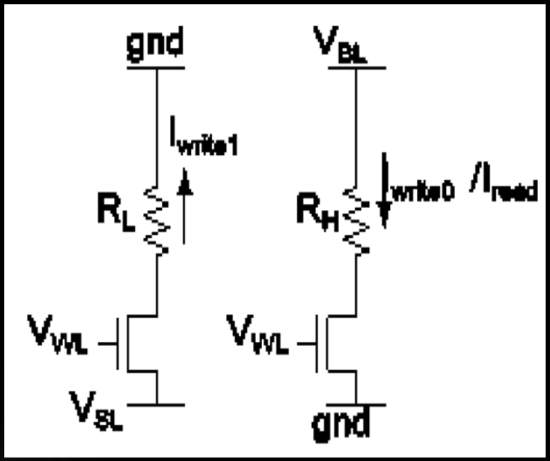
- Write '0' (AP to P): Positive voltage applied to Bit Line, current from BL to SL

$$V_{GS} = V_{DD} - IR \qquad V_{DS} = V_{DD} - IR$$

$$I_{DS} = \frac{K}{2}\frac{W}{L}(V_{GS} - V_{TH})^2(1 + \lambda V_{DS})$$

- To switch an MTJ, the current through the MTJ must be greater than the critical switching current (I_{SW}).





READ OPERATION

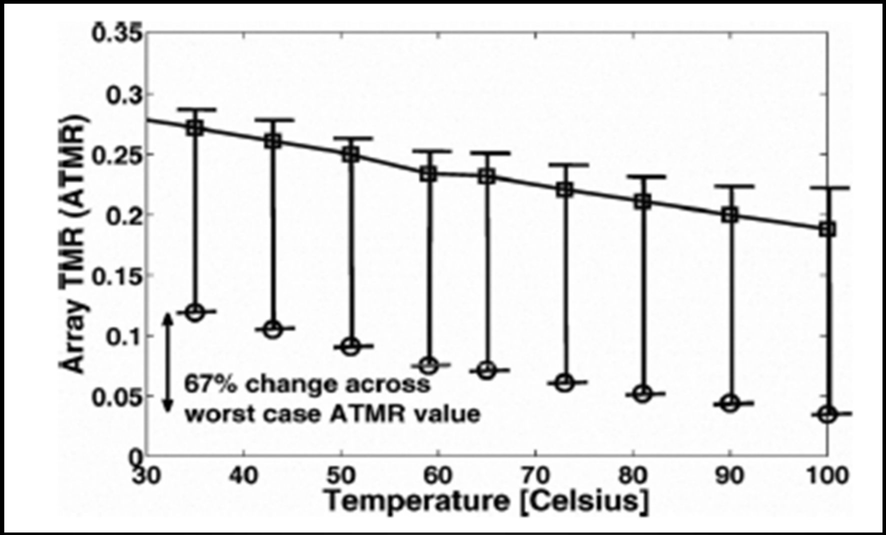
- To read the cell, a small voltage (V_{READ}) is applied to the Bit Line
- The resistance of the cell is detected using a sense amplifier
- Sense Amplifier is can be used in two modes
  - Current Mode: The current sensed is compared against a generated bias current
  - Voltage Mode: The Bitline voltage is allowed to drop for a set amount of time. Then the voltage is compared to a set bias voltage

READ/WRITE OPERATION DEFINITIONS

- Write margin is quantified as $I_{WRITE} - I_{SW}$
- Read margin is quantified as $I_{SW} - I_{READ}$
  - Disturb error: cell is flipped while reading
  - Can happen if read margin is too small
- Distinguishability: Depends on difference of current between reading a ‘1’ and reading a ‘0’
  - Distinguishability: $I_{READ,0} - I_{READ,1}$

OTHER FACTORS

- Self-Heating
  - STTRAM cells can begin self-heating during operation which affects read disturbance and accurate sensing



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