Transport via coherent state superpositions in triple quantum dots

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Spin qubits based on interacting spins in double quantum dots have been demonstrated successfully. Readout of the qubit state involves a conversion of spin to charge information, which is universally achieved by taking advantage of a spin blockade (SB) phenomenon resulting from Pauli's exclusion principle. SB manifests itself as a rectifier where current flows freely in one direction, but is blockaded in the other [1]. The blockade is found to be not perfect at zero magnetic field due to a mixing of singlet and triplet states in a field gradient resulting from the hyperfine interactions. These leakage currents are dramatically suppressed when a small external field splits off the triplet states from the singlet one. At present, more complex spin qubit circuits such as triple quantum dots are being developed. Here we show, both experimentally and theoretically, that in a linear triple dot SB becomes bipolar with current strongly suppressed in both bias directions and also that a new quantum coherent mechanism becomes relevant. In this mechanism, charge is transferred non intuitively via coherent states from one end of the linear triple dot circuit to the other, without involving the centre site [2]. We show that current only flows through the triple quantum dot when four configurations are degenerate, i.e. at quadruple points (QP). First, we focus on a QP where configurations of four and five electrons are degenerate. When a bias is applied in a magnetic field beyond ~10mT 'bipolar' SB is observed where current is suppressed in both bias directions. As the field is reduced to zero, SB leakage resonances are observed within the transport region. Of special interest are two very sharp resonances (marked as L-R in the figure) which correspond to alignment of states in the left and right dot but not in the centre and which result from a purely quantum coherent effect: electrons occupy states that involve their transference from one extreme to the other without ever visiting the centre. Such states have been invoked theoretically for possible applications such as spin bussing or quantum rectification. Further, we analyse another QP where configurations of two and three electrons are degenerate.

[1] K. Ono , D. G. Austing ,Y. Tokura and S. Tarucha, Science, **297**, 5585, (2002).
[2] M. Busl, et al, Nature Nanotechnology, in press. doi:10.1038/nnano.2013.7.

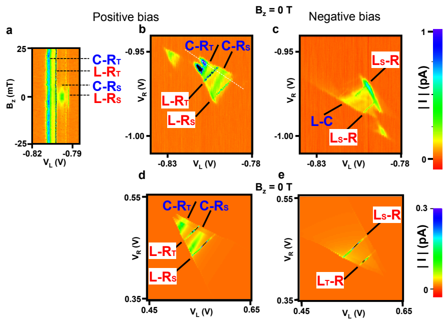

Figure 1. Leakage current through the TQD at quadruple points 5 and 6 for zero B. a) I(B) measured with a bias of 0.5 mV by sweeping $\mathbf{V}_L$ and $\mathbf{V}_R$ along the white dashed line in b). The dotted lines indicate the positions of the various resonances b–e), Results for a 0.5 mV bias of either polarity. Both for positive (b,d) and negative (c,e) bias and for experimental (b,c) and theoretical (d,e) results. One can clearly distinguish resonance lines with two different slopes: the L-R resonance lines, where (2,1,1) and (1,1,2) states are on resonance, and the steeper C-R resonance lines that occur when the energy of states (2,1,1) and (2,0,2) are aligned.