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GMR Materials: A New Generation of Miniaturizated Technology

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Abstract: *The discovery of GMR opened new windows in the field of nano-materials, and nowadays research in these materials has become fashionable due to its tremendous technological potential and the deep fundamental physics involved in it. The discovery of giant magneto-resistance (GMR) has been a huge impact on our life, especially for mass data storage devices. Initial experiments conducted by Grunberg and Fert are explained. Basic physics of the GMR effect can be explained by the two-current model, which the conduction of a current is, consist of two different spin electrons. Details of GMR applications, such as hard-disk read-heads, sensors and magnetic memory chips are presented. One of the important aspects of GMR discovery was that it was immediately turned into commercially available products (the first GMR Hard disk head was introduced by IBM in 1997) with a giant market share. The highest storage capacity in the modern computers is attributed to the discovery of GMR. The story of GMR effect tells us how an unexpected scientific discovery could give rise to completely new technologies, new science and new commercial products, that means the new technology promises smaller and faster tools.*

Keywords: *GMR; Spin Dependent Tunneling (SDT); Hard disk drive; Sensors; Spin-Valve*

I. Introduction

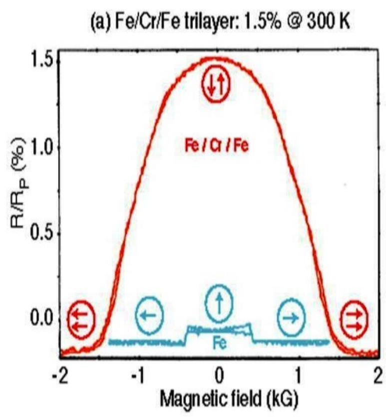
Giant Magneto Resistance ratio (GMR) materials have been reported by many workers since their initial discovery in 1988 [1, 2]. The initial development of these materials was driven by their potential for thin film head applications, and now initial demonstration of a thin film head using GMR materials [3]. GMR materials also have potential in many other applications, such as MRAM [4] and the first GMR magnetic field sensor products, which were announced in 1994.The 2007 Noble Prize for physics was awarded to Professors Peter Grunberg and Albert Fert for the discovery of giant magneto resistance (GMR) in which the spin as well as the charge of the electron is manipulated and exploited in nanoscale magnetic materials. GMR only manifest in nanoscale materials and the considerable demands of the magnetic data storage industry to drive up the data density stored on a hard disk fuelled an enormous international research effort following the initial discovery with the result that more than 5 billion GMR read heads have been manufactured since 1997, ubiquitous in hard disk today. This technology drive continues to inspire exploration of the spin current in the field now known as spintronics generating new ideas and applications. GMR also represented the first example of a new kind of technology called "Spintronics".

GMR the newest generation of hard disk drive storage. It provides almost three times the data density of its immediate predecessor, magneto resistive head technology. Disk storage technology strives to improve areal density-in other words, how much data can be packed into a given space. And where MR technology can store up to 3.3 gigabytes per square inch, GMR squeezes in 10 gigabytes per square inch-over 40 gigabytes per drive. As more data is squeezed into the same amount of space, the devices needed to accurately read the data also must keep pace. GMR is designed to pack as much data onto a disk that can be retrieved accurately – with as new moving parts as possible. The technology is based on a discovery made by two scientists in the late 1980s as mentioned a bellow. Disk drives that are based on GMR use these properties to help control a sensor that responds to very small rotating on the disk. The magnetic rotation yields a very large change in sensor resistance, which in turn provides a signal that can be picked up by the electric circuits in the drive. Nowadays, due to the requirement of the novel applications, traditional magnetic field sensing methods are being revised and often substituted by emerging technologies [5].

II. Noble Prize in Physics 2007

Two physicists, a Germany and a French researcher, who independently discovered an effect that makes today's tiny hard drives possible were awarded the 2007 Noble Prize in physics. They figured out that materials made up very thin, alternating layers of various metallic and nonmetallic elements experienced significant variations in resistance. The major research area of Albert Fert was electronic transport in magnetic materials. During the 1960s and 1970s, he had investigated the concepts spin dependent scattering [6]. This became the basic for understanding the GMR effect in magnetic multilayers. In the 1980s, started his research in magnetic layers and in 1988, he along with his group found GMR in Fe/Cr supper lattice [7].

Fig.1 **Peter Grunberg** **Albert Fert**



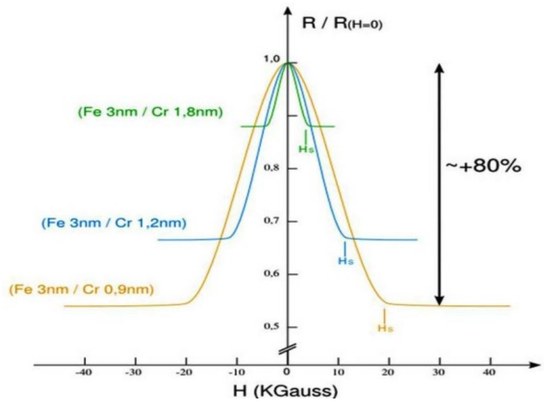


Fig.2: The results from Grunberg's original paper. T = room temperature. The current and the applied magnetic fields are along the same axis in the plane of the layers. [8]

Fig.3 the results from Fert's original Paper.T= 4.2K the current and the applied magnetic field are along the same axis in the plane of the layers. [1]

GMR effect

GMR is the change in electrical resistance in response to an applied magnetic field .It was discovered that the application of a magnetic field to Fe/Cr multilayer resulted in a significant reduction of the electrical resistance of the multilayer as shown in Fig.(4).

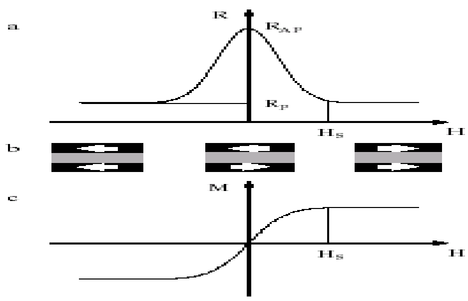


Fig.4. Schematic representation of the GMR effect (a) Change in the resistance of the magnetic multilayer as a function of applied magnetic field. (b): the magnetization configurations (indicated by the arrows) of the multilayer (trilayer) at various magnetic fields: the magnetizations are aligned anti-parallel at zero fields; the magnetizations are aligned parallel when the external magnetic field H is larger than the saturation field Hs. (c); the magnetization curve for the multilayer. [9].

GMR Technology

The discovery of GMR property opened the way to a new generation of simple, strong magnetic sensors and devices, for instance, read heads for disc drives, isolators and control circuitry for electrical machinery. New technology promises smaller, faster tools and Low cost sensor can be constructed using Wheatstone bridge designed with the GMR materials placed between two flux concentrators made from soft adjacent layers (SAL). as shown in fig.(5)

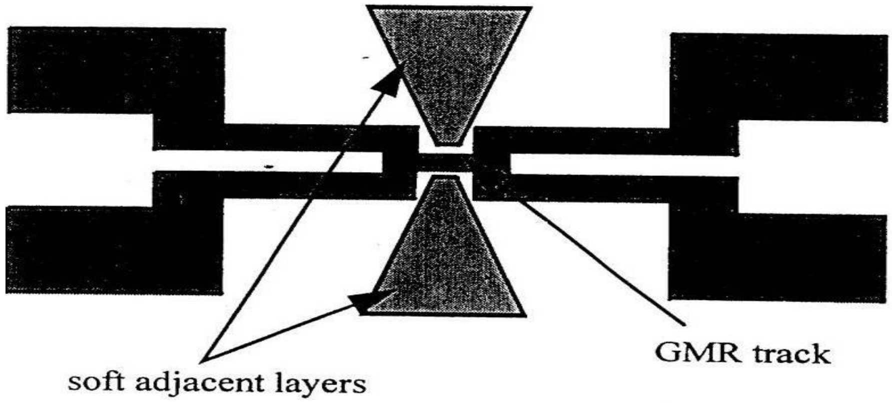


Fig.5 Details of GMR device element

The flux concentrators produce directional field amplification by approximately the ratio of the length of the concentrators to the gap between them [10]. One potential application the GMR sensor is for measuring changes in rotation of small magnetic fields that may be used to monitor the speed of a motor or the wheels in an antilock-braking system in car [11]. This could be done by placing small magnets on the axle and measuring the rotational speed with a GMR sensing device. Other applications include solid state compasses, current sensors for safety power breakers and electricity meters, imaging detector for use in geophysical exploration and detection of landmines, defect detection using eddy-current mapping, currency detection and detection of motor Vehicles for traffic control. These magnetic sensors have the advantage of measuring physics properties such as direction, presence, rotation, angle or electrical currents without actual contact to the medium being measured as they only detect changes in magnetic field that has been created or modified by the physical properties. As such, some signs processing is required for the output signal of these sensors for translation into the desired parameter.

The concepts for a variety of GMR sensors are briefly discussed an illustrated in articles by Caruso et al., Heremans, Smith and Schneider [12-14]. Non-volatile Electrons is, at the moment, the only commercial vendor for on-chip GMR sensors. In the field of data storage, the current magneto resistive (MR) elements used in read heads are sputter-deposited NiFe (Permalloy) films. GMR multilayers are, however candidates for new type of MR read heads that offer more sensitive magneto resistive response. Besides exhibiting superior temperature stability, GMR sensors are able to offer signals 20-30 times larger than that of the Permalloy MR sensors and, at the same time, linear over most of the operation range. In 1994, magnetic read heads fabricated using ‘‘spin-valve’’ structure have been demonstrated to be the world’s most sensitive sensor for detecting computer data on magnetic hard disk [15]. In 1997, IBM/Hitachi introduced the first GMR hard drive using ‘‘spin-valve’’ structure with capacity of 16.8 gigabytes (GB) storage density, marking a start in the transition from MR to GMR era in data storage industry [16]. Another challenge for GMR technology is to imagine a MRAM (magnetic random access memory) chip using GMR materials, replacing the conventional memory chip based on silicon capacitors and transistors. A MRAM is a single solid-state memory device that could store information magnetically. It exploits the spin rather than the charge of the electron and has the advantages of non-volatility, fast data accessibility, non-destructive read out and high storage capacity. A proposed MRAM device consists of an array of magnetic plots cut in the top of a GMR pseudo spin-valve structure [17]. Information is written by flipping the magnetization of the plots and is read by sensing the resistivity of each plot. The ‘‘0’’ and ‘‘1’’ state depend on the relative magnetization orientation of the magnetic layers.

Applications of Giant Magneto-Resistance (GMR)
1- Sensors on GMR

The successful commercialization of GMR sensors in hard disk read heads has opened the way to the application of GMR sensors in other situations where size, speed and sensitivity are important parameters [18]. Examples can be found in a wide variety of situations such as nanoscale arrays of GMR sensors for 100 μm scale spatially resolved eddy current detection

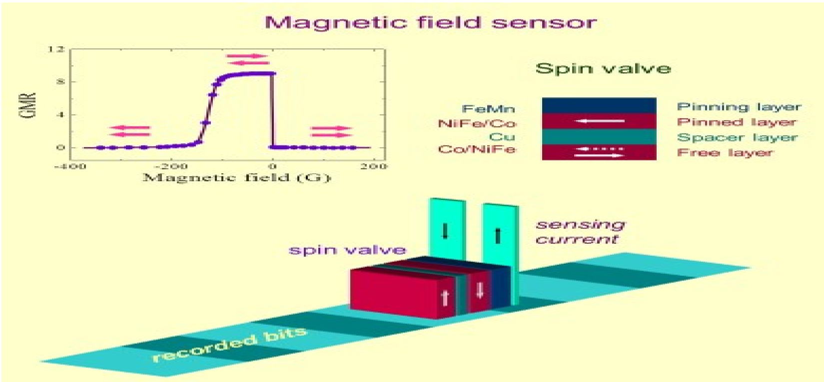


Fig.6. shows several types of magnetic field sensors

[19], biological sensors for molecule tagging [20, 21], galvanic isolators [22], traffic control, engine management systems, magnetic separation and electronic compasses. The life of GMR based sensors is very short. In fact, the first commercial GMR sensors were introduced in 199[23]. The rapid evolution of GMR sensors technology has opened a wide and promising range of applications. Apart from electrical measurement related systems, GMR based sensors are nowadays being utilized in different fields as engineering, physics, biology, space. Michelena et al. [24-26] introduced the possibility of using GMR commercial sensors in space applications. GMR sensors have not been flown yet but Spanish National Institute of aerospace technology is working on the adaptation of a miniaturized GMR three axis sensors (HMC2003, from Honeywell) to the attitude control system in the frame of the OPTOS project, which is a 10x10x10 cm3 Picosat devoted to be technological test bed. The circuitry consists of conditioning and electronics blocks.

2-Spin Valves Sensor

The new multilayer structures [27, 28-31], called spin-valves, typically consist of a ferromagnetic layer pinned by direct exchange coupling to an antiferromagnetic layere and separated by a decoupling non-magnetic layer from an unpinned and magnetically soft 'free' ferromagnetic layer easily switched by a small applied magnetic field as shown in figure (7).

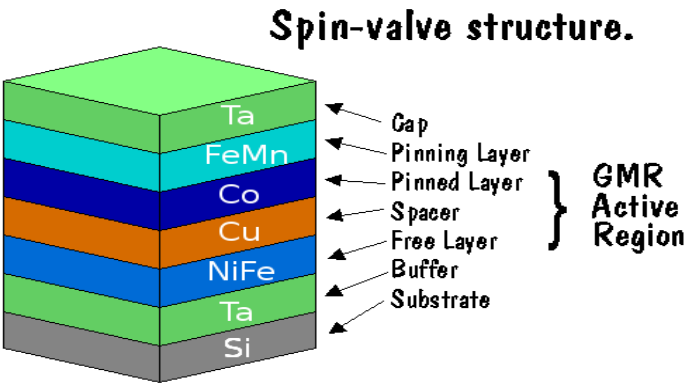


Fig.7. Spin Valves Sensors

3-Read Heads and GMR Data Storage

The technology of the read head in a hard disk has developed since the invention of the hard disk in 1956. A true nanoscale device, a modern read head will typically have more than a dozen nanoscale layers, controlled on the atomic scale, subject to more than 250 processing steps and in operation 'flies' typically 10-15 nm above the hard disk platter which is spinning at up to 15 000 rpm. A review on read head sensor technology is given by

Childress [32]. A schematic diagram of the overview of the hard disk showing the disk platter, actuator and location of the read-write head over the spinning platter is shown in figure (8).

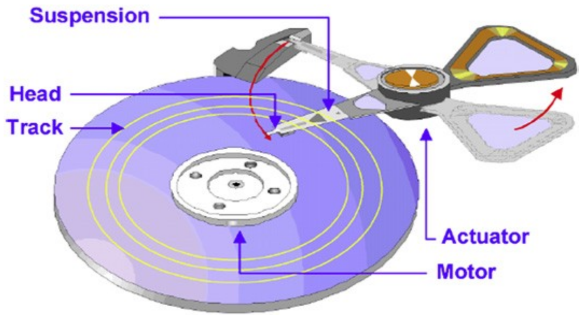
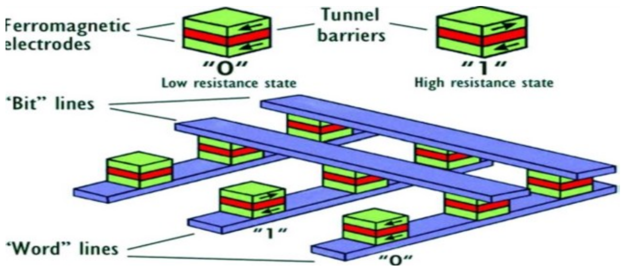


Fig.8. Schematic diagram of a hard disk platter showing recorded tracks, actuator and suspension onto which the head is attached. [32].

4-Magnetic Random Access Memory (MRAM)

In addition to the phenomenal contribution that GMR has made to magnetic hard disk storage devices, there has been considerable effort, especially by Motorola/Free scale, IBM [33] and Infineon, for developing a magnetic random access memory (MRAM) to compete with DRAM and SRAM which would have the advantages of non-volatility, radiation hardness and low energy consumption. In an MRAM device, magnetic tunnel junctions (MTJs) are both the storage and the read element. A typical MRAM architecture is shown in figs (9) [34] where the digital '1' and '0' states are achieved by an MTJ in either the parallel anti-aligned

Fig.9. Schematic diagram of a possible MRAM architecture. The memory cells are shown at the top to be magnetic tunnel junctions with the two memory states represented by parallel and anti-parallel alignment of the ferromagnetic layers. The bits are assembled and connected in an array as shown below creating 'word lines' and 'bit lines'. The voltage across a single bit can be read by connecting to the array appropriately and the magnetization orientation of the bits changed by the magnetic field created from the passing of a write current [35].



or the aligned state. MTJs took over from GMR devices in MRAM applications due to their high magneto resistance, high resistance, which makes them compatible with CMOS technology, ease of scaling to small dimensions and a weak variation with temperature. Developments in spin-transfer switching and the enhanced MR values found with crystalline and textured barriers have recently given new impetus to these developments.

III. Summary

Since the discovery of Giant Magneto Resistance (GMR), people has been studied a fundamental physics behind the phenomenon and applications of using the effect. The GMR has been a huge impact on our life, especially for mass data storage devices. GMR's application to the read head of hard discs greatly contributed to the fast rise in the density of stored information and led to the extension of the hard disk technology to consumer's electronics. Besides in terms of further technological advances, the development of spintronics revealed many other phenomena related to the control and manipulation of spin currents. Thus basically GMR of the magnetic multilayers opened the way to an efficient control of the motion of the electrons by acting on their spin through the orientation of a magnetization. Giant Magneto Resistance (GMR) technology is being applied to those applications today and the newer GMR technologies such as Spin Dependent Tunneling (SDT) will make even more of these applications possible. Several applications will be presented on the use of individual GMR materials. So at the beginning of this century outstanding progress had been made both in designing the magnetic properties through atomic engineering, and in understanding and controlling the spin-dependent electron transport. And materials exist that allow thermally stable magnetic particles to be produced down to size of a few nanometers, seemingly opening a bright future for high-density spin storage.

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