A MAGNETIC FIELD EFFECT TRANSISTOR WITH SPIN TRANSPORT CONTROL

George MAHALU *mahalu@eed.usv.ro*
Adrian GRAUR *adriang@eed.usv.ro*
"Ştefan cel Mare" University of Suceava, Str.Universităţii nr.13, RO-720229 Suceava

Abstract. *In this paper work is analysed a magnetic field effect transistor structure. This device is imaged for generation of highly spin-polarized currents, whose operations is governed by a magnetic field. Is presented some approach methods of the physical study of device function under spintronics phenomenon. On the other hand is proposed a new approaching technique that consists in fractal form formalisms application. Not in the last ordering is considered the way to controlling the MFET channel conductivity under spin polarized carriers control.*
Keywords: *spin, magnetic FET, channel, giant magnetoresistance, DMS phenomenon, magnetic shell.*

Introduction

In the last time the spin of mobile carriers plays an active role in the new electronic devices function. In this sense was been imagined some physical structures which involving these new technologies. Many of these have at base the diluted magnetic semiconductor (DMS) phenomenon [2]. The currently accepted mean for DMS ferromagnetism is that it is the local antiferromagnetic coupling between the carriers (i.e., holes in GaMnAs) and the Mn magnetic moments that leads to long range ferromagnetic ordering of Mn local moments. The carrier system also becomes spin-polarized in the process with the carrier magnetic moment directed against the Mn magnetic ordering by virtue of the antiferromagnetic hole-Mn coupling. In same time the total magnetic moment of the spin polarized carriers is extremely small. In this sense must be mentioned that $n_c << n_i$ and $\|\boldsymbol{S}\| > \|\boldsymbol{s}\|$ where $\boldsymbol{S}$ and $\boldsymbol{s}$ are respectively the Mn and the hole spin [12].
The relevant DMS effective magnetic hamiltonian can be written as:

$$H_m = \int d^3 r J(r) S(r) s(r) \qquad (1)$$

where $S(r)$ and $s(r)$ are respectively the Mn and hole spin densities. The coupling $J(r)$ between Mn local moments and holes spins can be ferromagnetic ($J<0$) or antiferromagnetic ($J>0$), in principle. The effective interaction between the Mn local moments, mediated by the holes through H_m, is always ferromagnetic.
The simplest way to understand DMS ferromagnetism is to neglect all disorder effects and assume that the system can be thought of as a collection of local moments of density n_i interacting with itinerant holes of density n_c.

MFET (Magnetic Field Effect Transistor) electronic device

Based on the spintronics theory is possible to be image a new electronic device, similar with the field effect transistor (FET) from the classic electronics. One same device can be called magnetic field effect transistor (MFET) [1].

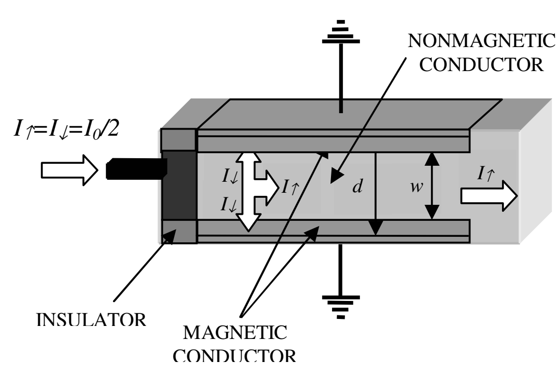

Figure 1. Principle structure of the MFET

Let be a sandwich configuration, with a nonmagnetic (NM) conducting channel and a surrounding magnetic material (MM) whose external boundaries are grounded. Electric current flows parallel to the NM/MM interface, instead of being normal to it as in a spin filter. The spin polarization in the NM conductor is created by electrons injected from a magnetic material [8,10].

If an unpolarized constant current be driven through the channel entrance, away from the channel a difference will develop between spin-up and spin-down currents. Nonequilibrium electrons with one of the spin direction will preferentially leave the NM channel. Thus, the transparency of the NM/MM interface is different for spin-up and spin-down electrons due to the conductivity difference in these materials. With high probability these electrons will dissipate at the grounded external boundary without return to the channel. Consequently, a polarized electric current is generated in the channel with the polarization increasing as a function of the distance from the channel entrance.

In device design implementation is considered two classes of MM's for the magnetic shell [4].

The first consists in diluted II-VI magnetic semiconductors (DMS). These compounds may have a sufficiently high degree of spin polarization (SP) because of the very large Zeeman splitting of the spin subbands.

The second consists in some ferromagnetic metals, like Ni, Fe or Co [6,7,9,11], which may be used for the magnetic shell. In contrast to ordinary electronic devices, where a combination of a metal with a semiconductor is used, this scheme may be implemented as an all-metal device. This device exhibits sensitivity to changes in the magnetic field. Indeed, the selective transparency of the NM/MM interface provides different decay length-scales for the spin-up and spin-down electrons along the channel.

If into the NM channel is injected only one constant current and restricting ourselves to current variation only in the x direction, the current in the channel, like sum of two spin components, is given by:

$$I = \frac{2I_0}{w}\sum_n \frac{\sigma_N \, cosh[k_n(L-x)]}{k_n \, cosh(k_n L)} \cdot \left(< f_n^+ >_w^2 \pm \frac{< f_n^+ >_w < f_n^- >_w}{2} \right) \tag{1}$$

where: $I_0=I$ at $x=0$, σ_N is the conductivity of the NM channel, k_n is damping parameter, L is the spin-guide length and $f^{\pm}(z)$ are the z-dependent parts of the special solution of the spin transport equation:

$$\nabla \cdot \left(\sigma_{\uparrow\downarrow} \nabla \mu_{\uparrow\downarrow}\right) = \Pi_0 e^2 \sigma_{sf}^{-1} (\mu_{\uparrow\downarrow} - \mu_{\downarrow\uparrow}) \tag{2}$$

where: $\Pi_0^{-1} = \Pi_\uparrow^{-1} + \Pi_\downarrow^{-1}$ and $\Pi_{\uparrow,\downarrow}$ are the densities of states at the Fermi level of the up and down spins, σ_{sf} is the spin-flip scattering time, $\sigma_{\uparrow\downarrow}$ are the corresponding conductivities and $\mu_{\uparrow,\downarrow}$ are the nonequilibrium parts of the electrochemical potentials for the two spin directions.

Spintronics phenomenon in MFET

Into devices like above described can appear an diffusive effect, called Stern-Gerlach (SG) effect. This is an effective spin separation of electrons in metals and semiconductors. Ballistic transport lasts for femptoseconds up to a picosecond, diffusive transit across a micron sample can take from a picosecond to a nanosecond, and spin relaxation time can be between a fraction of a nanosecond to a microsecond. Ordinary, SG fails to work with electrons because transverse magnetic fields give rise to the Lorentz force which makes, for example, moving to the left spin up electrons turn around and move to the right, smearing out spin separation.

The theories pointing to observing a SG-like spin separation in both metals and semiconductors. One way of measuring a nonequilibrium spin in metals is the Silsbee-

Johnson method of spin-charge coupling. One can either switch an external inhomogeneous magnetic field, or inject nonequilibrium spin into a metal in a static field, to measure the time evolution of the spin.

Conform all above shown, in the function of the MFET can appear in addition the SG-like spin separation effect. One idea in this case is to assure for those two carriers transport kind different passing ways. This idea can stand to a base building of a new structural theory with new device creating purpose.

Percolation theory

This theory assumes the model of carrier-mediated ferromagnetism, but now the carriers are pinned down with the localization radius *a*. The disorder, averaged out in the mean-field theory, plays a key role in the carrier localization.

Is possible to show that the problem of the ferromagnetic transition in a system magnetic bounded conducts to the polaron study. The polarons can be mapped onto the problem of overlapping spheres well-known in the percolation theory. The latter problem studies spheres of the same radius *r* randomly placed in 3D space with some concentration *n*. Overlapping spheres make clusters as the sphere radius *r* becomes larger. In this mode, more and more spheres joint into clusters, the clusters coalesce, and finally, at some critical value of the sphere radius, an infinite cluster spanning the whole sample appears. This problem has only one dimensionless parameter, r^3n, and therefore can be easily studied by means of Monte-Carlo simulation.

Each sphere of the overlapping spheres problem corresponds to a bound magnetic polaron, which is a complex formed by one localized hole and many magnetic impurities with their spins polarized by the exchange interaction with the hole spin. The concentration n of spheres coincides with the concentration n_c of localized holes. The expression for the effective polaron radius in terms of the physical parameters of the system under consideration is not trivial and has been found in [1]:

$$r^3 n = \left(0.86 + \sqrt[3]{a^3 n_c}\, \ln \frac{T_c}{T} \right)^3 \qquad (3)$$

Here $0.64 \approx 0.86^3$ is the critical value of the parameterr^3n at which the infinite cluster appears, and T_c is the Curie temperature of the ferromagnetic system under consideration.

Like was shown into our earlier work [2]. Thus, the modelling of the clusters by the fractal form techniques is possible.

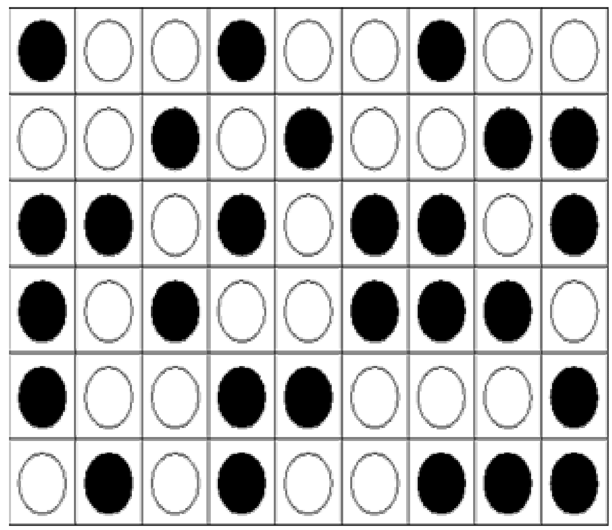

Figure 2. An incompressible mixture of A and B magnetic particles

Under these featuring studies, can be approaching an interesting research about preparing the channel MFET transistor environment by physical properties view angle, with conductivity deducting goal.

Conclusions

In long of same studies is possible to be approaching the problem of the giant negative magnetoresistance. This effect can be observed by switching the magnetization directions in the upper and lower magnetic layers from being parallel to each other, to having antiparallel directions. When the upper and lower magnetic layers have parallel magnetization directions, a polarized current will arrive at the channel exit, since electrons with only one spin direction will be transported preferentially through the magnetic layers to the grounding. In contrast, when the magnetic layers' magnetizations are antiparallel, the output current will be unpolarized, and it will decrease significantly in magnitude. This effect could be of particular interest in the case of a ferromagnetic metal shell where residual magnetization may remain upon switching off the magnetic field.

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