Scientific Writing Essay: First draft

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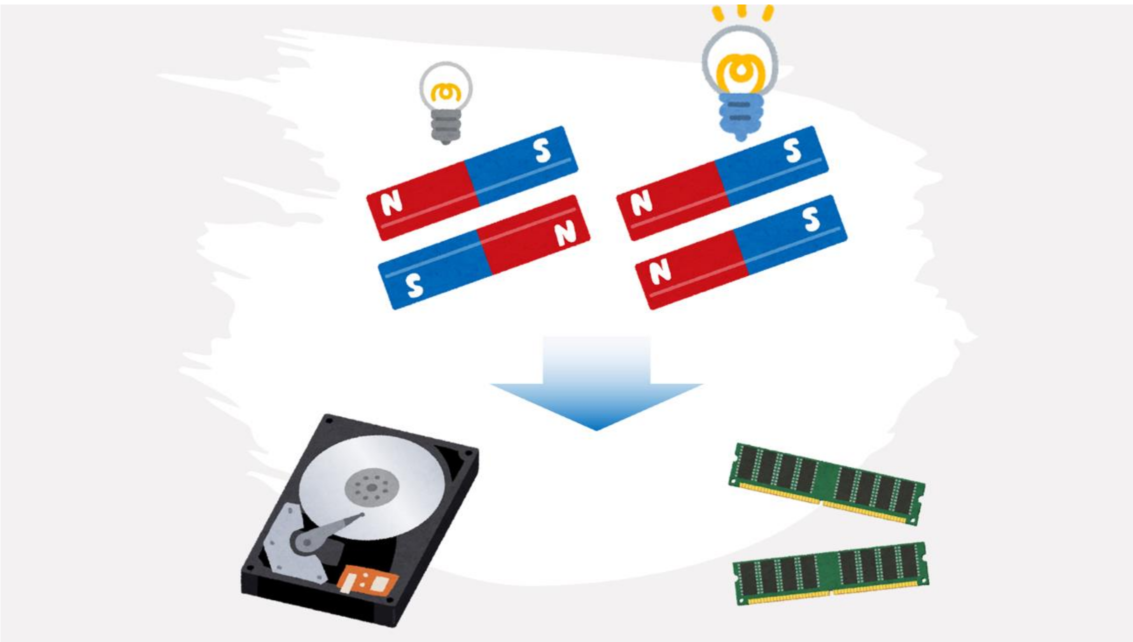
Title: Giant magnetoresistance and its applications



In laptops, hard disk drives (HDD) are a common device for secondary storage. Basically, HDD consist of several platters or disks, Read-and-Write heads and arms. A binary data is physically processed in the form of a configuration of numerous small magnetic domains or their boundaries. This corresponds to a situation where many bar magnets are arranged on the disk.

In this essay, I mainly focus on the Read heads. One of the most traditional Read heads is called “Inductive head”. The mechanism of Inductive head follows Faraday’s law of induction, and the whole procedure to read data from the disk is like that of phonograph records. When the magnetic domains along the disk switch to the opposite direction, the north or the south pole is generated, which induces perpendicular magnetic fields to the disk. By rotating the disk, the Read head goes under time-dependent magnetic field, which turns the data of the magnetic domain into voltage.

In 1956, IBM developed the first commercial HDD which had about 20 Kbits/in^2. This is about one one-hundreds millionth density of data of the current HDD and is obviously not sufficient for us today. It was an observation of a giant magnetoresistance (GMR) that made a major breakthrough for significantly densified Read heads.

In order for you to understand GMR, first I wish to draw your attention to magnetoresistance (MR). Under a magnetic field, resistance of materials changes depending on its magnitude and direction in general, which is called MR effects. Then, what is “Giant” MR or GMR?

A MR ratio is given as $(R_{F'} - R_F)/R_F$, where F and F' mean two different magnetic fields and R_F and $R_{F'}$ mean the resistance under the field F or F' respectively. Then “Giant” means a large MR ratio. There is a positive correlation between the size of MR ratio and the binary data detection of HDD. The larger MR ratios can lead high integration since weaker signals of HDD can be sufficiently detected.

GMR is a phenomenon that occurs in multilayer structures made up of alternating magnetic and non-magnetic layers. It was first observed in 1988 by Albert Fert and Peter Grünberg independently, and they were jointly awarded the Nobel Prize in Physics in 2007 for this discovery. That result was reported using Fe/Cr superlattices which was fabricated by the contemporary nanotechnology method at that time, that is, molecular beam epitaxy. In the material, Fe and Cr layers correspond to bar magnets and mere metals (not magnets), respectively. It is called superlattices as such materials are totally artificial ones. In the superlattices, we can define a MR ratio by applying the relative orientation of magnetizations to magnetic fields F and F'. This is because, roughly speaking, magnetizations behave magnetic fields. When the magnetizations of Fe layers are parallel, the resistance is low, and when they are antiparallel, the resistance is high. Before the discovery of GMR, MR ratios are typically known as about 5%. However, around 4 K (~ -269 ℃), the MR ratio representing the difference between the two configurations increases to about 40%.

Why can this happen? One of the simplest ways to explain this phenomenon is to focus the number of spins of electrons in each magnetic layer. A spin is one of the natures of electrons and corresponds to a rotation or an angular momentum of electrons. Spins are also the origin of magnetizations, so if there are many or dominant electrons which have upward spins in a material, it has a magnetization of upward. And if such a situation occurs without external magnetic fields, the matter is called a magnet. In solids, there are so many electrons, and they are the minimal entity of currents. Electrons are so small that their dynamics like transports are described by quantum mechanics. It is difficult to introduce several ways to treat such phenomena theoretically, but just remember that, roughly speaking, electrons forming currents are "in the same boat", and the boats are labeled by spins.

Now, let's go back to the topic to consider the situation where electrons in a Fe layer move in another Fe layer through a Cr layer. When the incoming electrons have the major spin of the accepting Fe layer, there are many siblings of the same spins in the "boat", and the magnitude of currents becomes large. However, when they have minor spins, there are few siblings, and the magnitude of currents becomes small. GMR is highly useful for Read heads thanks to the device engineering called spin valves. A key to understand spin valve is to separate two Fe or magnetic layers into pinned and free layer. Magnetizations in the pinned layer can be fixed by some technical method, and those of the free layer are to refer the magnetic field induced by the disks. Such devices based on GMR are already sold in stores, and the MR ratio at room temperature is about 10%. As mentioned above, MR ratios are crucial to realize high integration of HDDs, and the HDDs using GMR heads have about 100 Gbits/in^2. Today, MR ratios are still improving year by year using the tunnel magnetoresistance (TMR), in which the conductor layer is replaced by an insulating layer, contributing to the high integration of HDDs.

But the story is yet to finish. There is another discovery or a second surprise stimulated by GMR: a qualitative change of electronics. The behavior of spin valves makes us feel that a set of spins has information like a set of charges and voltage. Then, how about a current of spins? This can be achieved by electrons of a specific spin, and they are called spin-polarized electrons. Spintronics is a technology that uses not only the charge but also the spin of electrons to carry information. GMR is contributed to improve the performance of Read heads, while current of spins can be applied to writing processes based on the above idea that comes from spin valves. There are already some devices using such idea, such as the magnetic random access memory (MRAM). A key phenomenon of such writing processes is a magnetization reversal. In quantum mechanics, local magnetizations have precession movements under magnetic fields, which corresponds to the dynamics of tops. The magnetizations are basically aligned to the magnetic fields. When spin-polarized electrons go through the magnetizations, there are two kinds of tops or angular momentums. If the configuration of the two angular momentums is anti-parallel, they are canceled out partially and the local magnetizations are to rotate and to fall down. By increasing the number of spin-polarized electrons, such effects become larger, which leads the local magnetizations to take a new direction. This is nothing but a writing process!

In conclusion, the discovery of GMR is crucial in terms of not only improvement of the quantity of data of HDD, but also yielding a novel quality of electrons.

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References:

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