Magnetoresistive Random Access Memory

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Abstract- *Magnetic RAM (MRAM) is a new memory technology with access and cost characteristics comparable to those of conventional dynamic RAM (DRAM) and the non-volatility of magnetic media such as disk. That is MRAM retains its memory even after removing power from the device. Such a non-volatile memory has important military applications for missiles and satellites. Clearly such a device could also have important commercial applications if the non-volatility were accomplished without impacting other properties of the memory, notably density, read and write speed, and lifetime. IBM in cooperation with Infineon is promising to launch this new technology ,that will eliminate the boot-up process of a computer and thus enable it to turn on as instantly as a television or radio, using memory cells based on magnetic tunnel junctions. This paper discusses the following aspects in detail: Attractions of this new technology How MRAM works MRAM Architecture, Magnetic Tunnel Junctions - future of MRAM Challenges faced Anticipated Applications*

Keywords- TMR, MRAM, MTJ, GMR, ferromagnetic, Spintronics, magneto electrons, DRAM, spin logic

I. INTRODUCTION

Magnetic RAM (MRAM) is a new memory technology with access and cost characteristics comparable to those of conventional dynamic RAM (DRAM) and the non-volatility of magnetic media such as disk. That is MRAM retains its memory even after removing power from the device. Such a non-volatile memory has important military applications for missiles and satellites. Clearly such a device could also have important commercial applications if the non-volatility were accomplished without impacting other properties of the memory, notably density, read and write speed, and lifetime. IBM in cooperation with Infineon is promising to launch this new technology that will eliminate the boot-up process of a computer and thus enable it to turn on as instantly as a television or radio using memory cells based on magnetic tunnel junctions. The key to MRAM is that, as its name suggests, it uses magnetism rather than electrical power to store data. This is a major leap from dynamic RAM (DRAM), the most common type of memory in use today, which requires a continuous supply of electricity and is terribly inefficient.

The first MRAM devices to be realized used toggle memory switching, in which a magnetic field is used to change the electron spin. Toggle MRAM was easier to develop, but it is very hard to scale down. Second-gen MRAM devices use a spin-polarized current to switch the spin of electrons. So-called STT-MRAM devices are faster, more efficient and easier to scale-down compared to toggle MRAM. STT-MRAM chips are now beginning to be introduced to the market.

Spintronics, or spin electronics, refers to the study of the role played by electron (and more generally nuclear) spin in solid state physics, and possible devices that specifically exploit spin properties instead of or in addition to charge degrees of freedom. For example, spin relaxation and spin transport in metals and semiconductors are of fundamental research interest not only for being basic solid state physics issues, but also for the already demonstrated potential these phenomena have in electronic technology (some short reviews). The prototype device that is already in use in industry as a read head and a memory storage cell is the giant magneto resistive (GMR) sandwich structure which consists of alternating ferromagnetic and nonmagnetic metal layers. Depending on the relative orientation of the magnetizations in the magnetic layers, the device resistance changes from small (parallel magnetizations) to large (antiparallel magnetizations). This change in resistance (also called magneto resistance) is used to sense changes in magnetic fields. Recent efforts in GMR technology have also involved magnetic tunnel junction devices where the tunneling current depends on spin orientations of the electrodes type Style and Fonts

II. MRAM

You hit the power button on your television and it instantly comes to life. But do the same thing with your computer and you have to wait a few minutes while it goes through its boot up sequence. Why can't we have a computer that turns on as instantly as a television or radio? IBM, in cooperation with Infineon, is promising to launch a new technology in the next few years that will eliminate the boot-up process. Magnetic random access memory (MRAM) has the potential to store more data, access that data faster and use less power than current memory technologies. The key to MRAM is MAGNETIC RAM that, as its name suggests, it uses magnetism rather than electrical power to store data. This is a major leap from dynamic RAM (DRAM), the most common type of memory in use today, which requires a continuous supply of electricity and is terribly inefficient. Twenty-five years ago, DRAM overtook ferrite core memory in the race to rule the PC memory market. Now it looks like ferromagnetic technology could be making a comeback, with IBM Corp. and Infineon Technologies charging a joint team of 80 engineers and scientists with the task of making magnetic RAM (MRAM) a commercial reality within four years. MRAM retains its memory even after removing power from the device. Such a non-volatile memory has important military applications for missiles and satellites.

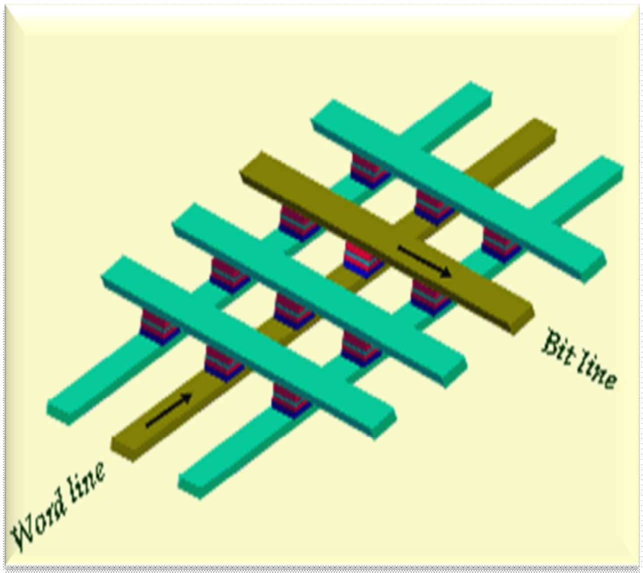

Fig.1- MRAM Architecture

III. SPINTRONICS

The word spintronics short for spin electronics was coined in the 1990s to describe devices that take advantage of "spin," a quantum mechanical property of an electron that takes only two values: spin up and spin down. Spintronics research flowered following the discovery of the giant magnetoresistance (GMR) effect in the late 1980s. IBM Almaden Research Center researchers realized that GMR could be used to make more sensitive hard disk drive read heads. Parkin discovered the fundamental underlying spintronics phenomena that made the spin valve a reality while researching novel properties of superlattices formed from combinations of various magnetic and nonmagnetic materials based on flowing charge currents through these superlattices.

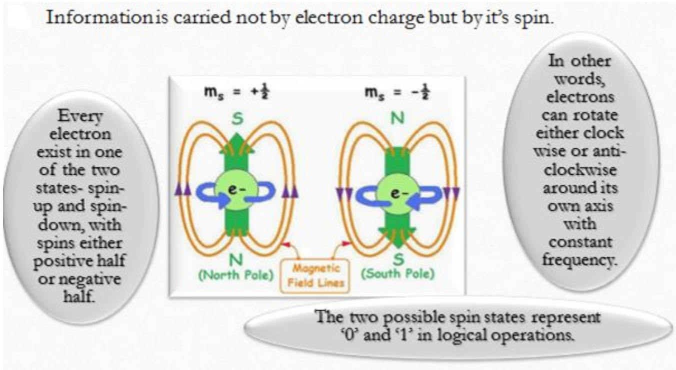

Fig.2- Spintronics Principal

By working at the atomic scale, he discovered that by sandwiching a nonmagnetic layer of material between two magnetic layers, where each of the layers was just a few atoms thick, and by applying small magnetic fields, the current flowing through the sandwich could significantly be changed. The reason was that within the magnetic layers, the electrical current, which was composed of negatively charged electrons, became "spin polarized" all the electrons' spins became oriented either "up" or "down," depending on the magnetic orientation of these layers just like nanoscopic compass needles, which point to either the North or South Pole. Small magnetic fields reorient these compass needles.

IV. READING DATA

To read the bit of information stored in this memory cell, you must determine the orientation of the two magnetic moments. Passing a small electric current directly through the memory cell accomplishes this. When the moments are parallel, the resistance of the memory cell is smaller than when the moments are not parallel. Even though there is an insulating layer between the magnetic layers, the insulating layer is so thin that electrons can "tunnel" through it from one magnetic layer to the other. The first to propose a magneto-resistive readout scheme was Jack Raffel. Magnetoresistance ratio is the ratio of change in electrical resistance to minimum resistance of a magnetic material when it is subjected to an electric field. His scheme stored data in a magnetic body, which in turn produced a stray magnetic field that could be detected by a separate Magnetoresistive sensing element.

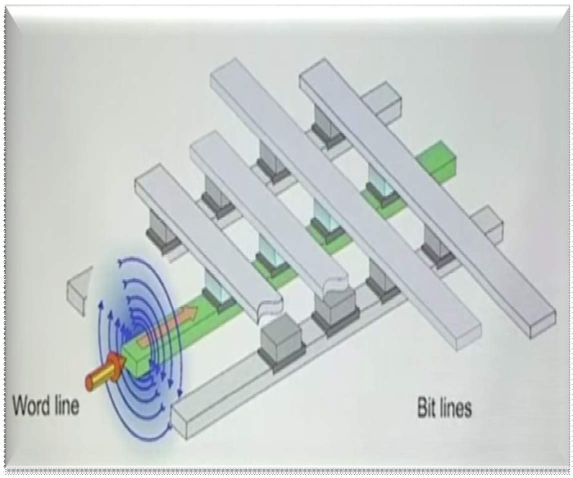

Fig.3- MRAM Current Flow in Reading Operation

The concept was not high density because it was difficult to get a sufficiently large external stray field from a small magnetic storage cell. This scheme is used in most of today's MRAM cells. There were difficulties in getting the cell to write consistently, and the difference in resistance between a "1" and "0" .was only about 0.1% of the inherent cell resistance, an impractically low signal. The first published proposal for fabricating magnetic memory cells on a silicon support chip used inductive read-out rather than Magnetoresistive readout. This was (and still is) an important concept for MRAM because interconnections between an array of magnetic cells and the required circuitry to make a memory are probably too complex for separate memory and support circuitry.

V. WRITING DATA

To write to the device, you pass currents through wires close to (but not connected to) the magnetic cells. Because any current through a wire generates a magnetic field, you can use this field to change the direction of the magnetic moment. The arrangement of the wires and cells is called across-point architecture: the magnetic junctions are set up along the intersection points of a grid. Wires called word lines run in parallel below the magnetic cells. Another set of wires called bit lines runs above the magnetic cells and perpendicular to the set of wires below. Like coordinates on a map, choosing one particular word line and one particular bit line uniquely specifies one of the memory cells. To write to a particular cell (bit), a current is passed through the two independent wires (one above and one below) that intersect at that particular cell. Only the cell at the cross point of the two wires sees the magnetic fields from both currents and changes state. MRAM works by etching a grid of criss-crossing wires on a chip in two layers with the horizontal wires being placed just below the vertical wires.

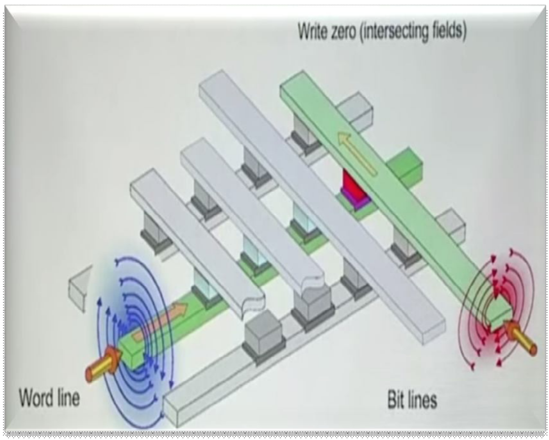

Fig.4- MRAM Current Flow in Writing Operation

At each intersection, a "magnetic tunnel junction" (MTJ) is created that serves as a switch and thus as a repository for a single bit of memory. The MTJ is essentially a small magnet whose direction is easily flipped. Common materials for the MTJ include chromium dioxide and iron-cobalt alloys. Current runs perpendicularly, "tunneling" through the insulator that separates it from a sheath of copper. At the base of one of the electrodes is a fixed anti-ferromagnetic layer that creates a strong coupling field. When a magnetic field is applied, electrons flow from one electrode to another, creating 0 and 1 states.

VI. APPLICATIONS

The advantages of the MRAM using SPINTRONICS as:

1. Denser - More memory cells on single small chip.
2. Non-volatile - Save data in case of a power failure.
3. Reduced power consumption
4. Immediate boot up - "Instant-On" Computing
5. Read & Write to Memory Faster
6. High bandwidth

Applications using spin polarized electrical injection have shown threshold current reduction and controllable circularly polarized coherent light output. Examples include semiconductor lasers. Future applications may include a spin based transistor having advantages over MOSFET devices such as steeper sub-threshold slope. The **Magnetic Tunnel Transistor** with a single base layer has the following terminals:

1. Emitter (FM1)
2. Injects spin polarized hot electrons into the base.
3. Base (FM2)

Spin dependent scattering takes place in the base. It also serves as a spin filter. Collector (GaAs): A Schottky barrier is formed at the interface. It only collects electrons that have enough energy to overcome the Schottky barrier, and when states are available in the semiconductor. MTT promises a highly spin polarized electron source at room temperature. **Storage Media** Antiferromagnetic storage media have been studied as an alternative to ferromagnetism, especially since with antiferromagnetic material the bits can be stored as well as with ferromagnetic material.

The main advantages of antiferromagnetic material are:

1. Non-sensitivity against perturbations by stray fields
2. Far shorter switching times
3. No effect on near particles.

VII. LIMITATIONS

Besides of all these advantages and its applications there are some challenges or variation which limits the use of MRAM which need to be resolved. They are as:

1. Heat problem
2. EMI problem
3. Temperature fluctuation causes electron scattering and resistance variation
4. Uniformity of barrier
5. Magnetic intensity difference

VIII. CONCLUSION

If MRAM chips are to debut, the completely different architecture will make DRAM chips obsolete and issue a new era of memory chips. MRAM solves your problem of losing data typed on your computer unless you are connected to uninterruptible power supply, as MRAM doesn't forget anything when power goes out. The difference is conventional RAM, uses electrical CELLS to store data, MRAM uses magnetic cells. This method is similar to the way your hard drive stores information. When you remove power from your computer, conventional RAM loses memory, but the data on your hard disk remains intact due to its magnetic orientation, which represents binary information. Because magnetic memory cells maintain their state even when power is removed, MRAM possesses a distinct advantage over electrical cells. There is still a long way to go before MRAM is ready for prime time. Neither IBM nor Motorola, for instance, is expected to go into mass production until they prove that they can make 256 megabit chips the standard memory module used today. But, as total sales of computer memory in 2000 were estimated by Semico Research Corporation to have been worth $48 billion, manufacturers have a considerable incentive to ensure that MRAM becomes a serious challenger for DRAM's crown.

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