Effect of Magnetic Dopants on Transport Properties of Trilayer Nanostructure

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The problem of quantum coherent transport of spin-polarised electrons through the ferromagnetic/non-magnetic/ferromagnetic trilayer nanostructure is considered. The non-magnetic metal layer is doped with three magnetic atoms. The calculations of a spin-dependent transmission coefficient as a function of energy of incoming spin-polarised electrons for different spin configurations of magnetic dopants are performed. The spin polarised conductance with respect to non-zero bias and gate voltages and temperature is calculated. The spin polarisation of the conductance is also found as a function of the bias voltage and gate voltage.

Theoretical model

The device consists of a non-magnetic metallic layer between two non-interacting ferromagnetic leads both made of the same material. The layer is doped with three magnetic dopants.

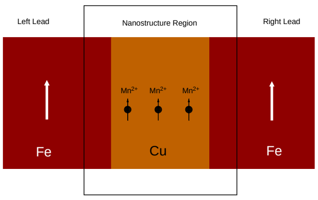

Figure 1. Schematic view of the investigated ferromagnetic/ non-magnetic/ ferromagnetic structure.

We assume that the direction of electron spin is fixed by the injection process from the left ferromagnetic lead into the metallic region.

Hamiltonian of the system has the form

$$H = -\frac{\hbar^2}{2}\frac{d}{dx}\left[\frac{1}{m(x)}\frac{d}{dx}\right] + U_0(x) + U^{\sigma}_{dop}(x)$$

where $m(x)$ is the position-dependent effective mass of conduction electron, $U_0(x)$ is the potential of the nanostructure without magnetic impurities, and $U^{\sigma}_{dop}(x)$ is the magnetic dopants potential:

$$U^{\sigma}_{dop}(x) = \sum_{k=1}^{N} J_0 S_z(X_k) s_z(x) \delta(x - X_k)$$

where N is the number of dopants, J_0 is the coupling constant, $S_z(X_k)$ is the z-component of dopant spin localised in the positions X_k, and $s_z(x)$ is the z-component of conduction electron spin.

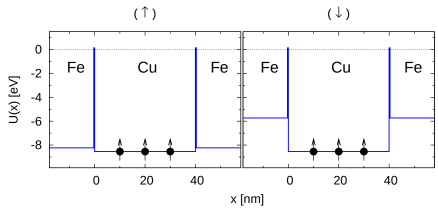

Figure 2. The model potential in case of the parallel spin configurations of dopants and without bias and gate voltages applied [1, 2]. Energy scale relative to $E_F = 0$.

Results

We performed numerical calculations of the spin-polarised current using the typical material parameters for Fe/Cu/Fe system at 4.2 K. We assumed that the ferromagnetic leads were polarised in parallel, the width of Cu layer was 40 nm and the layer was doped by three Mn ions [3]. The distance between them was 10 nm.

To investigate the tunnelling of spin-polarised electrons through the considered nanostructure we calculate the spin-dependent transmission coefficient $T^{\sigma}(E)$ using the transfer matrix methods (cf. [4]).

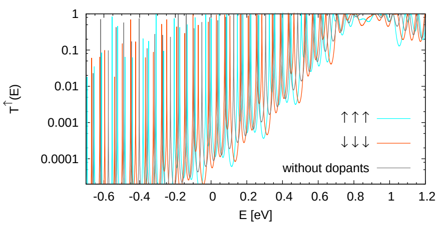

Figure 3. The spin-up transmission coefficient as a function of energy for different spin configuration of magnetic impurities. Energy scale relative to $E_F = 0$.

In the linear response theory the spin-dependent conductance is given by the formula [5]

$$G^{\sigma}(V_b, V_g) = -\frac{e^2}{h}\int_0^{\infty} dE\, T^{\sigma}(E, V_b, V_g)\frac{\partial f_{FD}(E)}{\partial E}$$

where $f_{FD}(E)$ is the Fermi-Dirac distribution function, V_b is the external bias, and V_g is the gate voltage applied to the Cu layer.

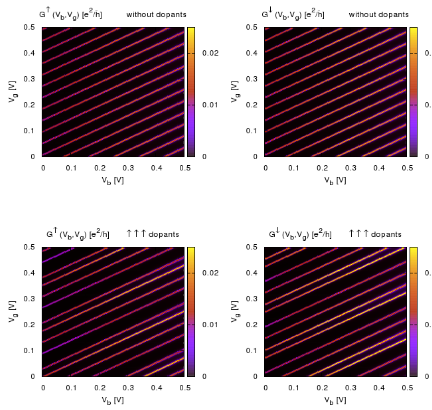

Figure 4. The spin-up ($G^{\uparrow}$) and spin-down ($G^{\downarrow}$) conductance.

For a fixed spin state of dopants the spin polarisation of the conductance has the form [6]:

$$P(V_b, V_g) = \frac{G^{\uparrow}(V_b, V_g) - G^{\downarrow}(V_b, V_g)}{G^{\uparrow}(V_b, V_g) + G^{\downarrow}(V_b, V_g)}.$$

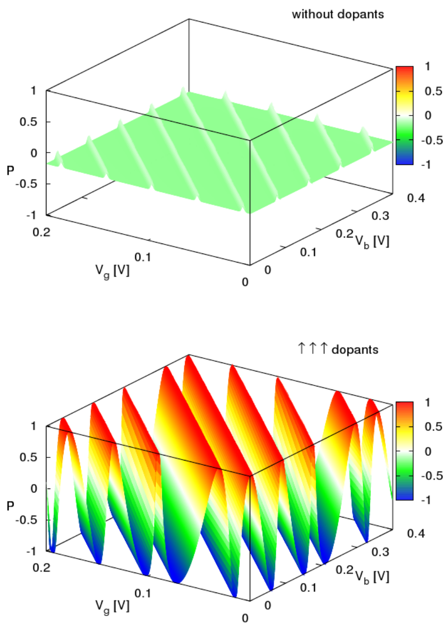

Figure 5. Dependence of the spin polarisation of the conductance on the applied bias and gate voltages.

Conclusions

- The spin polarisation of the conductance changes entirely after doping the Cu layer.
- The calculated conductance of spin-polarised electrons has pronounced maxima for the values of the applied voltage which correspond to the energies of resonant electron states.

References

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