Based on the comparison with other kinds of storage devices to predict the future development of STT-MRAM

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Abstract. Now day with the development of technology, our electronic device is upgraded. Which will bring more data to storage. This causes the development of memory device. Now we already have SRAM flash memory are being widely used. But as the we use it for long time, the disadvantage of these memory device is shown, therefore, a new memory device --STT-MRAM are been created, which is we are going to introduce, we will show you how it basic structure which is MRAM work and the mechanism of the magnetic tunnel junction (the part it storage messages) and how spin electron influence the MTJ to make it more effective. Follow that we will list and make a comparison of the advantage of STT-MRAM and the disadvantage of flash memory, SRAM and DRAM to show the potential of the STT-MRAM. After mentioned about the benefit of STT-MRAM, we will mention about the disadvantages of it such as hard to maintain high thermal stability barrier. We will give the possible solutions follow that. This text intended to introduce this new type of memory device-STT-MRAM and show the potential of it in the future.

Keywords: STT-MRAM; mechanism; comparison.

1. Introduction

Storage is an important part of a computer architecture, and it is divided into volatile and non-volatile, non-volatile means that data is still present regardless of power or not, allowing the system to operate in sleep mode without losing data. Among the many non-volatile memories at present, Flash technology is the most advanced. The dissertation is going to introduce the non-volatile memory called MRAM, which is also the most likely alternative to Flash, and predict the possible development of it in the future.

First, this paper introduces the structure and principle of two types of MRAM, and then the second part will compare the performance of STT MRAM with other memories, such as SRAM, DRAM and FLASH. In key challenges and solutions part, it will talk about two of difficulties that STT MRAM has now and to solve specific problems, it offers some possibly reliable methods and solutions to improve the STT MRAM. This article also gives and summarizes some ideas about the STT MRAM to help others, as well as tries in the storage devices and science world.

The purpose of this paper is to highlight the advantages of MRAM in some aspect through comparison, so as to introduce this new type of memory to the public and lay a good foundation for its future application and development.

2. The mechanism of STT-MRAM

2.1. The structure of MRAM

The storage unit of MRAM is the Magnetic Tunnel Junction, which is consisted by an oxide layer sandwiched between two layers of magnetic film. The oxide layer is magnesium oxide (MgO). The layer of magnetic film whose magnetic moment is held in place called Pinned Layer, and the layer whose magnetic moment can be flipped called Free Layer. When the two layers of magnetic moments are connected in forward parallel, the current is easy to pass, and the MRAM writes information to be 0, otherwise to be 1 [1]. Figure 1 shows Right-hand rule and figure 2 shows Direction of the current flow and Magnetic from S to N

Figure 1. Right-hand rule.

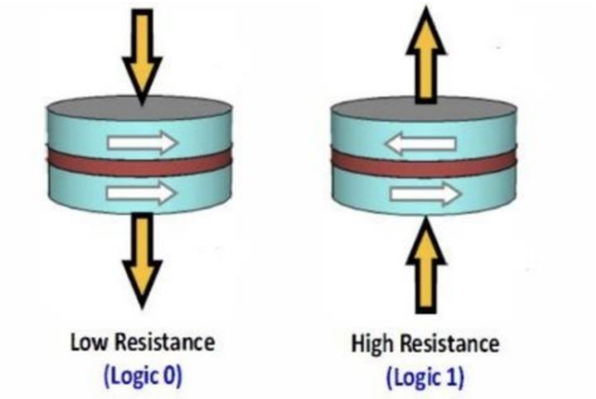

Figure 2. Direction of the current flow and Magnetic from S to N.

When the MRAM is in a Parallel state, the resistance is small with a giant magneto-resistive effect, and the read is 0. When the MRAM is in the Anti-Parallel state, the resistance is large with a giant magneto-resistive effect, and the read is 1.

2.2. Toggle MRAM

Toggle MRAM is the first generation of MRAM, which is also the simplest type. It uses current to generate a magnetic field so that the Free Layer has different magnetization direction, and the magnitude of resistance decide by the direction of magnetic moment of Free Layer and the Giant Magneto-resistive Effect. In this paper, the right-hand rule is used to judge the direction of the magnetic field generated by the current in the wire, so as to determine the parallel or antiparallel state of the magnetosphere [2].

Giant Magnetoresistance refers to the resistivity of a magnetic material that changes dramatically in the presence and absence of an external magnetic field. It can explain why Parallel and Anti Parallel states of magnetic moment can change the magnitude of the resistance.

Magnetic metals and alloys generally have this phenomenon of magnetoresistance. Under normal circumstances, the resistivity of the material is only slightly reduced in the magnetic field. However, under certain conditions, the resistivity decreases considerably, which is about 10 times higher than the magneto-electric resistance value of usually magnetic metals and alloy materials, known as "Giant Magneto-resistance effect"

The GMR effect can be observed in thin film layers (about several nanometres thick) of alternating magnetic and non-magnetic materials. The resistance value of structural materials is influenced by the strength and direction of the magnetic field in the environment. In the case of strong magnetic field strength, in comparison, the resistance value of the material with the same direction of magnetization will be smaller than the material with the opposite direction.

With the support of these principles, Toggle MRAM can read and write the data. It has many advantages, for example, the structure of it is quite simple, and so the production cost is very low. However, because the magnetic field generated by the wire is so weak, the magnetic moment generated by the Free Layer will also be weak, which cause poor in efficiency and the requirement for a large current. [3]

2.3. STT-MRAM

Compared to Toggle MRAM, STT MRAM enables higher density, less power consumption, and lower cost. It is a magnetic property that provides non-volatile storage in a chip through the magnetic properties of electron spin. The structure of it is showed on the Figure 3.

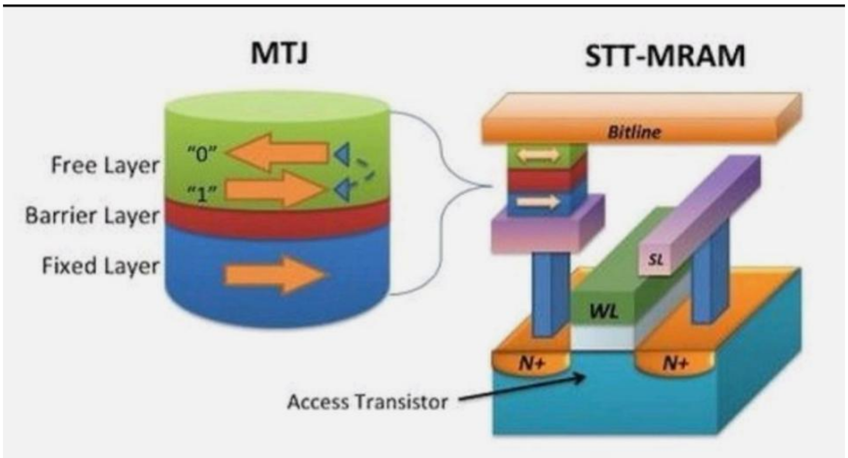

Figure 3. The structure of STT-MRAM.

The image on the left is a larger version of Magnetic Tunnel Junction (MTJ) consisting of Pinned Layer, Free Layer and Barrier Layer (MgO). The image on the right is the structure of STT MRAM, the drain of the triode is connected to one end of the MTJ (for example a Fixed Layer), and when the gate opens the triode, the source, drain, MTJ and bit line form a loop.

Spin is an inherent property of electrons which can be also considered that a small quantity of angular momentum. Electrons have two states of spin with opposite direction, that is spin up and spin down. An unpolarized current consists of electrons with 50 percent spin up and 50 percent spin down. On the contrary, a spin polarized current is one with more electrons of either spin. Figure 4. are the two states of electron spin [4].

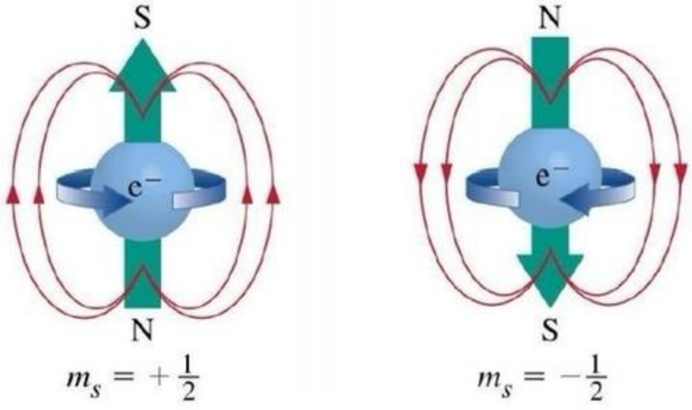

Figure 4. The images are two states of spin of electrons.

Spin transfer torque (STT) means an effect which the direction of a magnetic layer in a MTJ can be changed by a spin polarized current. The spin polarization current will be generated when the current passes through the fixed layer. Then, the polarization current will pass through the free layer and transfer the angular momentum to this layer, which will lead to the change of electron angular momentum and electron oscillation. Therefore, the STT MRAM can continue to work with the working principle of Toggle MRAM, which can see in the Figure 5 to understand better. [5]

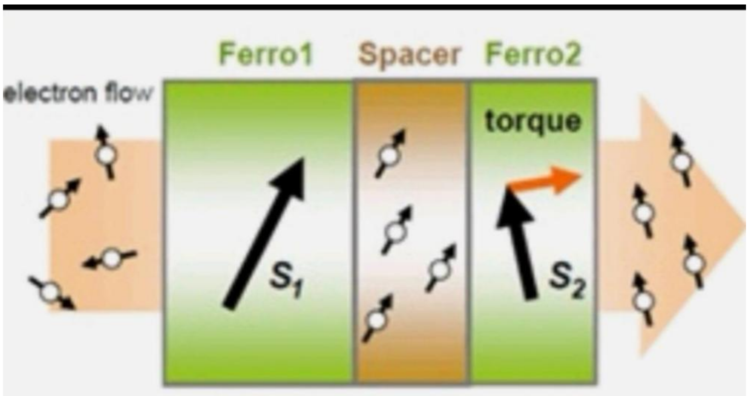

Figure 5. The process of current passing through the MTJ with a change in the spin angular momentum.

When the current passes through the Pinned Layer, the current will be polarized. And then the polarized current will pass the Free Layer, so the angular momentum can be transferred to this layer.

3. The comparison between different kinds of memory devices

3.1. Other kind of memory devices

Nowadays, we already mentioned about the mechanism about STT-MRAM, in recent research except the STT-MRAM, there still have many kinds of storage devices been used in our device and here we are going to talk and making a comparison those with STT-MRAM. There also have plenty of memory device but in this text, we are just going to talk about these memory devices and compare their density and read/write speed with STT-MRAM.

3.2. Cooperation of other kinds of memory devices with STT-MRAM

First, we are going to simply describe the structure and mechanism about these memory devices. Static RAM, which is kind of volatile memory as same as the Dynamic RAM.A typical SRAM is made up by four transistor with two resistances or six transistors or even more. For the Dynamic RAM, its typical structure has a transistor and a capacitor. Flash memory use floating-gate transistor to storage information. The way of these memory devices to storage information basically is the same as the STT-MRAM which represent it as 1 or 0. But the way their represent it is different from each other. [6] Figure 6 shows the typical structure of DRAM with transistor which transfer information (current with different potential different) into capacitor.

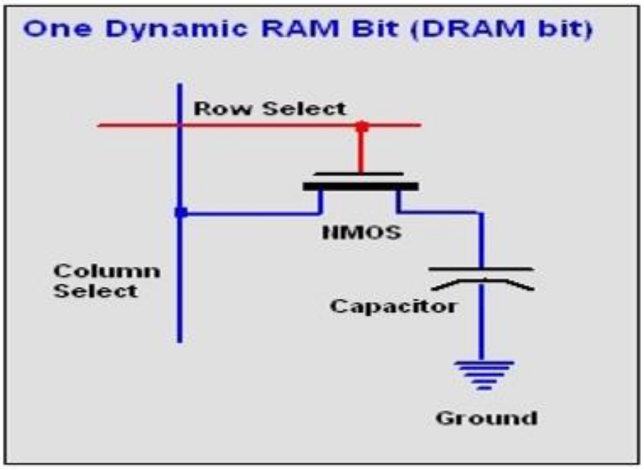

Figure 6. The typical structure of DRAM.

Dynamic RAM storage the information on the capacitor as charge and it is 1 or 0 depend on whether it charge or discharge. As the transistor open, it will allow the charge to pass which allow us to read or write the information into the capacitor and when it close in logic the charge inside should remain, and sense amplifier will read information by detect the volt of the capacitor. Recently, there has charge lose during the transfer of charge, so it must be refreshed to keep the data.

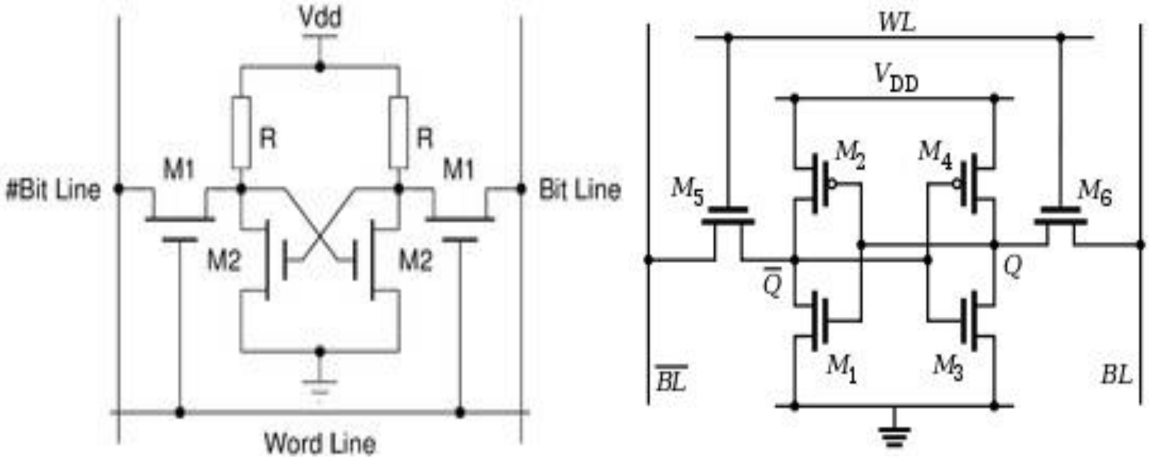

Figure 7. Two different kinds of typical structure of SRAM.

As can be seen from figure 7, on the left-hand side is the structure of SRAM with four transistor and two resistor which will need higher power and have lower storage density compare with the right-hand side the structure of SRAM with six transistors.

Statics RAM's typical structure have six transistors, realize the no need to refresh after every time storage information. Compare with these two, DRAM have lower number of transistor than SRAM which make it have a higher storage density, but it also cost more power. And as both of they are volatile memory devices, once the power been cut down will cause the loss of the information. [7]

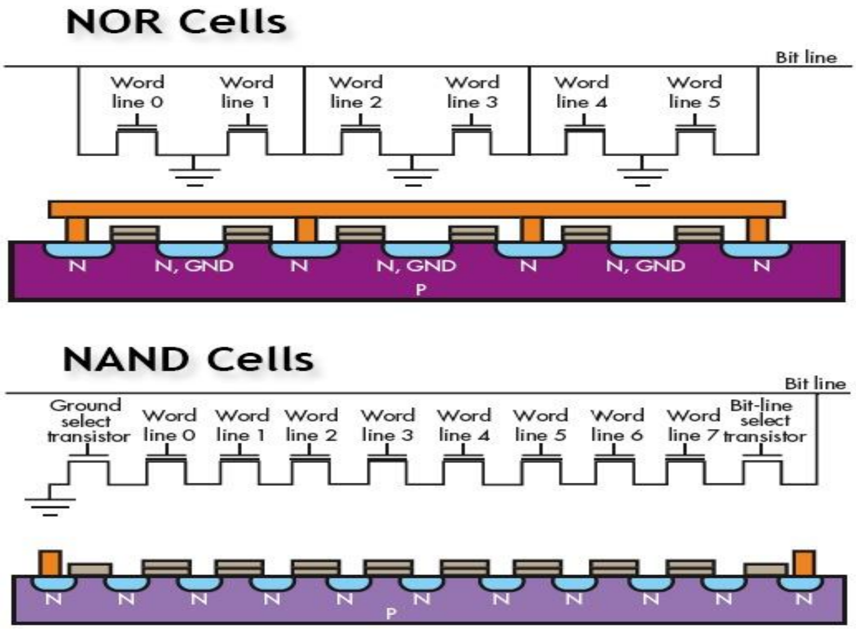

Figure 8. The typical structure of NOR flash and NAND flash.

Flash memory have many kinds of like NOR flash and NAND flash now day as shown in figure 8. NOR use the volt to transfer the current into floating gate to represent information and NAND use tunnel injection to write and tunnel release to read. As a non-volatile memory it won't lost data easily as SRAM which make it stable and it also easy to carry. But the flash memory still has slow read/write velocity and short life such problem. Now we already know that the STT-MRAM is use the spin current to go through the Magnetic tunnel junction to make it magnetization and therefore to change the resistance of Magnetic tunnel junction. And this will make STT-MRAM have a simple structure, lower cost make it have a high storage density and can rewrite infinite time. As a non-volatile memory device, it won't lost data as flash memory once lost power. It also can by change the number of charge pass through Magnetic tunnel junction to make it need low power or have faster velocity to read/write. [8]

4. Key Challenges and solutions

4.1. The improvement of magnetic tunnel junction in a MRAM

4.1.1. Challenges of MTJ faced

In Plane Magnetic Anisotropy was used in magnetic tunnel junction at early time. However, It has two disadvantages:

Thermal stability will deteriorate as the process decreases. The storage life of an in-plane MTJ depends on the thermal stability barrier and the magnetic anisotropy field. As the process size shrinks (< 50nm), the marginal effect of the film intensifies, resulting in a significant magnetic vortex state, which is difficult to maintain a high thermal stability barrier, and even stable magnetization cannot exist, which will limit the storage density of MRAM. Secondly, magnet tunnel junctions with in-plane magnetic anisotropy reduce the flipping efficiency of spin transfer moment. [9]

4.1.2. Solution

Therefore, for the same thermal stability barrier, scientists found vertical magnetic anisotropy could make the critical reversal current of MRT lower than that of in-plane magnetic anisotropy.

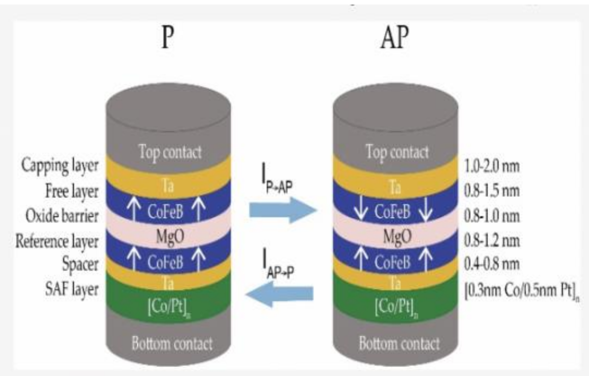

Figure 9. The detailed structure of magnetic tunnel junction (MTJ).

Figure 9. Shows that the more detailed structure of a MTJ with perpendicular magnetic anisotropy (PMA-MTJ). It has 7 different layers shown in figure above. According to the tunnel magneto-resistance effect, the resistance of two columns (*R*p or *R*ap) is determined by the relative magnetization direction to the two ferromagnetic layers (parallel or anti-parallel). Therefore, MTJ can be used to form logical '0' and '1' through different configurations. Correspondingly, spin transfer moment reversal efficiency is higher.

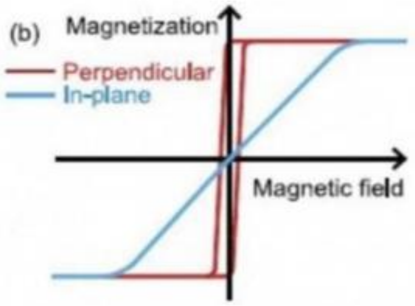

Figure 10. Magnetization curves along the in-plane and vertical directions.

Figure 10 describes the direction of the magnetic carve in different way that proving that the easily magnetized axis is along the vertical direction. In view of the above advantages, researchers have been committed to the construction of high density and low power consumption PSTT-MRAM with using vertical magnetic anisotropy magnetic tunnelling junction structure. [10]

4.2. The improvement of writing and reading of STT-MRAM

4.2.1. Challenges that STT-MRAM faced

Researchers notice that STT-MRAM has many problems due to using STT-MTJ as their storage medium. Researchers summarize them into the following three types, which are: write failure, decision failure and read destruction failure. For instance, the write failure refers to that the MTJ of the destination unit does not flip as expected during the write operation. A read failure means that the read operation fails to obtain the real state of a storage cell. Read failure is unexpected flipping of memory cells happens during a read operation, which may greatly affect and lead to the loss of real data. Furthermore, STT-MTJ also faces many kinds of challenges: It is quite hard to ensure that: 1) the read operation memory cell has a large enough resistance difference; 2) the MTJ will not be affected by the read current which can cause unnecessary switching occurs; 3) the MTJ of the memory unit can’t complete the set switching during the write cycle. These make researchers begin to focus on how to optimize MTJ to achieve more efficient STT-MRAM.

4.2.2. Solutions

The typical representative of the device optimization is to achieve this by changing the structure of MTJ to form a three-terminal device that is called CPSTT-MTJ that is showing on Figure 11.

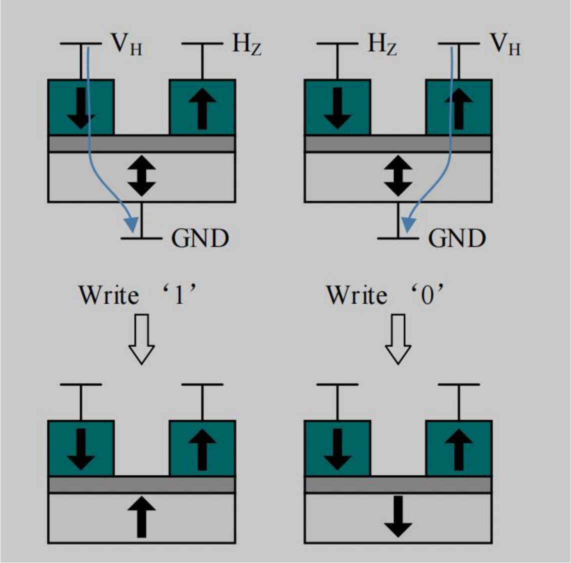

Figure 11. The structure of CPSTT-MTJ.

This new type of STT-MTJ can be seen as two ordinary MTJ combining. Among them, free layer has two stable states, one of which called a PAP which means that the left side of the fixed direction of magnetization and free layer is parallel to the direction, the right side of the fixed direction of magnetization and freedom layer is anti-parallel, the other one is named as APP which is opposite to the motion of the PAP.

Therefore, the storage state can be easily obtained by comparing the magnitude of the left and right sides resistance of the device. The write operation, CPSTT-MTJ can also be regarded as writing only a regular MTJ. As shown in Figure 11, when the current flows through the free layer from the fixed layer of one of the MTJ, it will transform the magnetization direction of the free layer into the direction parallel to the anti-phase of the fixed layer, so as to achieve the write operation. Compared with STT-MTJ, CPSTT-MRAM has a more flexible and quicker way to read and write and is able to achieve zero read and write damage and a high reliability beyond the theory.

5. Conclusion

This article mainly discusses about the model of the STT-MRAM as well as the operating principle and structure of it. It also compares with other 2 to 3 current other types of MRAM and found out some advantages of STT-MRAM. After comparing their writing method and working principle. It is showing that STT-MRAM has a wider use and more chances around the while its speed and power better than the rest of storage devices. What's more, there are some disadvantages and issues that the MRAM faced at present, to try to improve them, the article introduced a few methods to cover. For instance, scientists could change the type of writing method from spin transfer torque (STT) to the spin orbit torque (SOT) as the second one has faster written speeds and lower write power consumption. This could be seen as a new attempt and development of the storage devices in computers and in some ways, it makes the STT-MRAM better and more competitive among other products in the market. In the end, this article is a good example and resources to introduce the STT-MRAM. At the same time, it could also regard as a brief guidance providing some information for the future researchers to help them to do further experiments or make MRAM more efficiency and well-used in more areas.

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