Naneng 307: Giant Magnetoresistance (GMR) "A Review"

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Abstract:

Magnetoresistance is known in the literature as the change in the resistance of any material when it is placed in a magnetic field. However, when the copper which is nonmagnetic metal is placed in a magnetic field, its resistivity changes. This shows how resistivity is indeed dependent on the applied magnetic field. Many researchers got attracted to GMR sensors because of the widely used properties which will be mentioned in detail in this Review. One of the most common advantages is that GMR is well known for its small dimensions and that it requires a low power source. We also will discuss some of the main applications like Spin Valve Sensors and Hard Disk Drivers.

I. INTRODUCTION AND HISTORY

Magnetoresistance is the change in the resistance of a material (any material) when it is placed in a magnetic field [1]. When a nonmagnetic metal such as copper is placed in a magnetic field, the change in its resistivity, and hence it's resistance, is so small that it is negligible. On the other hand, when a magnetic material such as iron is placed in a magnetic field, the change in the resistivity depends on the direction of the current flow with respect to the magnetic field. It is worth mentioning that very large magnetoresistance, which is denoted as giant magnetoresistance (GMR), occurs in certain special multilayer structures, which exhibit substantial changes in the resistance (e.g., more than 10 percent) when a magnetic field is applied. Historically, GMR was discovered in the late 1980s by Peter Grünberg (Julich, Germany), Albert Fert (University of Paris-Sud) and their coworkers. Magnetoresistance itself, however, was well documented back to Lord Kelvin's experiments in 1857 [1].

Fig. 1 Albert Fert (left) and Peter Grünberg (right) in 2007 in the auditorium of Stockholm University.

Peter Grünberg and Albert Fert were awarded the 2007 Nobel Prize "for the discovery of Giant Magnetoresistance" [1]. GMR was discovered in 1988 and was of the most influential impacts in development of magnetic devices. GMR based devices include the read heads of hard disk drives, in addition to, a wide range of magnetic field sensors.

II. THEORY

The basic principle of GMR is as follows:

- The resistivity $\rho_{//}$ for current flow parallel to the magnetic field decreases
- The resistivity $\rho_{\perp}$ for current flow perpendicular to the field, increases by roughly the same amount.

Accordingly, as resistivity changes differently in both directions, the effect is anisotropic, thus named anisotropic magnetoresistance (AMR) [1]. Physically, this phenomenon occurs because the applied field rotates the orbital angular momenta of the 3*d* electrons as shown in Fig. 2. This rotation alteres the scattering of conduction electrons in their respective paths of movement. Electrons with movement aligned with the field experience more scattering than those moving perpendicularly. Fig. 2 (b) shows how resistivity is dependent on flow direction against applied magnetic field.

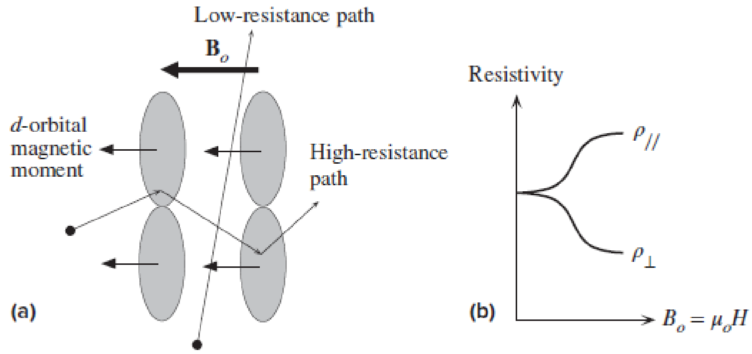

Fig. 2 (a) Principle of AMR. (b) Anisotropic resistivity effect

III. DEVICE

These materials have a special multilayer structure composed of two ferromagnetic layers (Fe or Co or their alloys, etc.) separated by a nonmagnetic transition metal layer (such as Cu), called the spacer:

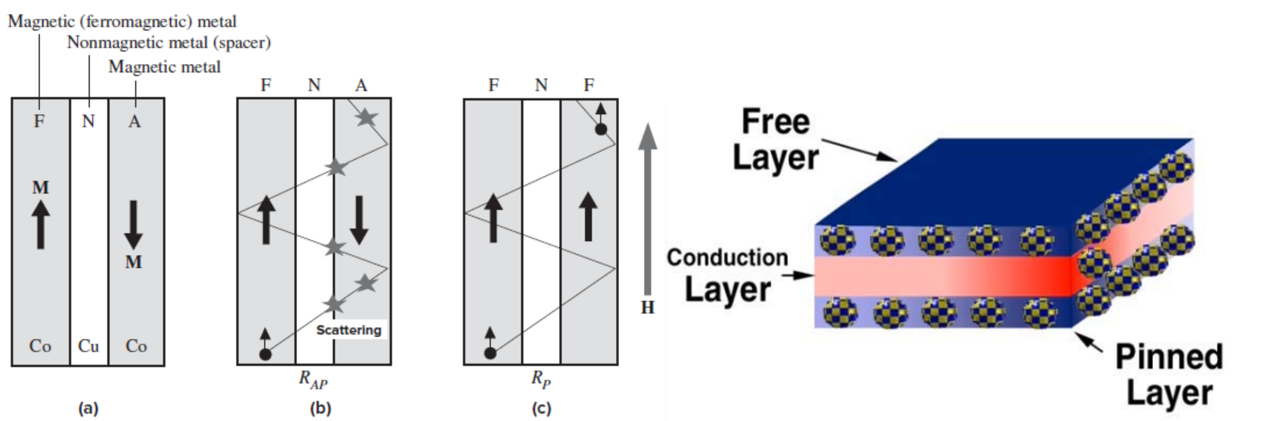

Fig. 3 Device schematic

Both magnetic layers are thin (less than 10 nm), while the nonmagnetic layer is even thinner. The magnetization of the two ferromagnetic layers depends on the thickness of the spacer material. Not to mention, these two layers are coupled indirectly through the thin spacer. Without an external magnetic field, magneziations are antiparallel leading to antiferromagnetic arrangement.

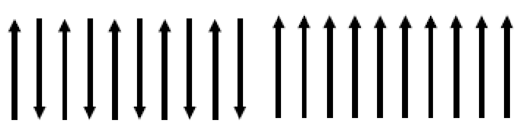

Fig. 4 Antiferromagnetic (left) and ferromagnetic (right) arrangements.

Therefore, the two arrangements are:

- FNA: antiferromagnetically coupled configuration
- FNF: ferromagnetically coupled configuration

It is worth noting that N stands for the nonmagnetic metal. Both these arrangements create a very large difference in their resistances, whilst the antiparallel structure has much larger resistance R_{AP}than parallel structure resistance R_P.

GMR effect is defined as: $$\left(\frac{\Delta R}{R_p}\right)_{\mathrm{GMR}} = \frac{R_{\mathrm{AP}} - R_P}{R_p}$$

Table 1 summarizes typically reported ΔR⁄RP values for the GMR effect in simple trilayers and multilayers.

Table 1: GMR effect in trilayers and multilayers [2]

Sample	Structure and Layer Thicknesses	$\Delta R/R_P$ (%)	Temperature (K)
CoFe/CAgCu/CoFe	Trilayer	4–7	300
NiFe/Cu/Co	Trilayer, 10/2.5/2.2 nm (spin valve)	4.6	300
$Co_{90}Fe_{10}/Cu/Co_{90}Fe_{10}$	Trilayer, 4/2.5/0.8 nm (spin valve)	7	300
$[Co/Cu]_{100}$	100 layers of Co/Cu, 1 nm / 1 nm	80	300
$[Co/Co]_{60}$	60 layers Co/Cu, 0.8 nm / 0.83 nm	115	4.2

IV. Applications

GMR sensors indeed have attracted many researchers due to the widely used properties of the GMR as it is used in various applications because these sensors have not only high bandwidths but also sensitivity independent of the magnetic field [3]. One of the most common advantages is that GMR is well known for its small dimensions and that it requires a low power source.
Some main applications will be discussed.

- Spin Valve Sensors
- Hard Disk Drivers
- Other Applications

A. Spin Valve Sensors

A typical GMR-based sensor consists of seven layers [4]:

1. Silicon substrate.
2. Binder layer which is made of tantalum.
3. Sensing (non-fixed) layer made of NiFe or cobalt alloys. However, the magnetization can be reoriented by the external magnetic field as mentioned before.
4. Non-magnetic layer which can be made of copper.
5. Fixed layer is made of a magnetic material such as cobalt.
6. Antiferromagnetic (Pinning) layer. The FeMn or NiMn can be used.
7. Lastly the Protective layer is made made of tantalum.

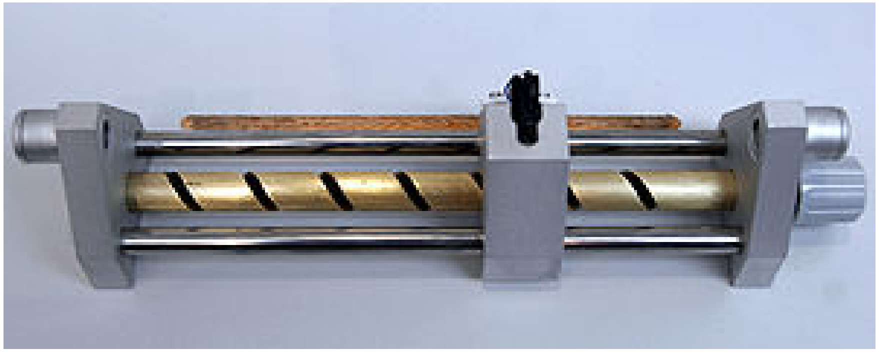

Fig.5 A copy of GMR sensor developed by peter Grünberg [4]

B. Hard disk drives

It is known that the information in hard disk drives (HDDs) is encoded using the change in magnetic domains. The magnetization change is associated with the logical level 1 while no change represents logical 0.

In the current technology there are 2 main recorded methods: longitudinal and perpendicular.

The magnetization is expected to be normal to the surface in case of longitudinal method. As studied there exist transition regions called domain walls which formed between the magnetic domains, in which the magnetic field direction changes inside the material.

Now to read the magnetic field direction just above the magnetic domain wall, assume that the magnetization direction's direction is fixed normal to the surface in the antiferromagnetic layer and parallel to the surface in the sensing layer. [5]

Changing the direction of the external magnetic field deflects the magnetization in the sensing layer. And so the electrical resistance of the sensor decreases, and So on.

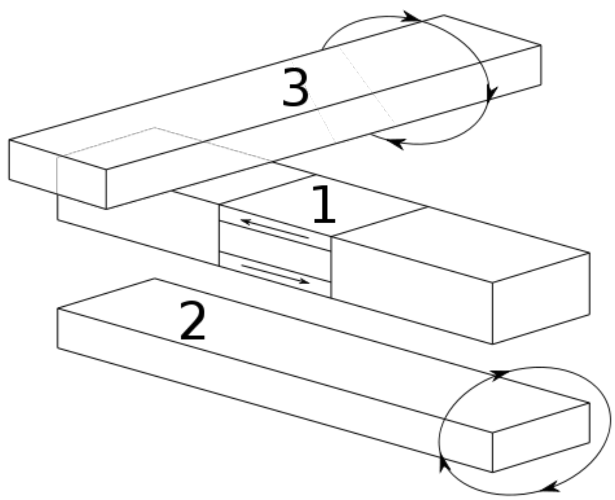

Fig.6 the use of Spin Valve in MRAM [5]

3- Other Applications:

- **Magnetic RAM**: A MRAM (magnetoresistive random-access memory) has a similar structure to the spin-valve sensor mentioned before. The general principle can be summarized that the encoded bits are made by the magnetization direction in the sensor layer. Moreover, it is applicable to measure the resistance of the structure.
- **Magnetoresistive insulators** for contactless signal transmission

V. CONCLUSION

The effect of GMR is well observed as a change in the electrical resistance depending on the magnetization, also depending on the alignment of the ferromagnetic layers whether they are in a parallel or an antiparallel alignment. From this review, we can conclude that the total resistance is relatively high for antiparallel alignment and so it is relatively low for parallel alignment, also we can control the direction of the magnetization by applying an external magnetic field. Many researchers got attracted to GMR sensors because they are used in various applications as they have high bandwidths and sensitivity independent of the magnetic field.

Reference

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