On spintronics of multilayer magnetic nanostructures

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1. Features of spitronics magnetic nanostructures

The exchange interaction between the spin polarized states of conductivity electrons and localized spin states in multilayer magnetic structures underlies the effects of electric field-controlled change of localized magnetic states and the spin dependent electron scattering which depends on the configuration of the localized magnetic states. The efficiency of the first effect characterizes by the threshold spin current density which is sufficient to overcome the magnetic anisotropy forces. In this context, the most favorable is the generation of spin current and spin polarization through the spin-orbit interaction when, in contrast to the generation through an effective magnetic field of an magnetic polarizer, the spin current is not accompanied by charge transfer and power consumption. For the magnetic nanostructures (both ferro- (FM) and antiferromagnetic (AF) types) these effects are associated with electric controlled magnetization, dynamics, switching and the magnetoresistance effect that are related to magnetic writing and reading information. In the AF case, the mentioned spin interaction results in the electric controlled high frequency dynamics of the AF order vector that is currently a completely unsolved problem. Thus, it is relevant the study the electric field-controlled magnetization dynamics and the magnetoresistance effect in FM multilayer nanostructures, in particular, in the tunnel ferromagnetic nanostructures [1]. The microscopic description of the electric-controlled dynamics in the tunnel multilayer ferromagnetic nanostructures is based on the modified for magnetic system theory of non-equilibrium Green functions with the real-time propagation of the embedded Kadanof-Baym equations which are quantum-kinetic equations for the one-particle propagator [2]. It is shown, that these equations in the tight-binding representation systematically describe features of the spin dependent tunneling and the spin torque effect with respect to localized magnetic moments and localized magnetic order.

2. The model Hamiltonian of the electric-controlled magnetic nanostructuress

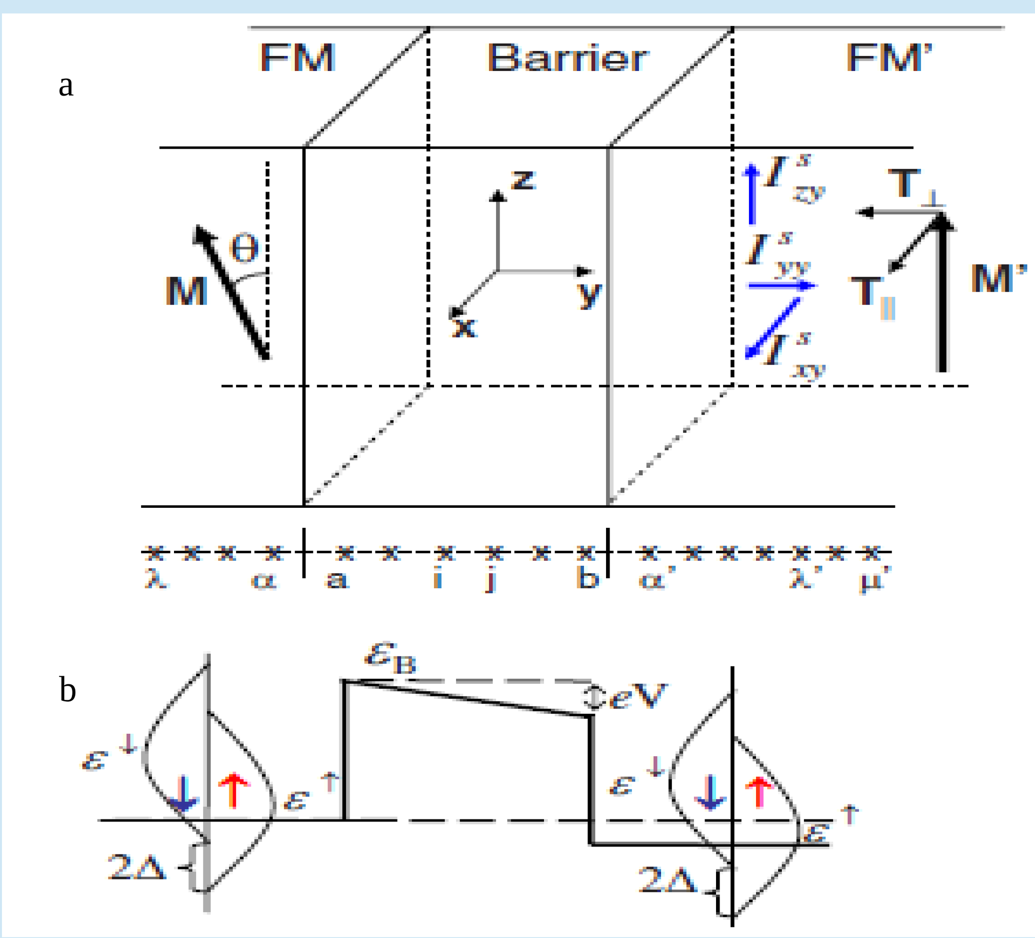

Fig. 1. (a) Schematic structure of the FTJ consisting of left and right semi-infinite FM leads separated by a thin nonmagnetic barrier. The magnetization M' is along z, whereas the magnetization M of the left lead is rotated by an angle θ around the f the left y. (b) Schematic of the potential profile, where the spin resolved density of states in the FM lead have an an exchange spin splitting of .

The electric current control of magnetic states in magnetic multilayer nanostructures (both FM and AF types) is based on the spintronic spin-torque effect of the interaction between the spin current and the localized magnetic moments, as it is shown in the example of the FM tunnel junction (FTJ) (Fig.1). In the typical FTJ the semi-infinite leads are modeled as a chain localized spins with translation invariance in the plane perpendicular to the electron flow along y axis. The order parameter *M'* ||*oz* , while the order parameter *M* of the left lead is rotated by an angle θ around the *y* axis. The on-site torques delivered in the right lead are represented by the in-plane ($T_\parallel$) and out-of-plane ($T_\perp$) components of the torque *T* induced by the spin current density *Q.* The model Hamiltonian composed of the two FM layers coupled via the barrier layer, which atomic structures modeled by in tight-binding approximation. Its analysis based on the modified non-equilibrium Green's function method. The model Hamiltonian is represented by the sum,

$$H = H_L + H_R + H_C + H_T \qquad (1)$$

with indexes corresponding to the FM left (*L)* and right (*R)* layers, nonmagnetic barrier *C* layer and the interlayer coupling *T.* In the tight-binding approximation and the second quantization representation of creation $c^\dagger_{i\sigma}$ and annihilation $c_{i\sigma}$ operators (and σ are the site and spin), the isolated and interaction contribution

$$H_\Omega = \sum_{i\in\Omega} \varepsilon_i \mathbf{c}_i^\dagger \mathbf{c}_i + \sum_{i\in\Omega} \Delta_i \mathbf{c}_i^\dagger \mathbf{m}_i \cdot \sigma\, \mathbf{c}_{i'} + \sum_{i,i'\in\Omega} t_{ii'} c_i^\dagger \mathbf{c}_{i'}, \quad \mathbf{c}_i^\dagger = \left(\mathbf{c}_{i\uparrow}^\dagger, \mathbf{c}_{i\downarrow}^\dagger\right), \; L,R,C\in\Omega, \; H_{int} = t_{a\alpha}\mathbf{c}_a^\dagger \mathbf{c}_\alpha + t_{b\alpha'}\mathbf{c}_b^\dagger \mathbf{c}_{\alpha'} + H.c. \, , \qquad (2)$$

3. The spin torque effect and the localized spin density

where ε_i is the on-site energy, $t_{ii'}$ is the hopping parameter, Δ_Ω is the exchange spin splitting driven by the magnetization $\mathbf{m}_i$. Observables are described by the one-particle non-equilib-ium Green's functions defined as

$$G(t,t') = \theta(t,t')\left\|G^>_{ii'}(t,t')\right\| + \theta(t',t)\left\|G^<_{ii'}(t,t')\right\|, \; G^>_{ii'}(t,t') = -i\left\langle c_{i\sigma}(t) c^\dagger_{i'\sigma'}(t')\right\rangle, \; G^<_{ii'}(t,t') = i\left\langle c^\dagger_{i'\sigma'}(t') c_{i\sigma}(t)\right\rangle . \qquad (3)$$

The one-electron Green's function with the Hamiltonian (1) obey the embedded Kadanoff-Baym equations [2] describing the spin-dependent transmission of electrons through the FMJ with interface scattering and the formation of the spin torque on the localized magnetization. The equation of motion for the one-electron Green function in the site basis representation is

$$\left\{i\partial_z - h(z)\right\} G(z,z') = 1\delta(z,z') + \int d\bar{z}\, \Sigma(\bar{z},z') G(\bar{z},z'), \; h = \left\|h_{mn}\right\|, \Sigma = \left\|\Sigma_{mn}\delta_{m,n=C}\right\| \; , \; m,n = (L,C,R) \; , \qquad (4)$$

where Σ implies the block matrix of the self-energy describing the electron interface scattering and subscripts refer to the matrix indices in different subspaces, the variable *z* implies the time on the time Keldysh contour composed of forward and backward real-time branches. Then spin density ***S*** and the spin torque ***T*** are described, respectively as

$$S_i = \frac{et}{8\pi^3\hbar}\int d\varepsilon\, \mathrm{Tr}_\sigma [G^{<\sigma\sigma'}_{\lambda'+1,\lambda'} - G^{<\sigma\sigma'}_{\lambda',\lambda'+1}] \text{ and } T_{\lambda'} = \frac{t}{16\pi^3}\int d\varepsilon\, \mathrm{Tr}_\sigma \sum_{\nu=1,-1} \boldsymbol{\sigma}[G^{<\sigma\sigma'}_{\lambda',\lambda'+\nu} - G^{<\sigma\sigma'}_{\lambda'+\nu,\lambda'}]. \qquad (5)$$

Here the localized spin density is driven by the spin torque induced by the spin current.

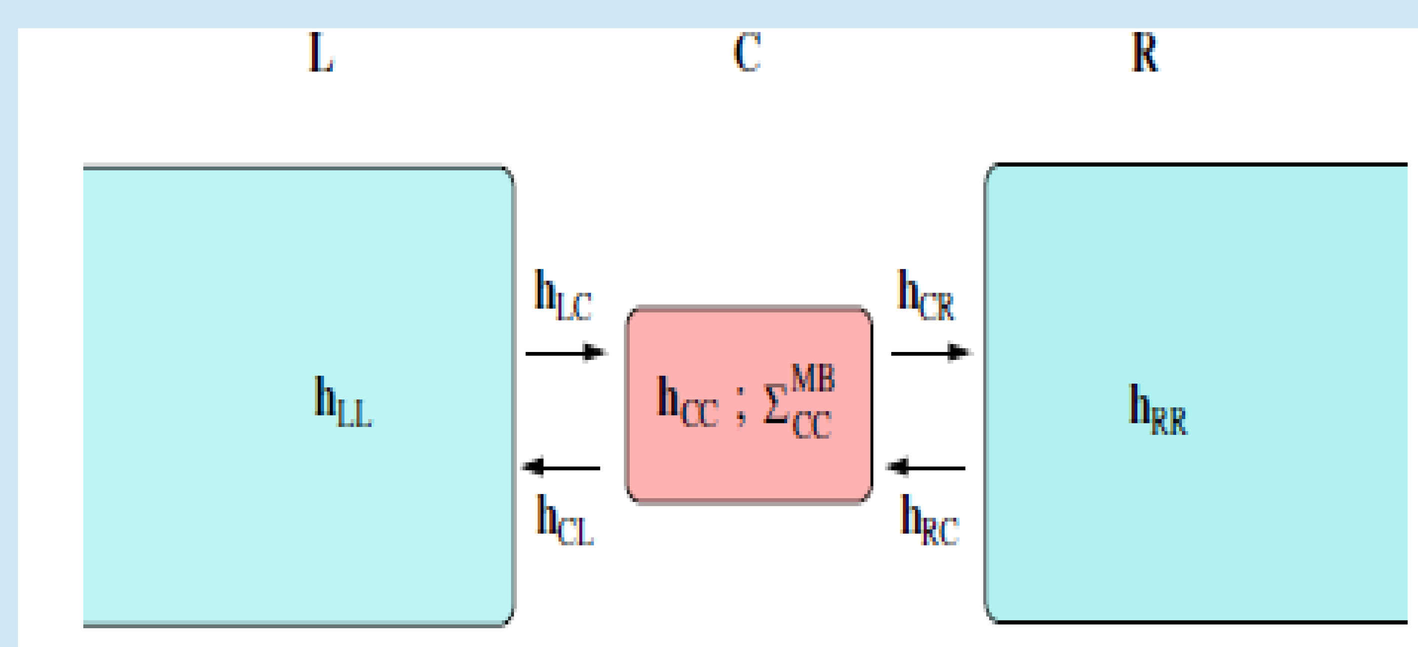

Fig. 2. Schematic view of the FTJ: The Correlated central region (C) is coupled to the left (L) and right (R) metallic electrodes via tunneling Hamiltonians H_C and H_α $\alpha = L,R$

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References

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