Design of MTJ-Based Spintronic Logic

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INTRODUCTION

• Traditional semiconductor technology is nearing it's physical limits beyond the 45nm node from which arise the issues of high power consumption and scaling limits.

• A promising candidate is spintronic logic which is non-volatile allowing for zero static power usage.

• Magnetic Tunneling Junction (MTJ) logic devices have the advantages of being programmable, high speed, high density and low power consumption.

MAGNETIC TUNNELING JUNCTION

• Spintronic devices like the magnetic tunneling junction (MTJ) play with the spin of electrons whereas traditional electronic devices rely on the flow of electrons through them.

• An MTJ has a sandwich like structure as can be seen below. The three layers are called the **Free** layer, **Spacer** and **Fixed** layer.

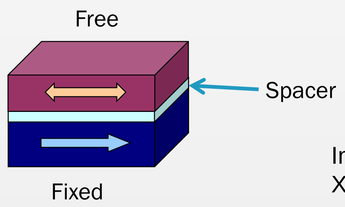
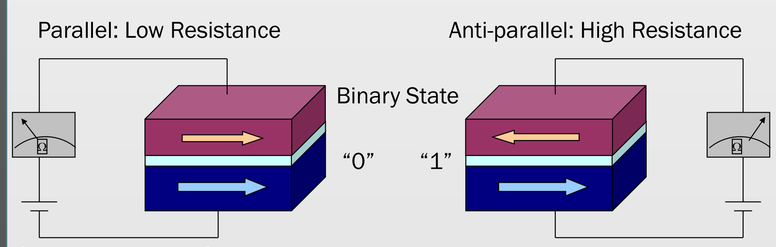


Image courtesy of:
Xiaofeng Yao

• An MTJ is a device which can hold two distinct states. Those states can be used to represent logic "0" or logic "1" in digital circuitry. These states are due to the MTJ's magneto-resistance (MR) effect.



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RESEARCH OBJECTIVES

The objectives of this research are two-fold:

1. To design a HSPICE model of the MTJ for easy simulation of hypothesized circuits.

2. To design digital logic circuits, starting with simple logic gates and applying them to more design more complex digital circuits, like an ALU (arithmetic logic unit)

Within the designing of more complex logic circuits, another device called a **nano-channel** (NC) needed to be designed.

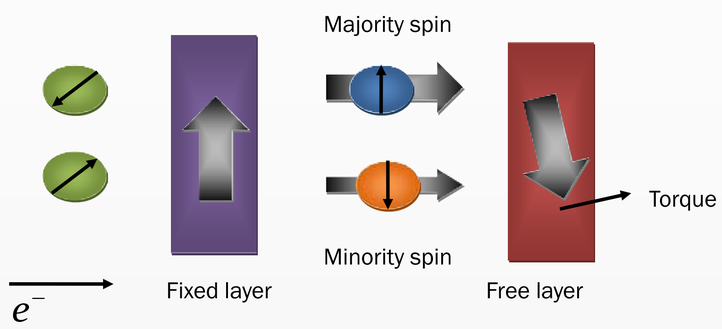
For now, NC's are barely past theoretical and there isn't much known about their physical behavior beyond the fact that they are used to transfer the state of one MTJ's free layer to another MTJ's free layer.

Because of this need, a basic and very ideal model of an NC was needed to be made as well.

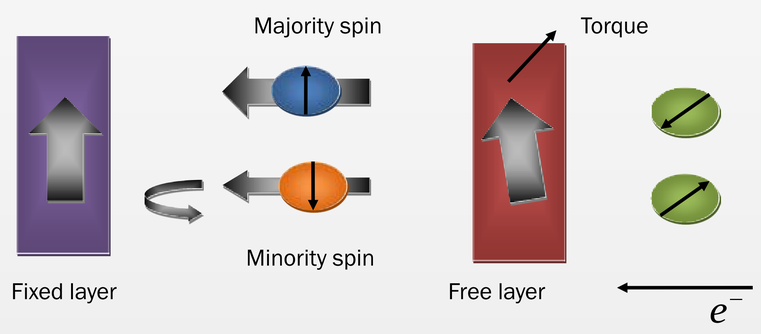
SPIN TORQUE TRANSFER OPERATION OF MTJ's

The **spin torque transfer** (STT) method chosen to operate MTJ's since it shows the potential for more promising results than the field driven method of operation. This method uses a direct current applied to the MTJ to change the state of the free layer.

Switching from anti-parallel to parallel ("1" to "0"):

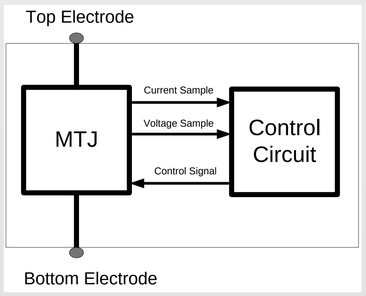


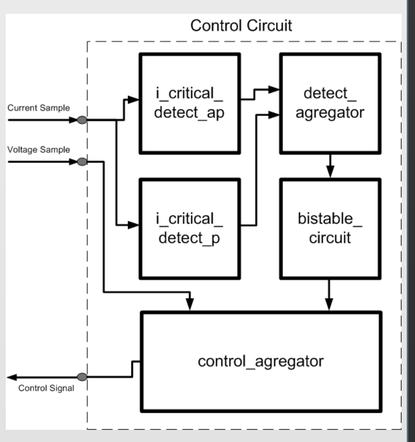
Switching from parallel to anti-parallel ("0" to "1"):



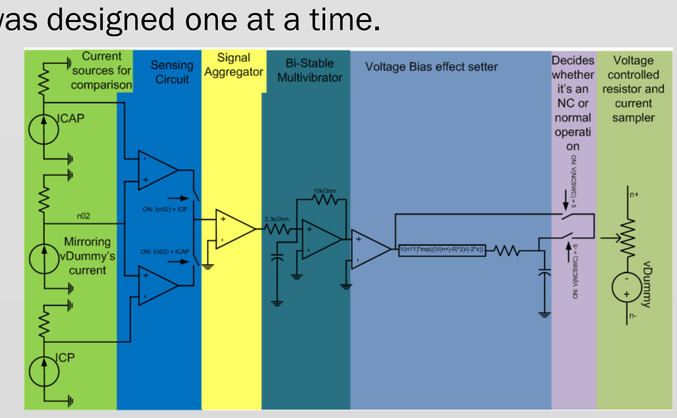
MTJ MODEL

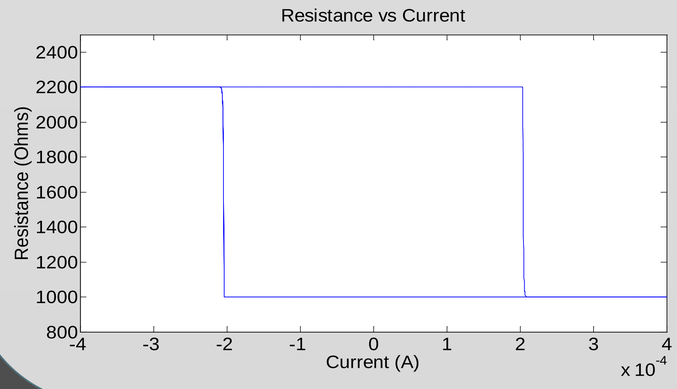
The modeling process was based on the general ideas presented below:





The actual circuit design was done in parts (modules) where each box in the control circuit was designed one at a time.

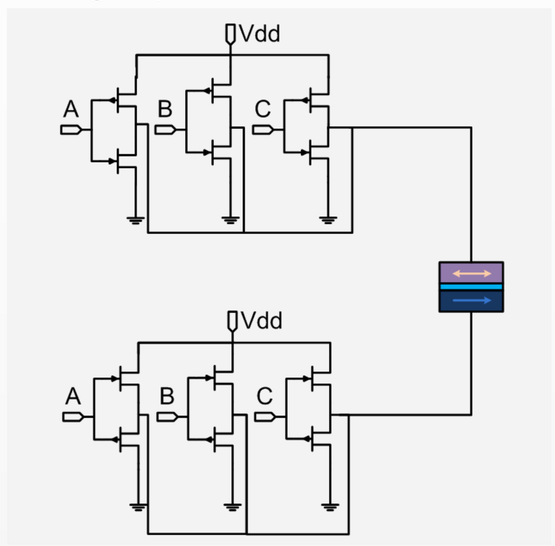


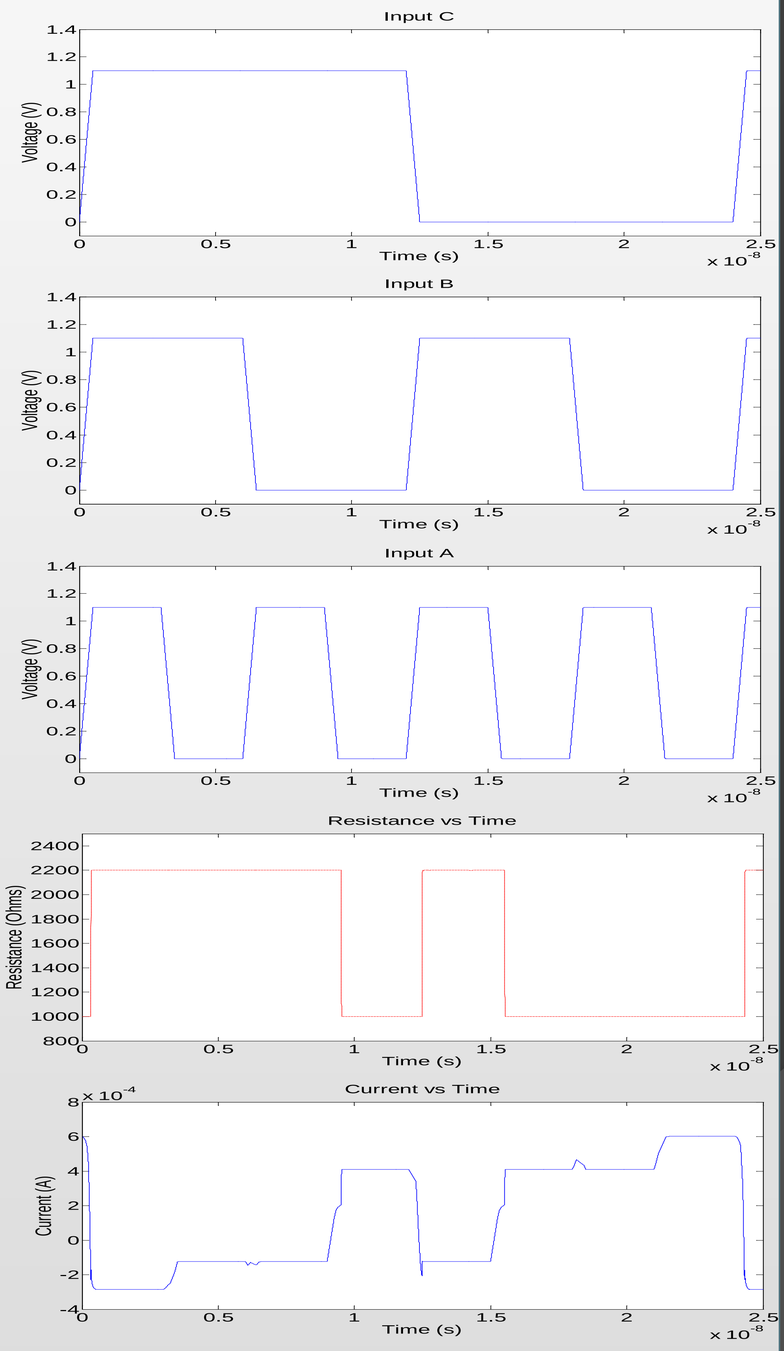


MTJ LOGIC

A three input current source can be designed to operate the MTJ cell as a logic gate. The Input C controls the logic operation:

C is "1" logic operation is OR
C is "0" logic operation is AND





CURRENT AND FUTURE WORK

• Currently there is work being done on a nano-channel macro-model add-on to the MTJ macro-model to help with the design of more complex MTJ circuitry. The nano-channel is used to transfer the magnetization of the free layer of one MTJ to the next.

• Future work will consist of designing more complex MTJ circuitry like an ALU (arithmetic logic unit).

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