THE NEW TYPE OF CURRENT AND SPIN POLARIZATION OSCILLATIONS IN NANO AND MICRO RINGS

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In our theoretical work we found a new type of spin polarization and current oscillations in conducting rings with inhomogeneous magnetic properties. We assume that the effective magnetic field magnitude in conductor is a function of coordinate but in all the bulk magnetization is collinear (Fig.1).

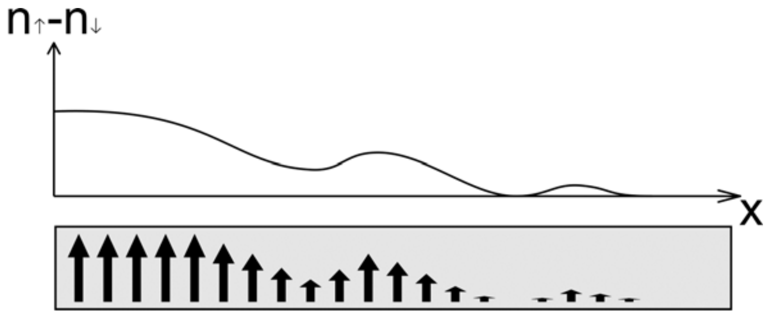

Fig.1: *Collinear magnetization and equilibrium spin density distribution.*

In this case the electronic system can be described by macroscopic variables: the spin density $n_{\uparrow\downarrow}(x)$ and spin current $j_{\uparrow\downarrow}(x)$ for each spin band (common two-current model [1]). The total current $j = j_{\uparrow} + j_{\downarrow}$ does not depend on the coordinate due to electro-neutrality. In case of the hydrodynamic electron transport (when the frequency of electron-electron collisions is larger than the frequency of collisions that does not conserve the momentum of electrons), the electron drift velocity $u(x)$ is equal for spin-up and spin-down electron bands. Using the Chapman-Enskog theory, we have obtained from the Boltzmann kinetic equation the set of spin hydrodynamics equations for non equilibrium electron spins, when the electron spectrum is spatially inhomogeneous:

$$N_{\uparrow\downarrow}\frac{\partial \mu^{c}{}_{\uparrow\downarrow}}{\partial t}+\frac{\partial}{\partial x}\left(n_{\uparrow\downarrow}u\right)=0\,, \tag{1}$$

$$mn\frac{\partial u}{\partial t}+n_{\uparrow}\frac{\partial \mu^{c}{}_{\uparrow}}{\partial x}+n_{\downarrow}\frac{\partial \mu^{c}{}_{\downarrow}}{\partial x}+ne\frac{\partial \phi}{\partial x}=0\,, \tag{2}$$

where $N_{\uparrow\downarrow}(x)$ is the equilibrium density of states at Fermi level, $\mu^{c}{}_{\uparrow\downarrow}(x)$ is a non equilibrium addition to the chemical potential, $\phi(x)$ is the electrical potential, m the effective electron mass, $n(x) = n_{\uparrow}(x) + n_{\downarrow}(x)$, and e is the electron charge. These equations are written in the linear approximation so that $n_{\uparrow\downarrow}(x)$ and $N_{\uparrow\downarrow}(x)$ do not depend on time.

We show that in the case of a closed conductor (for example, ring) these equations have a non zero solution in the form of “spin pendulum” oscillations, i.e., the oscillations of the full current and spin polarization with a frequency determined by the characteristics of magnetic inhomogeneity [2]. The frequency of these oscillations is given by

$$\omega^2 = \left[\oint \frac{m}{n}\mathrm{d}x\right]^{-1} \oint \left(\frac{\mathrm{d}}{\mathrm{d}x}\left(\frac{n_\uparrow}{n}\right)\right)^2 \frac{1}{N}\mathrm{d}x\,, \tag{3}$$

where $N^{-1} = N_\uparrow^{-1} + N_\downarrow^{-1}$ and the integration is made over the all ring. As could be seen from Eq.(3), the oscillation frequency can be varied in a wide range by setting the magnetization profile of the conductor. The inhomogeneous magnetization can be obtained by inhomogeneous magnetic impurities doping, for example, the ring can be made of GaMnAs (Fig.2).

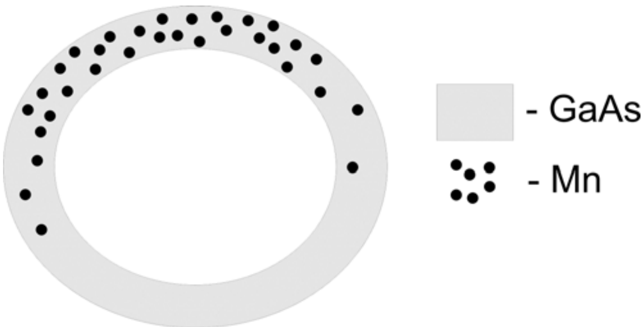

Fig.2: *Example of closed conductor with inhomogeneous magnetic properties.*

The hydrodynamic regime is difficult to realize, so we considered the situation with the diffusion spin transport and took into account the electron-electron collisions. The studied system is a closed conductor consisting of two parts with different magnetic properties. We use equations similar to those presented in [3] for obtaining the resistance $R(\omega)$ of the ring. We show that the conductance $Z(\omega) = \mathrm{Re}(R(\omega)^{-1})$ of this system as a function of the external EMF frequency ω has one maximum in the hydrodynamic or diffusive regime. This case was conformed to “spin pendulum”, and the conductance has many maxima in the case of ballistic regime [4]. The physics is that for the magnetically inhomogeneous structure the conductance as a function of ω oscillates due to the interplay of boundary conditions and contrast of two lengths: the spin diffusion length which depends on the frequency ω and the lengths of magnetically homogeneous regions. This result agrees with the results of [5], where the authors achieved the same behaviour of the AC spin valve conductance.

These new spin oscillations in closed conductors can be used in spintronic devices like the well known LC circuit used in radio electronics. It can be also used as “atoms” of novel metamaterials.

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