Single electron counting of spin-polarized current through a quantum dot

Masakazu Yamagishi [1], Narii Watase [1], Masayuki Hashisaka [1], Koji Muraki [2], and Toshimasa Fujisawa [1]

[1] *Department of Physics, Tokyo Institute of Technology, Tokyo, Japan.*
[2] *NTT Basic Research Laboratories, NTT Corporation, Atsugi, Japan.*

Spin dependent transport in non-magnetic semiconductor nanostructures can be used to manipulate both charge and spin degrees of freedom in electronic transport. Detection or generation of single electron spins would be an ultimate device to handle single electron spins. Here we demonstrate single-electron counting of spin-filtered and unfiltered current associated with Zeeman sublevels of an orbital in a quantum dot (QD). Fully spin-polarized current is detected when a spin-up Zeeman sublevel is located in the transport window. When both Zeeman sublevels contribute the transport, however, spin-down current is found to be always smaller than the spin-up current. This partially spin-polarized current can be explained with exchange enhanced spin splitting in the nearby low-density regions.

By adjusting some voltages on fine surface gates of an AlGaAs/GaAs device shown in Fig. 1(a), a QD with electron number N (= 1 – 5) is attached to a quantum point contact (QPC) working as a charge sensor. Application of in-plane field B (= 3 – 9 T) gives Zeeman splitting E_z for each well-separated orbital state. Extremely small current through the QD driven by a bias voltage V_b (= -2 – 2 mV) is detected by the single-electron counting scheme with a bandwidth of a few kHz [1]. The average dwell times in the empty state with (N – 1) electrons and the occupied state with N electrons determine the incoming rate Γ_{in} and the outgoing rate Γ_{out}, respectively. As shown in Fig. 1(c), their gate-voltage dependences show clear transition from spin-filtered transport for up-spins and unfiltered transport. Clear step-like dependences ensure high selectivity for spin-filtering. Importantly, step heights in the incoming rate are unequal, indicating spin-dependent rates $\Gamma_{in,\downarrow} < \Gamma_{in,\uparrow}$. Suppressed outgoing rate for unfiltered case ($\Gamma_{out,mix} < \Gamma_{out,\uparrow}$) also suggests the same tendency $\Gamma_{out,\downarrow} < \Gamma_{out,\uparrow}$. In contrast to the linear B dependence of Zeeman splitting, the ratio $\Gamma_{in,\downarrow}/\Gamma_{in,\uparrow}$ has no or weak dependence on B, as shown in the lower panel of Fig. 1(d), as well as on tunneling rates and electron number (tested for N = 1, 3, and 5). This spin-dependent tunneling rate could be attributed to the exchange enhanced spin splitting in the nearby low-density regions, as often discussed with the so-called 0.7 anomaly in the conductance of a QPC [2].

[1] T. Fujisawa et al., Science 312, 1634 (2006).
[2] K. J. Thomas et al., Phys. Rev. B 58, 4846 (1998).

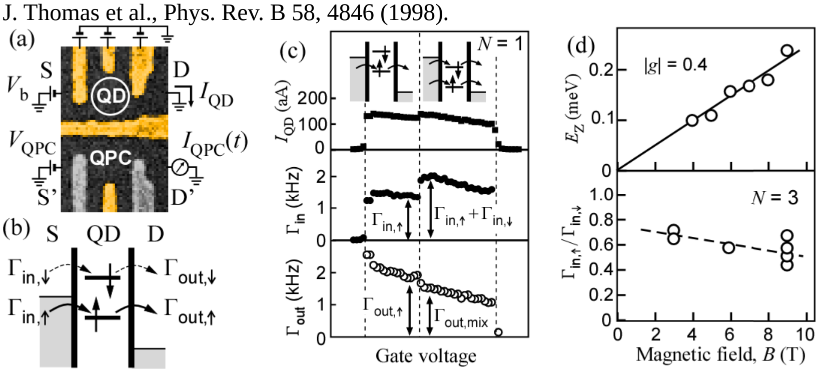

Fig. 1 (a) Schematic setup. (b) Energy diagram for spin-filtered transport. (c) Current, incoming and outgoing tunnel rates. (d) Zeeman energy and the ratio of incoming rates.