Giant MagnetoResistance

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Abstract

In this paper I give an overview of the history of Giant MagnetoResistance. I then go on to describe what Giant MagnetoResistance is and how it works. I then talk about its major commercial applications, and finally talk about GMR's legacy.

1 History

In 1988 there was considerable interest in layered magnetic structure. Independetly two groups were able to produce GMR, one in a multi-layered sample, the other in in tri-layer sample. Qualitatively this idea goes all the way back to 1936. Mott proposed a mechanism for the change in resistivity of ferromagnetic materials. In the 1960's Albert Fert wrote his Ph.D. thesis on spin dependent resistivity, however it wasn't until the mid 1980's that experimental methods had matured enough for scientists to create materials that exhibited Giant Magnetoresistance. Fert's and Peter Grünberg's groups used Molecular Beam Epitaxy to grow their samples which was the only method available at the time to grow the materials with the required thickness, 1nm. Later on sputtering would be used in commercial applications. Both Fert and Grünberg would recieve the 2007 Nobel prize for their independent discoveries of Giant Magnetoresistance.

2 Physics

For now this is goin to be qualitative with mathematics to come at a later date. Mott's arguement goes as follows. Consider two currents

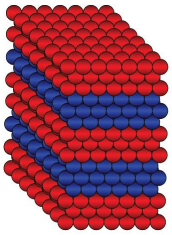


Figure 1: Grünberg's sample

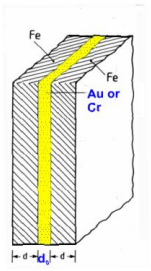


Figure 2: Fert's Sample

passing through a sample. The sample is ferromagnetic with all the spins aligned up. One current consists of spin up electrons, the other spin down electrons. Due to the energy needed flip a spin scattering from $|\uparrow\rangle \rightarrow |\uparrow\rangle$ will be nearly 1. One the other hand the spin down electrons have a much higher chance of being scattered cause they interact much more strongly with the spin ups. Fert's and Grünberg's groups both used a layered sample. The reason for this is if you pass a current through a sample, lets say tri layered where the first and third layer are aligned in a spin up arrangement, with the middle layer made of some non-magnetic material just so that the seperation of the aligned layers is less than the mean free path of the electron. The spin up current will see very few scattering events(resistance). The spin down current though will see a scattering event in both layers. Now if you flip the orientation of the third material you so that the first layer is anti-alligned with the second and so that the spin up's see the same number of scattering events in the third layer as the spin down's in the first layer you have drastically increased the total resistance. For example, if in the original configuration the spin

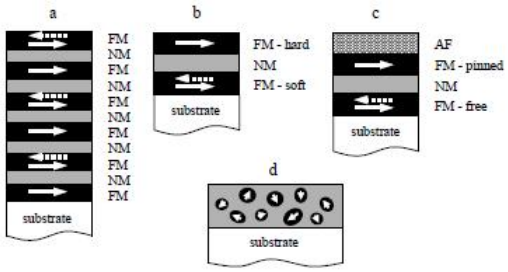


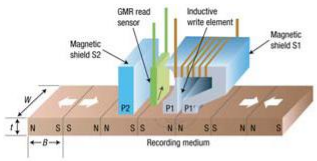
Figure 3: These are four examples of systems that show GMR. A) is layered magnetic,non-magentic layers B)and C) are both examples of spin valves D) is a granular sample.

down's see 10 times as much resistance as the spin ups, when you flip the orientation of the third layer you will increase the total resistance by roughly a factor of 3.

The first samples that exhbited GMR did it with the Current in Plane(CIP), by 1993 samples were produced with the Current Perpindicular to the Plane (CPP). More research is required.

3 Applications

As far as applications of science to consumer electronics few things have made as great of an impact as quicly as GMR did. GMR' most fa-



mous application is the Hard Disk Drive.
The way a hdd works is the head senses modulations in the magnetic field. The problem is as you decrease the magnetic domains(increase the memory density) you also decrease the magnetic field strength. In the early 90's anisotropic magnetoresistance was used to create hard drives. But as the need for more storage increased the size of the domains decreased and as such the field strength decreased too. Roughly a decade after GMR was discovered the effect was understood well enough hard drive manufacturers were willing to put the effect to use commercially. During the life span of GMR based hard drives the storage capacity increased almost 40,000%(I know it was some were from 1 gb to roughly 400 gbs I will find an exact number). Today hard drives are based on TMR. Some would argue that the discovery of Giant Magnetoresistance created the field of Spintronics. TMR is one effect that was born out of this research and has usurped GMR as the dominate technology in hdd. It is based upon quantum mechanical tunneling through layers. Another promising application of spintronics is MRAM or Magnetoresitive Random Access Memory. MRAM is a non-volatile form of memory meaning that it doesn't degrade over time like hdd based on gmr and tmr as well as flash memory. The memory cells in MRAM are tunneling junctions which have their magnetic field changed by the Word and Bit lines.

4 Conclusion and Future

GMR has had a succesful run in the industrial market place and its time has ended, but we still see its legacy, and will continue to. GMR research gave birth to TMR, CMR, and in general Spintronics. Tun-

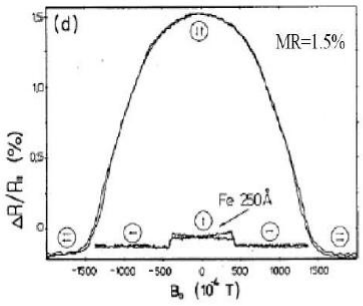


Figure 4: A comparison of GMR versus that of AMR

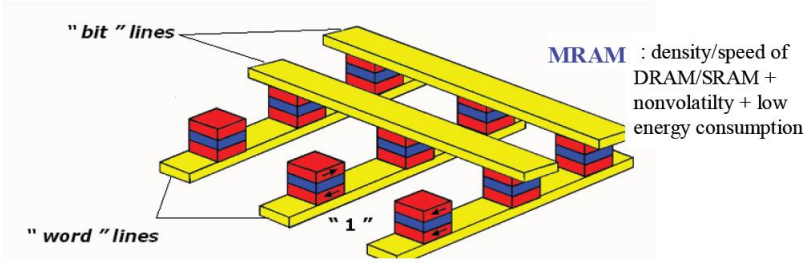


Figure 5: A schematic diagram of mram

neling Magnetoresistance has allowed us to see the price per gigabyte fall below 1 dollar. As of this writing Western Digital has announced the world's first 2 TB hdd.

5 References*

I have been fighting with Bibtex for days now, I don't know why it isn't working for me right now. For now this is a place holder. My references include Fert's and Grünberg's nobel lectures, I took the first two pictures from their presentation. I also used a GMR review which can be found here $http://physics.unl.edu/\ tsymbal/tsymbal\_files/Published\%20papers/GMR-review-preprint.pdf$.

References