TEMPERATURE AND VOLTAGE TMR DEPENDENCIES FOR HIGH PERFORMANCE MAGNETIC JUNCTIONS

H. Silva[1,2], *Y. Pogorelov*[1]
[1]*IFIMUP-IN, Universidade do Porto, Porto 4169-007, Portugal* [2]*CEOT, Universidade do Algarve, Faro 8005-139, Portugal*
huggsil@gmail.com

Recent spintronics magnetic junctions with ultra-thin MgO barriers attained as high tunnel magnetoresistance (TMR) as ~600% [1] at room temperature which makes them ideal for non-volatile high-density memories. Amazingly, TMR even reached ~1200% at low temperatures, but it can be also sensibly degraded with voltage [2], hence a detailed study of its temperature and voltage dependencies is fundamental for future device applications.

For nano-size junctions, a fully quantum description is required to take a proper account of specific coherency effects. The commonly used Green's functions in the Kubo formula framework [3] are not easy enough to include the electrical field (E) effect in an analytic way [4]. Here a tight-binding dynamics [5] is generalized to describe this effect on the spin-dependent quantum transmission for magnetic junctions with ultrathin non-magnetic spacers. Starting from the n-site atomic chain with on-site energies ε_0, locally shifted under E, and nearest-neighbour hopping amplitudes t, we write down the Hamiltonian in terms of local Fermi operators $\hat{c}_l$ and $\hat{c}_l^\dagger$ as:

$$H = \sum_{l=1}^{n}(\varepsilon_0 - lE)\hat{c}_l^\dagger\hat{c}_l + t\sum_{l=1}^{n-1}(\hat{c}_l^\dagger\hat{c}_{l+1} + \hat{c}_{l+1}^\dagger\hat{c}_l), \tag{1}$$

and obtain the local (non-normalized) amplitudes for the eigen-state with energy ε as:

$$p_l(x) = \xi^l \sum_{j=0}^{[l/2]} C_j^{l-j}(-\xi^2)^{-j}(j + x/\xi)_{l-2j}, \tag{2}$$

where $x = (\varepsilon - \varepsilon_0)/t$, $\xi = E/t$, C_m^n is the binomial coefficient, $[u]$ is the entire part of u, and $(u)_n = u(u + 1)\ldots(u + n - 1)$ is the Pochhammer symbol. Next this finite chain (called the gate, g) is attached to semi-infinite chains (source, s, and drain, d), with respective on-site energies ε_s, ε_d and hopping parameters (see Fig. 1, supposing that the electrical voltage drop between the sites in s, d elements is negligible), to generate a collective electronic state with energy ε. This defines the 1D transmission coefficient (spin-dependent through the Stoner shifts in ε_s, ε_d) for given electrical field as $T(\varepsilon) = -2i(t_{sg}t_d|\gamma_s|\sin q_s)/(t_s t_{gd} D)$ where the characteristic denominator:

$$D = \varphi[p_n(x_g) - p_{n-1}(x_g + \xi)\gamma_s] - p_{n-1}(x_g)\gamma_d + p_{n-2}(x_g + \xi)\gamma_s\gamma_d, \tag{3}$$

with $q_i = \arccos[(\varepsilon - \varepsilon_i)/2t_i]$, $\varphi = 1 + (n+1)\xi e^{iq_d}$, $\gamma_i = e^{iq_i} t_{gi}^2/(t_g t_i)$ for $i = s$, d and $x_g = (\varepsilon - \varepsilon_g)/t_g$, allows for up to n resonance spikes in the Landauer conductance formula. Its 3D generalized and temperature dependent form reads as

$$G = (e^2/h) \sum_{\mathbf{k}} f_s(\mathbf{k})[1 - f_d(\mathbf{k})]|T(\mathbf{k})|^2,$$

with the Fermi function $f_i(\mathbf{k}) = \{\exp[\beta(\varepsilon_i(\mathbf{k}) - \mu_i)] + 1\}^{-1}$ for a dispersion law $\varepsilon_i(\mathbf{k})$, chemical potential μ_i ($i = s,d$) and inverse temperature β. The calculated behaviour for a characteristic choice of model parameters (Fig. 2) shows an intriguing possibility of further enhancement of TMR efficiency by a proper choice of applied voltage on the quantum coherent device, as an alternative/addition to the previously suggested adjustment of its elemental composition [5]. Moreover, this voltage effect proves to be temperature stable, permitting to compensate the common temperature degradation of TMR.

References:

[1] S. Ikeda, J. Hayakawa, Y. Lee, K. Miura, H. Hasegawa, F. Matsukura, H. Ohno, "Intermag Europe 2008"
[2] S. Yuasa, A. Fukushima, H. Kubota, Y. Suzuki, K. Ando, Appl. Phys. Lett 89, 042505 (2006).
[3] J. Mathon, M. Villeret, H. Itoh, Phys. Rev. B **52**, R6983 (2005).
[4] C. Heiliger, P. Zahan, B. Yavorsky and I. Mertig, Phys. Rev. B **72**, 180406(R) (2005).
[5] H. G. Silva and Yu. G. Pogorelov, arXiv:0802.1436v1 [cond-mat.mtrl-sci].

Figures:

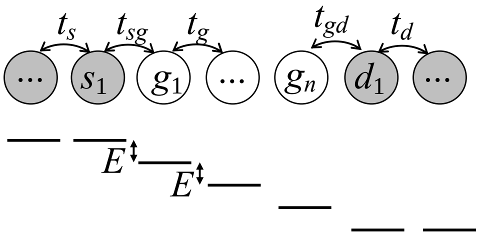

Fig.1 – On-site amplitudes, hopping parameters, and spatial distribution of electrical voltage in the composite chain system.

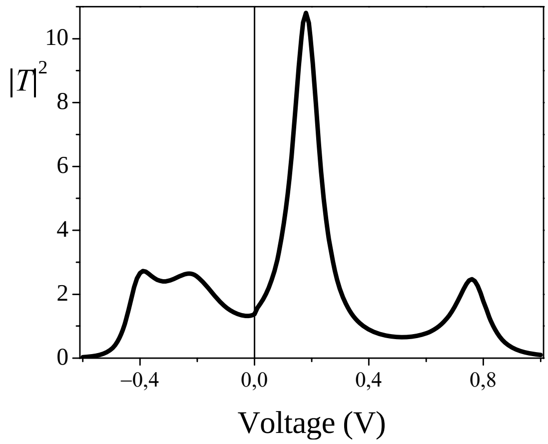

Fig.2 – 1D transmission coefficient $|T|^2$ (at zero temperature) of the composite chain system with parameters $\varepsilon_s = -0.5$eV, $\varepsilon_d = -1.0$ eV, $\varepsilon_g = 0.2$ eV (ε_F=0), $t_s = t_d = 0.5$ eV, $t_g = t_{sg} = t_{gd} = 0.25$ eV and $N_g = 4$ (number of planes) in function of the bias voltage.