A REVIEW ON MAGNETIC TUNNEL JUNCTION TECHNOLOGY

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Abstract- *The emerging field of spintronics is undergoing exciting developments with the advances recently seen in spintronic devices, such as magnetic tunnel junctions (MTJs). While they make excellent memory devices, recently they have also been used to accomplish logic functions. The properties of MTJs are greatly different from those of electronic devices like CMOS semiconductors. This makes it challenging to design circuits that can efficiently leverage the spintronic capabilities. The current approaches to achieving logic functionality with MTJs include designing an integrated CMOS and MTJ circuit, where CMOS devices are used for implementing the required intermediate read and write circuitry. Magnetic tunnel junction (MTJ)-based logic has a great potential, because of the non-volatility, unlimited endurance, CMOS compatibility, and fast switching speed of the MTJ devices. Recently, by direct communication between spin-transfer-torque-operated MTJs, several realizations of intrinsic logic-in-memory circuits have been demonstrated for which the MTJ devices are used simultaneously as memory and computing elements.*

Key Words: MTJ, STT, TMR

1. INTRODUCTION

The current CMOS technology faces major issues like scalability limits, device variability and power dissipation, casting a doubt on Moore's Law [1]. With the miniaturization of transistor dimensions and high standby power due to leakage currents has become important obstacle for scaling CMOS logic circuits at sub-100nm technologies. This has prompted researchers to investigate alternative technologies as an efficient replacement of the silicon based CMOS [2]. A possible solution to overcome this problem is introducing non-volatility into the logic circuits. Spintronic devices are one such alternative overcoming some of the above posed challenges [3]. Magnetic Tunnel Junction (MTJ), a spin based device is characterized by nonvolatility, low power consumption and increased integration densities (thus resulting in high scalability), making it a promising choice in multi domain applications[4]. In recent years, researchers have shown the potential of MTJs in many areas. Due to its non-volatility, it is used as memory devices like Magnetic Random Access Memories (MRAM) and Static Random Access Memories (SRAM)[5]. The Spin-transfer torque (STT) switching magnetic tunnel junction (STT-MTJ) is one of the most promising non-volatile storage technologies, which combines the advantages of CMOS compatibility, high speed, high density, unlimited endurance, and scalability [6].

Furthermore, by using the MTJ technology the effective area and interconnections delay (the data traffic on a main data bus between separated logic and memory modules can be reduced due to easy threedimensional integration of the MTJs on top of the CMOS layers. However, in hybrid CMOS/MTJ circuits the MTJs are used only as ancillary devices which store the computation results [6]. Logic devices like adders, subtractors, counters [II], flip-flops, ALUs and basic logic circuits implementing Boolean functionalities like NAND, NOR, AND, OR have also been designed using MTJs. Some of the above designs use a hybrid architecture where MTJs and CMOS are integrated with each other to produce the desired output.

Intermediate circuits are used to read and write data in between these components[7]. This circuitry adds integration complexity, power consumption, area and delay overheads. A more efficient way is to use only MTJ elements where logic functions are computed and stored within the non-volatile memory unit itself. This provides a dual capability of processing (logic) and storing (memory) data within a MTJ element contrary to the traditional Von Neumann architecture which use separately interlinked logic and memory modules [8]. Comparison between various solid state memory technology and MTJ are shown in Table 1 .
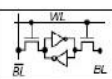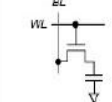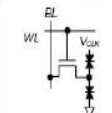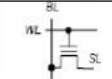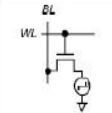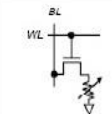
Memory Technology	Circuit Diagram	Read Time (ns)	W/E Time (ns)	Non-Volatile	Refresh	Cell Size (μm^2)	Voltage Supply (V)
SRAM		0.4	0.4	No	No	Large 0.346	1.2
DRAM		<15	<15	No	Yes 64 ms	Small 0.048	2.5
TSRAM		<3	<3	No	No	Small	< 0.5
Flash		14	Slow 10^3/ 10^2	Yes	No	Small 0.169	12/2.5
Phase Change Memory (PCM)		60	50/120	Yes	No	Small 0.249	3
MRAM		<25	<25	Yes	No	Small	1.8

Table 1 Comparison between solid state memory technology.

2. STRUCTURE OF MTJ

The magnetic tunnel junction (MTJ) is one of the most basic and also most significant spin-based device. The basic structure of the MTJ is shown in Fig. 1. The MTJ consists of two layers of ferromagnetic material separated by an extremely thin, nonconductive tunneling barrier. The thicker layer, which has a certain layer stack structure fixing its magnetic orientation, is called the fixed layer or the pinned layer. The thinner layer whose magnetic orientation can be changed freely according to an external magnetic field is called the free layer [9].

The MTJ exhibits two resistive states depending on the relative orientation of the magnetization directions of the two ferromagnetic layers due to the spin-dependent tunneling involved in the electron transport between the majority and minority spin states. If the spin orientations are parallel (P), applying a voltage across the MTJ is more likely to cause electrons to tunnel through the thin barrier without being strongly scattered, resulting in a high current flow and, therefore, low resistance (R_P). On the other hand, the resistance is high (R_{AP}) if the spin orientations are anti-parallel (AP) [10]. The resistance change is measured using the tunnel magnetoresistance (TMR) ratio. A high TMR ratio is one of the key parameters desired in both logic and memory applications. With the MgO oxide barrier, the TMR ratio can reach 500% at room

temperature. Most practical MTJs have TMR ratios between 50% and 150%.

A MTJ is a device in which two ferromagnetic layers, the pinned (fixed) layer and the free layer are separated by a thin insulating layer made up of metal oxide like AlO or MgO. An antiferromagnetic pinning layer is coupled with the pinned layer to make sure that its magnetic orientation remains fixedWith the evolution of supercomputers to handle complex computing tasks there is a requirement of a universal memory , as traditional memory technologies like SRAM, DRAM & Flash cannot serve the same purpose due to various limitations like low density in SRAM, Volatility of data in DRAM and Low operation speed & less endurance of Flash.
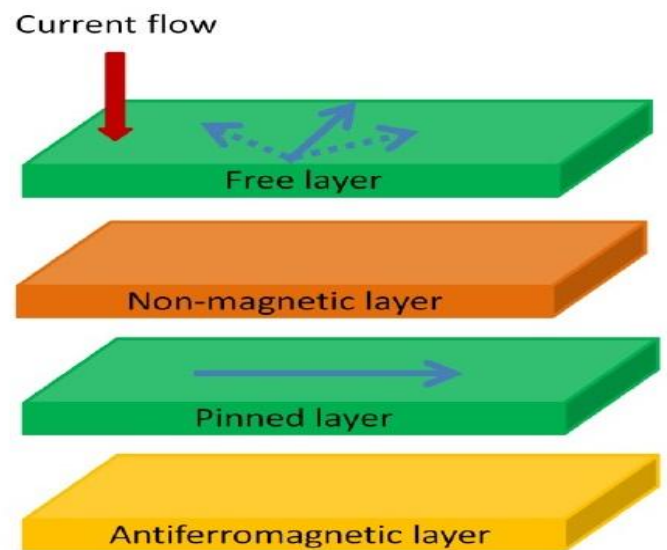

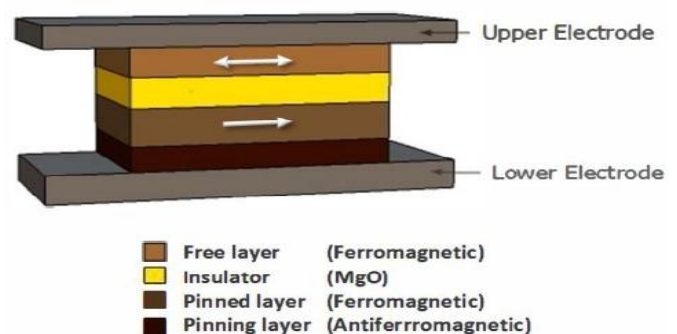Fig.1 Magnetic tunnel junction structure structure

Fig. 2 Schematic of a Magnetic Tunnel Junction (MTJ) element

3. LOGIC OPERATION IN MTJ

A MTJ is a device in which two ferromagnetic layers, the pinned (fixed) layer and the free layer are separated by a thin insulating layer made up of metal oxide like AIO or MgO. An antiferromagnetic pinning layer is coupled with the pinned layer to make sure that its magnetic orientation remains fixed. The orientation of the free layer can be controlled externally. The relative magnetic orientation between these two layers (pinned and free) determines the resistance state of the MT J element. A parallel orientation exhibits a low resistance which denotes a digital logic state 0. Conversely, an anti-parallel orientation exhibits a high resistance denoting a logic state I [11].
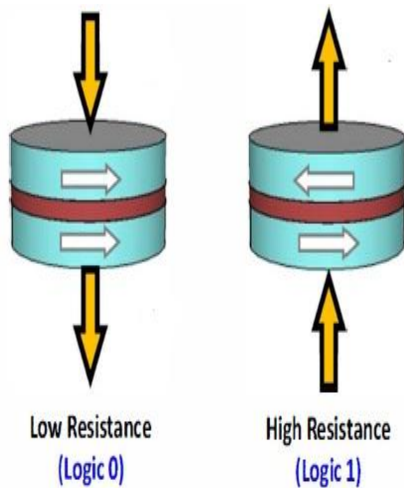

Fig. 3

Logic state in MTJ

4. WRITING OPERATION IN MTJ

The conventional writing operation of the MTJ (in memory applications) is carried out by applying two "half-select" magnetic fields generated by currents flowing through metal wires on top of the free layer. However, the current required in this writing scheme is extremely high, and it scales inversely with the device size. The discovery of the spin-transfer-torque (STT) phenomenon in 1996 brought the breakthrough of writing scheme indicates that the magnetization orientation of magnets can be controlled by the direct transfer of spin angular momentum from a spin-polarized current. Therefore, a current owing through an MTJ being polarized by the fixed layer will exert a torque on the magnetization of the free layer, and may eventually, switch the magnetization direction if the current density is sufficiently high. The STT writing scheme is illustrated in Fig. 4 [13].

In STT writing, the switching between R_P and R_{AP} is controlled by the direction of the writing current. Writing

current owing from the free layer to the fixed layer will write the MTJ into a parallel state (R_P), while that owing in the opposite direction will result in an anti-parallel state (R_{AP}). To ensure switching, the density of writing current has to be higher than the critical current density J_C, where J_C is defined as the minimum current density required to switch the MTJ for a given switching time. With the STT writing scheme, the MTJ can be used in circuit design as a current or bias voltage controlled variable resistance [12].
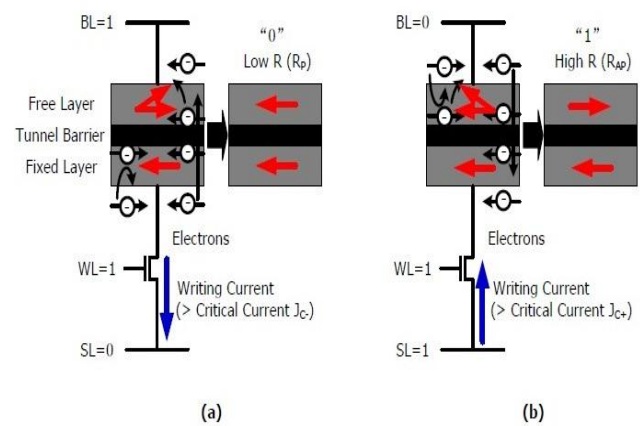

Fig.4 MTJ writing scheme (a) write from AP to P (b) write from P to AP

5. CONCLUSION

MTJ Based technology has the various advantages over the CMOS technology is in logic operation, low power consumption, Scalability. MTJ can be utilized in storage as well as logic computation. In most of the logic computation techniques MgO based MTJ are used.MTJ have a very important parameter i.e., Tunnel Magneto-resistance plays an important role in logic computation. A high TMR ratio is one of the key parameters desired in both logic and memory applications. All the important parameter of MTJ is very sensitive to the oxide thickness. The insulators used as insulating barrier are metal oxides like $Al_2 O_3$ and MgO, which often introduce trap states and defects. Due to the oxide there are some crystal defect occurs and due to this some leakage path are created which degrade the performance of MTJ structure and their application. They must be made thick to avoid formation of leakage paths at defect sites, but much thickness results in high tunnel resistances, which is a major impediment to efficient spin processing. So the challenge is controlling the oxide layer thickness in order to reduce the defects and to improve the efficiency of MTJ in terms of Tunnel Magneto resistance and spin transfer torque.

6. FUTURE WORK

To overcome the existing problem of the MTJ based logic computation, the aim to Design Magnetic tunnel junction architecture in order to improve the parameters like Tunnel magneto resistance ratio, Resistance Variation, Spin transfer torque component.

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BIOGRAPHIES

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