IEDMS 2018 Invited Talks and Speakers

Invited Speech 5

11/15 13:00 (T2A)   The Conference Hall of Pi, NTOU (畢東江博士國際會議廳)

Title: A Single-Spin Switch

Speaker: Professor Siegfried Selberherr
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Abstract:

Spin correlations at hopping are known to be responsible for large magnetoresistance at trap-assisted tunneling between normal metal and ferromagnetic electrodes. The reason is the spin-selective escape rate, which results in a non-zero average spin at a trap. Since the spin on a trap is a vector quantity, it produces unusual correlations in multi-terminal devices. We analyze a three-terminal device with ferromagnetic electrodes and demonstrate that the spin correlations result in current-voltage dependences characteristic to a single-electron transistor.

Biography:

Professor Siegfried Selberherr was born in Klosterneuburg, Austria, in 1955. He received the degree of Diplomingenieur in electrical engineering and the doctoral degree in technical sciences from the Technische Universität Wien in 1978 and 1981, respectively. Dr. Selberherr has been holding the venia docendi on computer-aided design since 1984. Since 1988 he has been the Chair Professor of the Institut für Mikroelektronik. From 1998 to 2005 he served as Dean of the Fakultät für Elektrotechnik und Informationstechnik. Prof. Selberherr published more than 400 papers in journals and books, where more than 100 appeared in Transactions of the IEEE. He and his research teams achieved more than 1100 articles in conference proceedings of which more than 180 have been with an invited talk. Prof. Selberherr authored two books and co-edited more than 45 volumes, and he supervised, so far, more than 100 dissertations. His current research interests are modeling and simulation of problems for microelectronics engineering. Prof. Selberherr is a Fellow of the IEEE, a Fellow of the Academia Europaea, a Fellow of the European Academy of Science and Arts, and a Distinguished Lecturer of the IEEE Electron Devices Society.

A Single-Spin Switch

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***Abstract* — Spin correlations at hopping are known to be responsible for large magnetoresistance at trap-assisted tunneling between normal metal and ferromagnetic electrodes. The reason is the spin-selective escape rate, which results in a non-zero average spin at a trap. Since the spin on a trap is a vector quantity, it produces unusual correlations in multi-terminal devices. We analyze a three-terminal device with ferromagnetic electrodes and demonstrate that the spin correlations result in current-voltage dependences characteristic to a single-electron transistor.**

***Keywords* — Single-spin switch, spin-dependent hopping, tunneling magnetoresistance.**

I. Introduction

Single electron hopping determines transport properties in undoped semiconductors and dielectrics. The Coulomb interaction plays an important role as it leads to the repulsion of the charges on a trap and the Coulomb blockade, which results in strong charge correlations at transport. From the point of view of devices, the Coulomb blockade has lead to the development of the single-electron transistor [1].

In addition to its electron charge, the electron possesses spin. The Pauli, or spin, blockade [2] results in large magnetoresistance and magnetoluminescence effects in organic semiconductors and organic light-emitting diodes [3] at room temperature. Since the spin on the trap is a vector quantity, it produces unusual correlations in multi-terminal devices, leading to the concept of a single-spin switch.

II. Single-Spin Switch

We consider a three-terminal device employing for its operation both the spin and the Coulomb blockade. Ferromagnetic source (S), gate (G), and drain (D) electrodes are characterized by the spin polarization $\mathbf{p}_i$ (i=S,G,D) (Fig.1). The potential at the trap between the electrodes is determined by the gate V_{GS}, drain-source V_{DS} voltages. The capacitances C_i (i=S,D,G) are assumed equal to C. The current I_i from an electrode i is positive, if it flows from the electrode to the trap. The current continuity $I_G+I_S+I_D=0$ is thus automatically ensured. A trap is weakly coupled to the three ferromagnetic electrodes by tunneling transition rates Γ_i. The spin on the trap is determined by the magnetic polarizations of the elctrodes, transition rates, and the weak non-quantizing magnetic field, which results in unusual correlations in the multi-terminal device.

The single-electron transistor mode is obtained when there is no tunneling between the trap and the gate $\Gamma_G = 0$ and all electrodes are non-ferromagnetic ($p_i = 0$) . We apply a constant gate voltage $V_{GS}=e/C_G$. For $V_{DS} < V_{GS}C_G/2/(C_S+ C_G)$ the junction's "trap-drain" is biased in opposite direction, and there is no source-drain current. At $V_{DS} > V_{GS}C_G/2/(C_S+ C_G)$, the Coulomb blockade is overcome, and the current starts flowing (Fig.2).

If a tunneling between the trap and the gate is possible ($\Gamma_S = \Gamma_G = \Gamma_D \equiv \Gamma$), the Coulomb blockade is lifted as an electron from the trap can escape to the gate at $V_{GS}=e/C_G$. The situation changes dramatically when the gate is ferromagnetic (p_G = 0.99, $p_S = p_D$ = 0). At $V_{DS} < V_{GS}/4$ only little current flows due to the spin blockade, while at $V_{DS} > V_{GS}/4$ the drain junction is positively biased, which lifts the spin blockade (Fig.3). A ferromagnetic drain ($p_G = p_D$ = 0.99, p_S = 0) does almost not alter the current-voltage behavior (Fig.4).

Adding ferromagnetism to the source instead of the drain ($p_G = p_S$ = 0.99, p_D = 0) does almost not alter the currents at $V_{DS} < V_{GS}/4$ (Fig.5), however, at $V_{DS} > V_{GS}/4$ the gate current remains negligible. Finally, if one considers all electrodes ferromagnetic ($p_S = p_G = p_D$ = 0.99), the gate current remains negligible in the whole range of V_{DS} (Fig.6). The drain current is blocked at $V_{DS}<V_{GS}/4$ as the gate junction is negatively biased, which prevents electrons from tunneling to the drain. At $V_{DS}>V_{GS}/4$ the drain current flows and is larger than in Fig.5 due the same polarization of source and drain. Although the current-voltage characteristic in Fig.6 is qualitatively similar to that of a single-electron transistor (Fig.2), the suppression of the gate current and the switching is due to the *spin correlations* and the *spin blockade* at spin-dependent trap-assisted hopping in a multi-terminal device with ferromagnetic electrodes.

IV. Conclusions

An operation of a three-terminal single-spin switching device employing for its operation both the spin and the Coulomb blockade is demonstrated.

References

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[4] V. Sverdlov and S. Selberherr, *SPIE August 2018,* accepted.

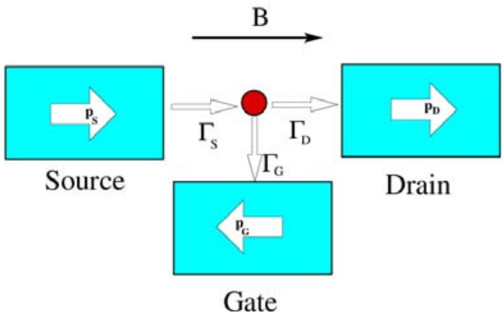

Fig.1: Schematic illustration of the device. Electron transport is caused by spin-dependent trap-assisted hopping between the ferromagnetic contacts.

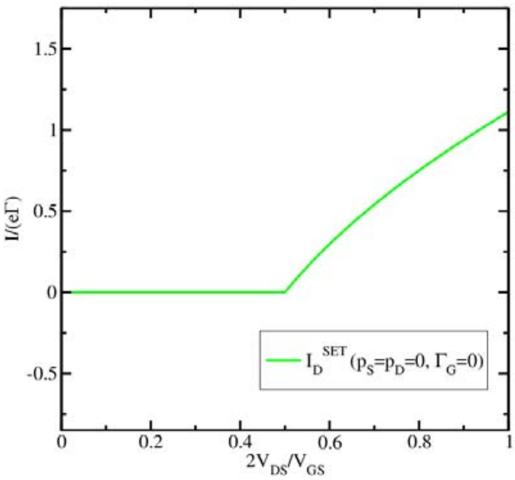

Fig.2: The SET drain current. All electrodes are normal. There is no coupling between the trap and the gate.

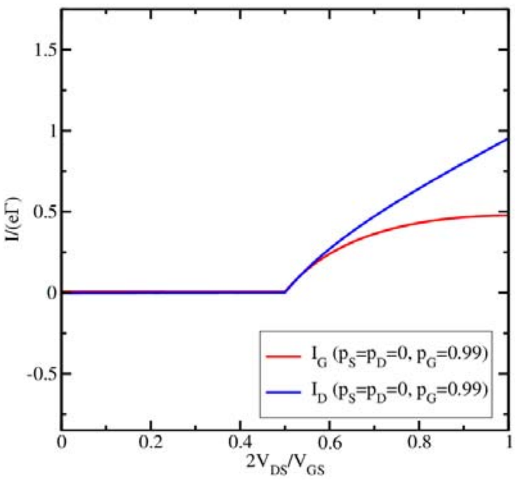

Fig.3: The drain and gate currents are suppressed, if the trap-drain junction is backward biased and the gate is ferromagnetic (p_G=0.99). The gate current is nonzero for $V_{DS}>V_{GS}/4$.

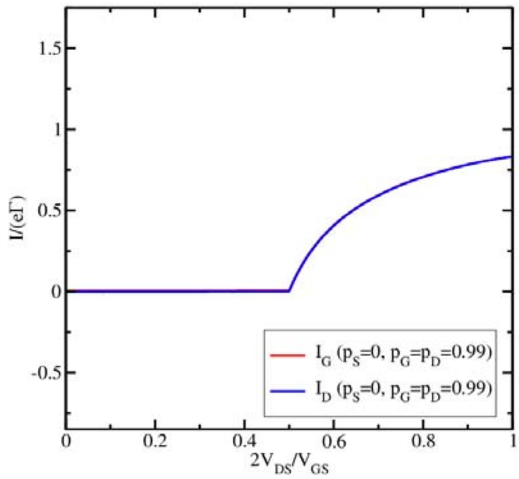

Fig.4: The currents are similar to those in Fig.3, when, in addition to the gate, the drain is ferromagnetic (p_G=p_D=0.99).

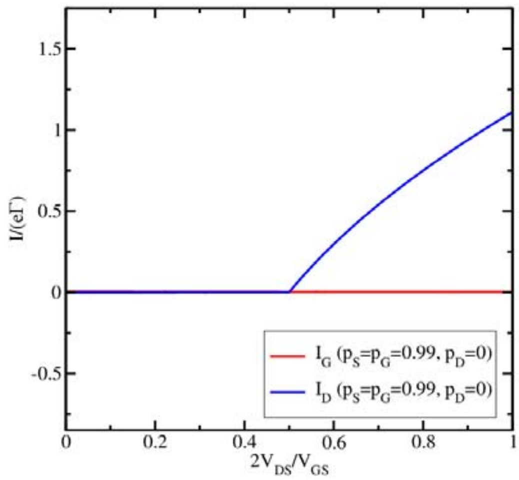

Fig.5 The gate current is suppressed when the source and the gate are ferromagnetic (p_S=p_G=0.99).

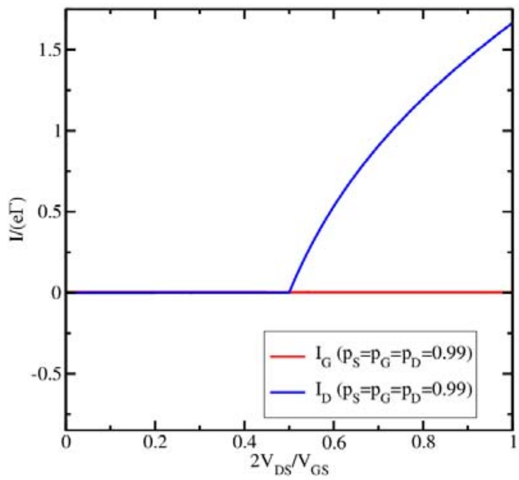

Fig.6: The drain current is the largest, while the gate current is suppressed, when all electrodes are ferromagnetic (p_S=p_G=p_G=0.99) in the configuration shown in Fig.1.