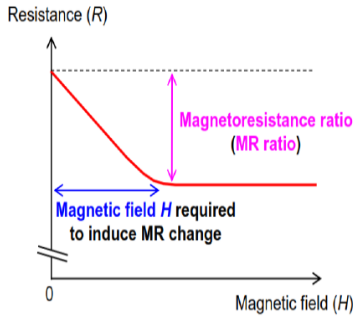
Anisotropic and Giant Magnetoresistance – Spins Valve

Rui Marques Carvalho

Abstract: This experiment had as main objectives the determination of the maximum magnetoresistance and the maximum sensitivity in the anisotropic and giant magnetoresistance and for the coupling field only in the giant magnetoresistance, with spins valve. All these quantities were determined for the different angles of observation, more concretely for the angles of 0º, 30º, 60º, 90º, 120º, 150º and 180º. Only in the determination of the maximum sensitivity for the anisotropic magnetoresistance did not observe the angle of 120º, but of 45º. In the anisotropic magnetoresistance, the maximum magnetoresistance values obtained for the respective angles observed were: 0,016Ω, 0,011Ω, 0,008Ω, 0,0097Ω, 0,011Ω, 0,0105Ω and 0,016Ω and the maximum sensitivity values were: 0,1%/Oe, 0,2%/Oe, 0,19%/Oe, 0,15%/Oe, 0,075%/Oe, 0,25%/Oe and 0,21%/Oe. In the giant magnetoresistance with spins valve, the maximum magnetoresistance values for the respective observed angles were: 0,029Ω, 0,065Ω, 0,075Ω, 0,082Ω, 0,076Ω, 0,072Ω and 0,023Ω, the maximum sensitivity values were: 0,14%/Oe, 0,72%/Oe, 0,92%/Oe, 0,82%/Oe, 1,37%/Oe, 0,91%/Oe and 0,16%/Oe and the coupling fields values were: 0T, 2,5T, 2,5T, 3T, 0,5T, 0T and 1T.

Magnetoresistance, what is?

A magnetoresistance is a change in resistance by an application of H.

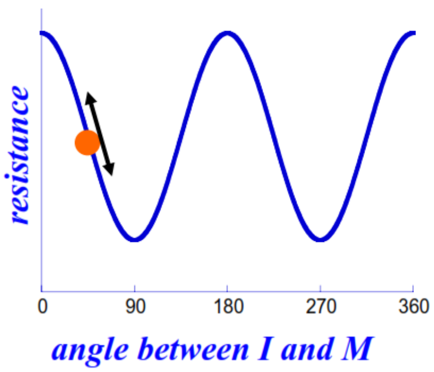


Change in resistance by an application of H

Anisotropic Magnetoresistance (AMR)

The AMR is a dependence of the electrical resistivity on the relative angle between the direction of the sense current and the local magnetization.

$\boldsymbol{\rho(\Theta)} = \boldsymbol{\rho(perp.) + (\rho(par.) - \rho(perp.)) \times \cos^2(\theta)}$, where $\rho(perp.)$ and $\rho(par.)$ are the perpendicular and parallel components of the resistivity, respectively and ϴ is the angle between I and M.



Variation of the resistance with the variation of ϴ

In AMR, the electron spin-orbit coupling results in a difference in the scattering cross-section when the electron current is parallel or perpendicular to the magnetically aligned atoms.

When I is parallel to M, the electronic orbits are perpendicular to current, the cross section increases for dispersion, producing high resistance.

When I is perpendicular to M, the electronic orbits are parallel to current, the cross section reduced for dispersion, producing low resistance.

Giant Magnetoresistance (GMR)

The Giant Magnetoresistance is the large change in electrical resistance of metallic layered systems when the magnetizations of the ferromagnetic layers are reoriented relative to one another under the application of an external magnetic field. This reorientation of the magnetic moments alters both the electronic structure and the scattering of the conduction electrons in these systems, which causes the change in the resistance.

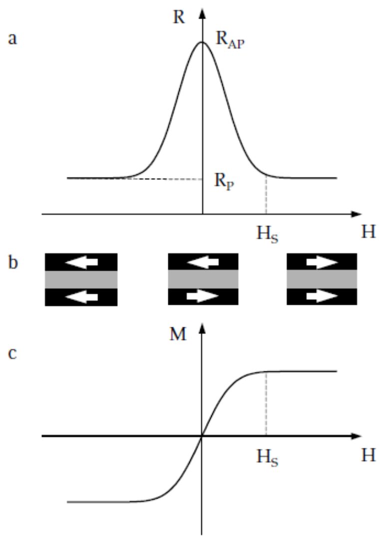
It is a model for electrical conductivity in metals – conduction current in ferromagnetic metals can be decomposed into two-carrier types-current.

The total conductivity can be expressed as sum of separate contributions from majority and minority electrons

An electron scatters when it enters the material with a magnetization opposite to its spin.

For the anti-parallel case both types of electrons are scattered.

When the magnetizations are aligned the up spin electron does not scatter in either magnetic layer.



a) **Change in the resistance of the magnetic multilayer as a function of applied magnetic field.**
b) **The magnetization configurations of the multilayer at various magnetic fields: the magnetizations are aligned anti-parallel at zero field; the magnetizations are aligned parallel when the external magnetic field H is**

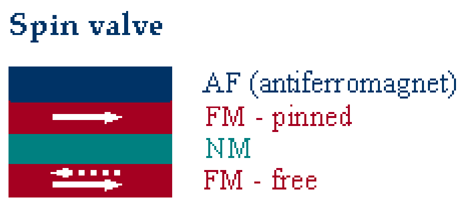
larger than the saturation field.

c) **The magnetization curve for the multilayer.**

Spins valve GMR

In spin valve GMR two ferromagnetic layers are separated by a thin non-ferromagnetic spacer. If the coercive fields of the two ferromagnetic electrodes are different it is possible to switch them independently. Therefore, parallel and anti-parallel alignment can be achieved, and normally the resistance is again higher in the anti-parallel case.

Research to improve spin valves is intensely focused on increasing the MR ratio by practical methods such as increasing the resistance between individual layers interfacial resistance, or by inserting half metallic layers into the spin valve stack. These work by increasing the distances over which an electron will retain its spin, and by enhancing the polarization effect on electrons by the ferromagnetic layers and the interface.



Example of Spins Valve

Experimental Details

The apparatus consists of two Helmholtz coils, which are connected to a current generator and a gaussimeter, which measures the applied magnetic field. In turn, the current generator is connected to a frequency generator. Between the two coils of Helmholtz, we find the sample that we want to study, which are several layers of “films”. The process is automated using a LabVIEW program.

First, we measured the giant magnetoresistance and its angular dependence for a spin valve with the following characteristics:

Ta(5nm)/CoFe(2nm)/NiFe(1,5nm)/Cu(2, 2nm)/CoFe(3nm)/MnLr(7nm)/Ta(5nm).

The measure in question was carried out at a current intensity of 0,001A at 0ºC. The magnetoresistance was observed for angles from 0º to 180º interspersed with 30º.

Finally, we measured the anisotropic magnetoresistance and its angular dependence for a thin film with the following characteristics:

Ta(5nm)/NiFe(20nm)/Ta(5nm).

The measure in question was carried out at a current intensity of 0,07A at 0ºC. The magnetoresistance was also observed for angles from 0º to 180º interspersed with 30º.

Results and Discussion

In this part of the experiment the maximum magnetoresistance was calculated for the different angles used for both the anisotropic and giant magnetoresistance as well as the maximum sensitivity was calculated.

Finally, the coupling field was also calculated for the different angles used, but only for the giant magnetoresistance.

Maximum magnetoresistance (MR_{max}): $MR_{max} = \frac{R(\max) - R(\min)}{R(\min)}$

Maximum sensitivity (%/Oe): $\%/Oe = \frac{\frac{\Delta R}{R}}{\Delta H} \times 100$

Coupling Field ($B_{acop.}$): $B_{acop.} = \left|\frac{B1+B2}{2}\right|$, where B1 and B2 correspond respectively to the minimum and maximum magnetic fields around the center of the hysteretic cycle.

Anisotropic Magnetoresistance (AMR)

The maximum magnetoresistance values for the different angles and using the above formula were as follows:

Θ(º)	**$MR_{max.}$(Ω)**
0	0,016
30	0,011
60	0,008
90	0,0097
120	0,011
150	0,0105
180	0,016

The maximum sensitivity values for the different angles using the largest slope in modulus in the graph of $\frac{\Delta R}{R}$ in function of ΔH were as follows:

Θ(º)	**%/Oe**
0	0,1
30	0,2
45	0,19
60	0,15
90	0,075
150	0,25
180	0,21

Giant Magnetoresistance (GMR) – Spins Valve

The maximum magnetoresistance values for the different angles and using the above formula were as follows:

Θ(º)	**$MR_{max.}$(Ω)**
0	0,029
30	0,065
60	0,075
90	0,082
120	0,076
150	0,072
180	0,023

The maximum sensitivity values for the different angles using the largest slope in modulus in the graph of $\frac{\Delta R}{R}$ in function of ΔH were as follows:

Θ(º)	**%/Oe**
0	0,14
30	0,72
60	0,92
90	0,82
120	1,37
150	0,91
180	0,16

The coupling field values for the different angles and using the above formula were as follows:

Θ(º)	**$B_{acop.}$(T)**
0	0
30	2,5
60	2,5
90	3
120	0,5
150	0
180	1

We verified that in the anisotropic magnetoresistance, the maximum magnetoresistance obtained for the different angles does not oscillate much, being within the expected parameters, taking into account the theoretical values. That is, the maximum magnetoresistance, important characteristic of magnetoresistance, is well determined. The values of the maximum sensitivity for the different angles also do not differ much between them, being within the expected results, by comparison with the theoretical values, that is, they were also well determined, making a good characterization of the magnetoresistance.

For giant magnetoresistante using the spins valve, I can conclude the same as for anisotropic magnetoresistance with respect to maximum magnetoresistance and maximum sensitivity, since the values obtained for the different angles remain relatively close and are within the expected parameters, in comparison with the theoretical values. With respect to the coupling field, which in general, for the different angles observed is non-zero, but not very different from zero, this is due to the fact that the spins valve has a non-magnetic separating layer with a sufficiently large, making the coupling between the two magnetic layers insignificant, and therefore, the field-dependent effect is also low.

Conclusions

As a final conclusion, I can verify that this work was useful, as I deepened my knowledge about magnetoresistance, studying in particular three very important characteristics of magnetoresistance: maximum magnetoresistance, maximum sensitivity and coupling field. I conclude that these three characteristics were well determined, because as I mentioned in my discussion of the results, the values obtained for them are within the expected by the theoretical results. I can therefore conclude that the experiment was well executed, and there was a lot of rigor.

References

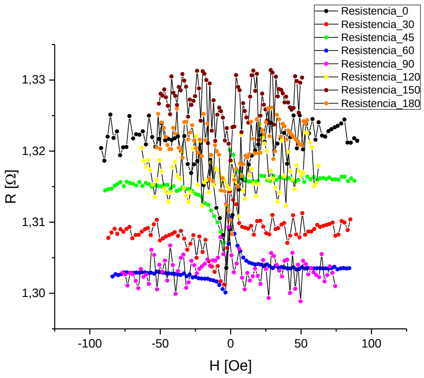
"Magnetorresistência Gigante em Multicamadas de Filmes Finos" – Alisson Carlos Krohling (pag.37 and 38);

"A brief introduction to giant magnetoresistance" – Liu Chang, Min Wang, Lei Liu, Siwei Luo and Pan Xiao (pag.3, 6 and 9);

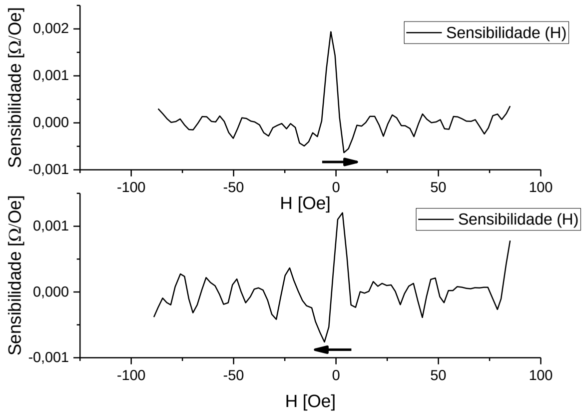
"Spintronics" (pag.9);

"Common magnetoresistance measurements: AMR, GMR, AHE/SHE, TMR" – Prof. Dr. Coriolan TIUSAN (pag.2, 15, 16, 17 and 24).

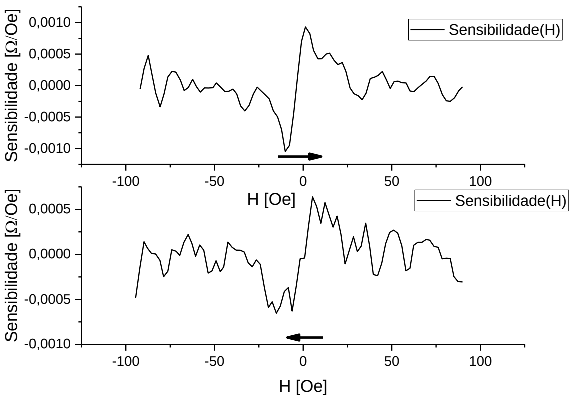
Annexs



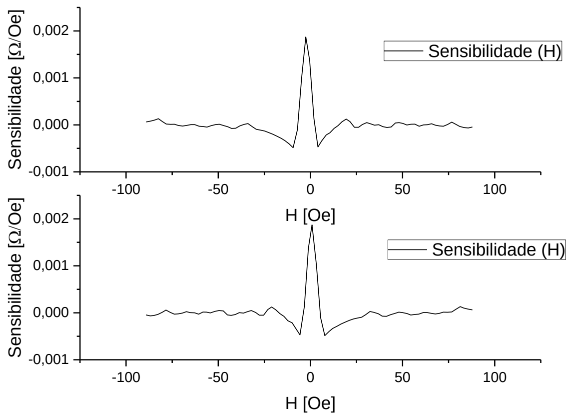
Graph of the resistance as a function of the field displayed to calculate the maximum anisotropic magnetoresistance for the different angles observed



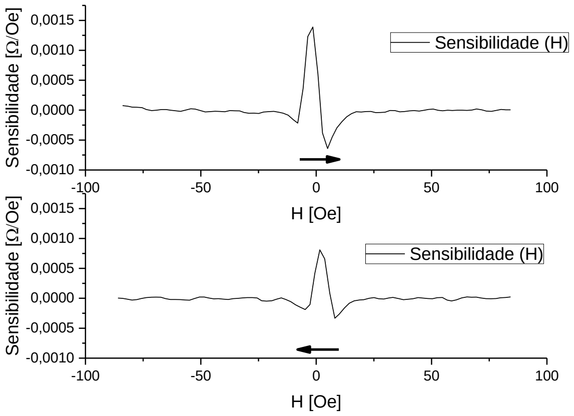
Graph used to calculate the maximum anisotropic sensitivity at 30º



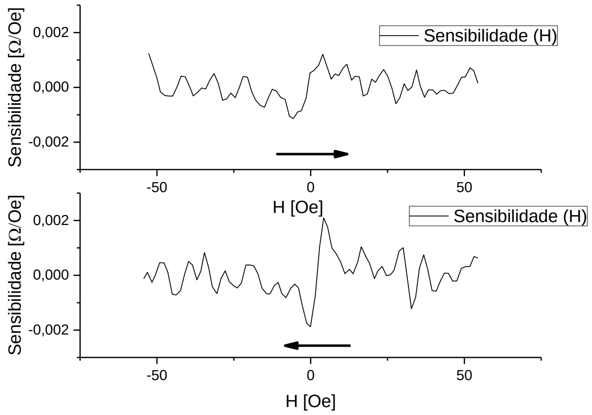
Graph used to calculate the maximum anisotropic sensitivity at 0º



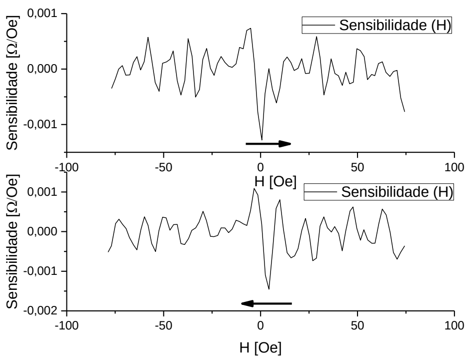
Graph used to calculate the maximum anisotropic sensitivity at 45º



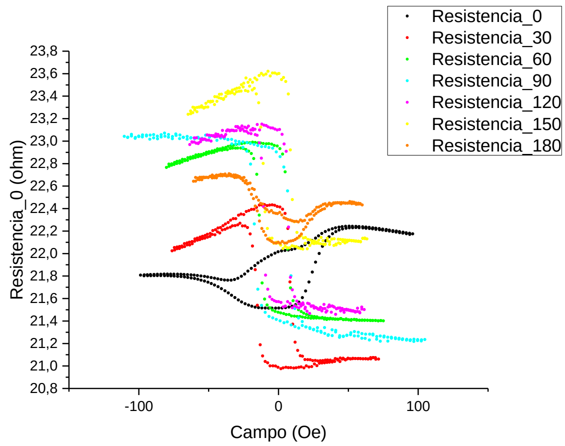
Graph used to calculate the maximum anisotropic sensitivity at 60º



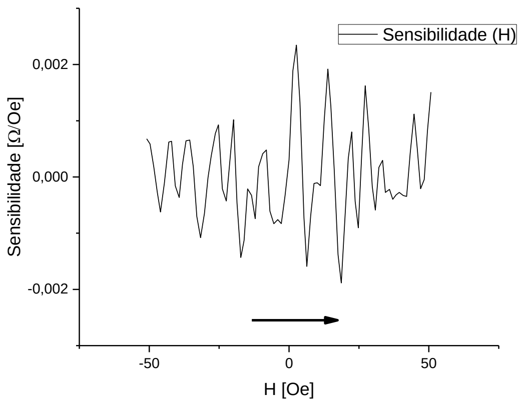
Graph used to calculate the maximum anisotropic sensitivity at 180º



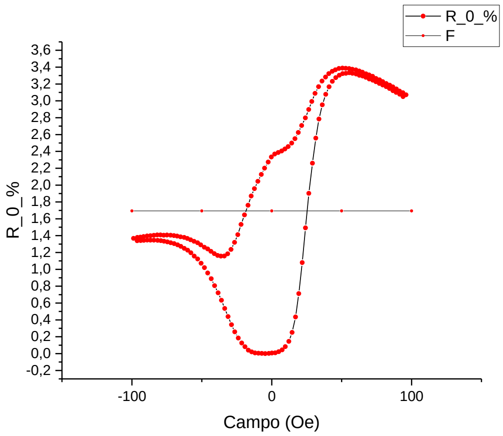
Graph used to calculate the maximum anisotropic sensitivity at 90º



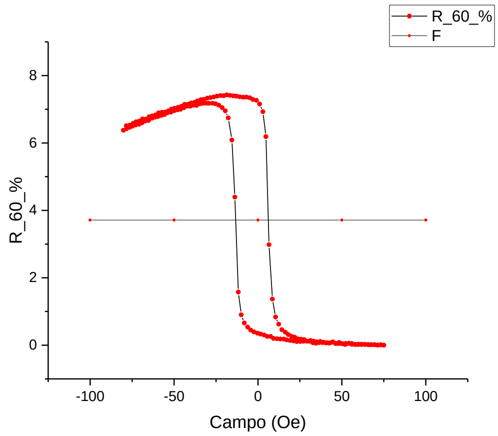
Graph of the resistance as a function of the field displayed to calculate the maximum giant magnetoresistance and coupling field for the different angles observed



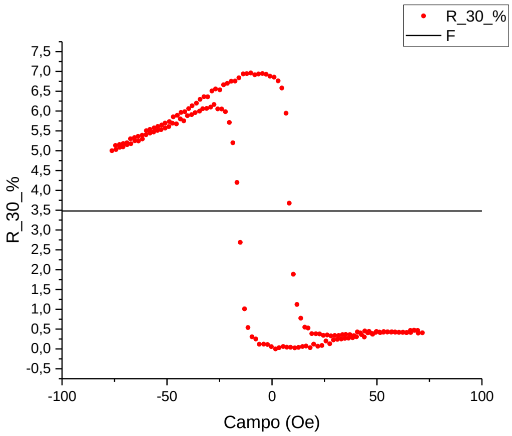
Graph used to calculate the maximum anisotropic sensitivity at 150º



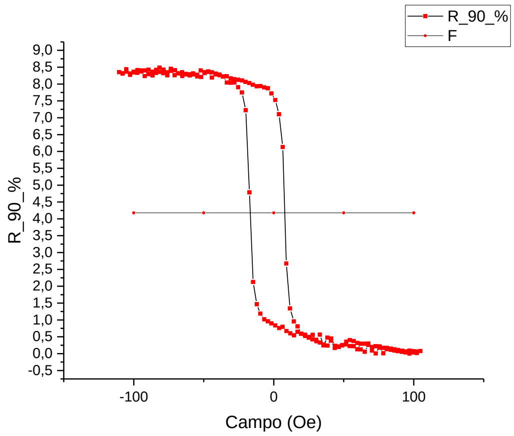
Graph used to calculate the maximum giant sensitivity at 0º



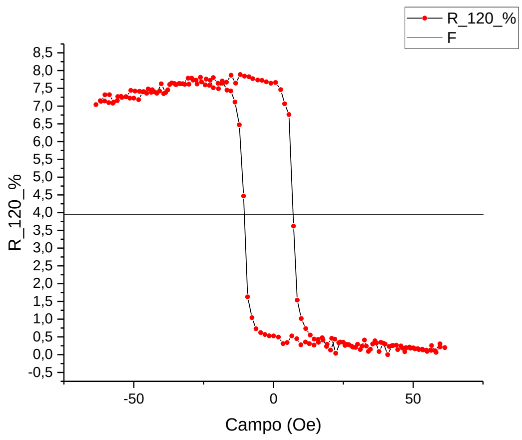
Graph used to calculate the maximum giant sensitivity at 60º



Graph used to calculate the maximum giant sensitivity at 30º

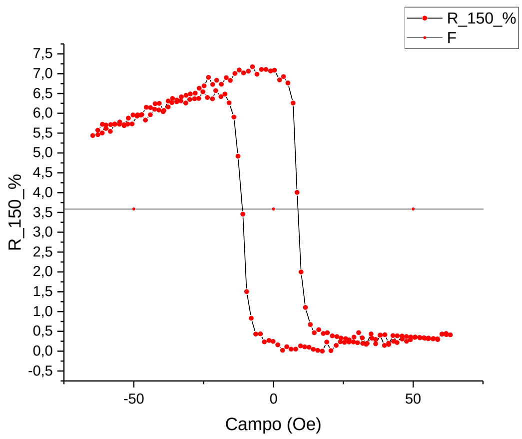


Graph used to calculate the maximum giant sensitivity at 90º



Graph used to calculate the maximum giant sensitivity at 180º

Graph used to calculate the maximum giant sensitivity at 120º



Graph used to calculate the maximum giant sensitivity at 150º