A Single-Spin Switch

Viktor Sverdlov and Siegfried Selberherr

Institute for Microelectronics, TU Wien, Gußhausstr. 27-29, 1040Wien, Austria

e-mail: {Sverdlov|Selberherr}@TUWien.ac.at

With magnetic tunnel junctions scaling down, new phenomena due to the correlated charge transport are anticipated. One relevant phenomenon is associated to the non-avoidable traps in the insulator. In particular, the Coulomb interaction leads to a strong repulsion on a trap, a Coulomb blockade, while the Pauli blockade results in spin-dependent correlations at the transport through quantum dots and traps [1,2]. Spin-dependent hopping is responsible for large magnetoresistance in ferromagnet-insulator-metal structures [3] and magnetic tunnel junctions, due to the strong dependence of the trap occupation n and the current on the avareage spin $\mathbf{s}$ of the trap, which are determined by the solution of the system:

$$\frac{d}{dt}n = \Gamma_S(1-n) - \Gamma_D n - \Gamma_D \mathbf{p}_D \mathbf{s}, \quad \frac{d}{dt}\mathbf{s} = \mathbf{p}_S \Gamma_S (1-n) - \Gamma_D \mathbf{s} - \mathbf{p}_D \Gamma_D n + [\mathbf{s} \times \boldsymbol{\omega}_L]$$

Here $\boldsymbol{\omega}_L$ is the Larmor frequency vector pointing along the magnetic field $\mathbf{B}$, $\Gamma_{S,D}$ and $\mathbf{p}_{S,D}$ are the tunneling rates and the degrees to which the electron spins are polarized along the corresponding magnetization direction in the source and drain electrodes, respectively.

Since the spin on the trap is a vector quantity, it results in unusual correlations in *multi-terminal* devices. Here we analyze a three-terminal device in the configuration shown in Fig.1, where the source (1), the gate (2), and the drain (3) are ferromagnets, each described by the corresponding spin polarization $\mathbf{p}_i$ (i = 1,2,3). The potential at the trap is determined by the gate voltage V_{GS}, the drain-source voltage V_{DS}, and the capacitances C_i (i=1,2,3), which are assumed equal. The current I_α from an electrode α=G(Gate), S(Source), or D(Drain) to the trap is defined positive, if it flows from the electrode to the trap. The current continuity $I_G+I_S+I_D=0$ is thus automatically ensured. In our investigations a constant gate voltage V_{GS} is applied. For $V_{DS} < V_{GS}/2$ the junctions "source-trap" and "trap-drain" are biased in opposite direction. Then, in single-electron transistor (SET) configuration ($\Gamma_2 = 0$, $p_i = 0$) the drain current is zero (Fig.2), while the current "drain-trap" I_D is negative at $V_{DS} < V_{GS}/2$, if all $\Gamma_i = \Gamma$ and p_2=0, for any value of p_1, p_3 (Fig.2). The ferromagnetic gate (p_2=0.99) suppresses I_D and I_G at $V_{DS} < V_{GS}/2$, however, a large I_G comparable to I_D is obtained (Fig.3, Fig.4), unless the source is also ferromagnetic (p_1=0.99) (Fig.5). The value of I_D is further boosted, if all p_i=0.99 (Fig.6). We note that, although the behavior in Fig.6 is similar to that of a SET (Fig.2), the switching is due to the *spin correlations* and *spin blockade* alone.

[1] K. Ono et al., Science 297, 1313 (2002).

[2] Y. Wang et al., Phys. Rev. X 6, 011011 (2016).

[3] Y. Song and H. Dery, PRL 113, 047205 (2014).

978-3-901578-31-1

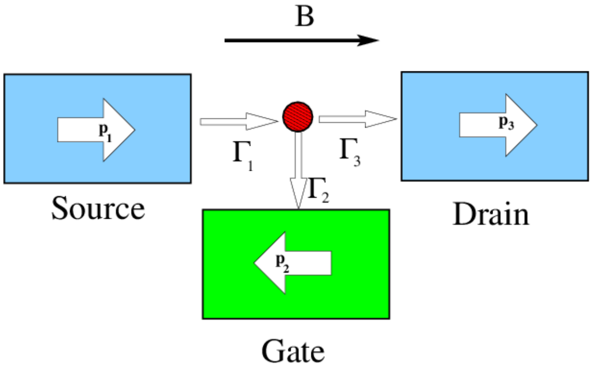

Fig.1: Schematic illustration of the device. Electron transport is caused by spin-dependent hopping between the ferromagnetic contacts.

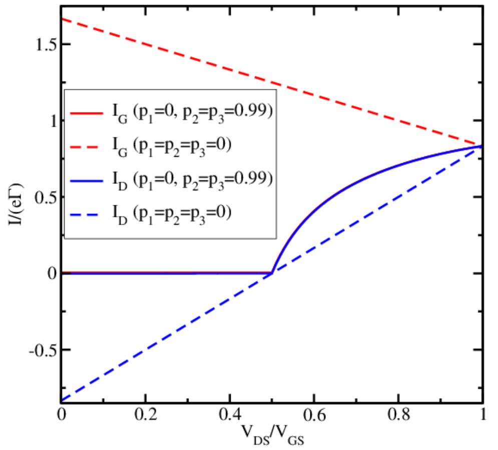

Fig.4: The currents are similar to those in Fig.3, when, in addition to the gate, the drain is ferromagnetic (p_2=p_3=0.99).

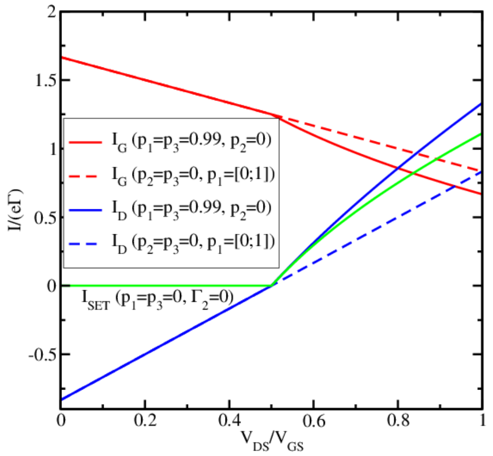

Fig.2: Gate and drain currents, when the gate is non-ferromagnetic (p_2=0). The SET drain current is also shown.

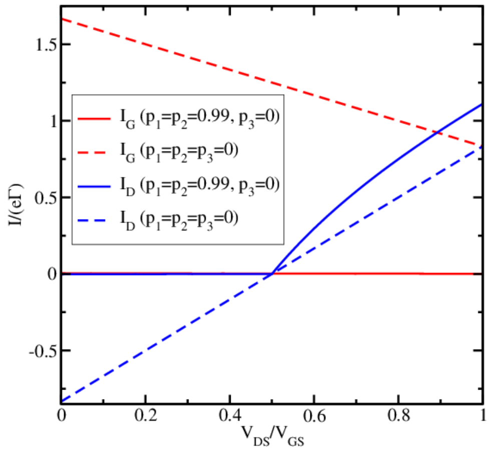

Fig.5 The gate current is suppressed, when the source and the gate are ferromagnetic (p_1=p_2=0.99).

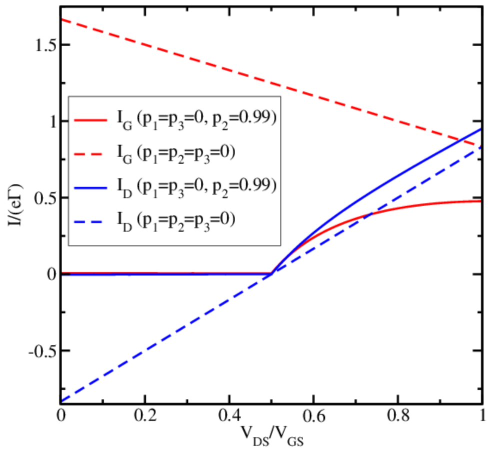

Fig.3: The drain and gate currents are suppressed, if the trap-drain junction is backward biased and the gate is ferromagnetic (p2=0.99). The gate current is nonzero for V_{DS}>V_{GS}/2.

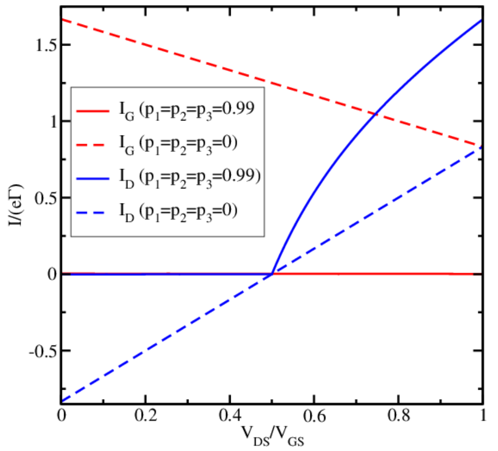

Fig.6: The drain current is the largest, while the gate current is suppressed, when all electrodes are ferromagnetic (p_1=p_2=p_3=0.99) in the configuration shown in Fig.1.

978-3-901578-31-1