Quantum dot spin valves and Cooper pair splitter spin correlation experiments using ferromagnetic split-gates

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Using the electron spin in 'spintronic' devices promises a large range of applications, for example in new types of transistors, or to gain fundamental insights into quantum physics. To these ends, we introduced individually magnetized ferromagnetic split-gates (FSGs) [1] to locally polarize the electron spin states, for example in semiconductor quantum dots (QDs). We first report on a double QD spin valve [2] consisting of two weakly coupled semiconducting QDs in an InAs nanowire, each with independently magnetized FSGs oriented either in parallel or anti-parallel. In tunneling magnetoresistance (TMR) experiments, we demonstrate a strongly reduced spin valve conductance for the *anti-parallel* orientations at zero external magnetic field, with QD polarizations of $\sim 27\%$. This value can be improved considerably by tuning the gate voltages and by a small external magnetic field ($\sim 40\,\mathrm{mT}$), yielding a continuously electrically tunable TMR signal. Using a simple model, we reproduce all our experimental findings, with a gate tunable QD polarization of up to $\pm 80\%$ [2].

The real strengths of such spin-polarized QDs as spintronic elements lies in their straight forward implementation into more complex nanoelectronic devices, for example in combination with superconducting elements. Here we present spin current correlation measurements in a Cooper pair splitter [3, 4]: in a standard superconductor, electrons of opposite spins form spin singlet Cooper pairs. These electrons can be spatially separated using two QDs coupled in parallel to a superconductor. These QDs we again spin-polarize by individual FSGs and measure the resulting electrical currents. In this case, we find a suppression of the split Cooper pair currents by $\sim 50\%$ for the two *parallel* magnetization configurations, compared to the anti-parallel configuration. This is consistent with a negative spin correlation between the two split Cooper pair currents: intuitively, a Cooper pair cannot split into two electrons of the same spin projection. From these experiments we find a spin correlation of $\left\langle \hat{C}_{\mathrm{exp}} \right\rangle \leq -1/3$ [5], clearly demonstrating a negative spin correlation due to Cooper pairing. This number deviates from the ideal case of -1, mainly due to the non-ideal spin polarization of the individual QDs [6].

Such QD spin filters are suitable for various other applications, for example to perform a solid-state Bell test [6], to investigate spin patterns in Rashba nanowires [7], or in equal spin Andreev reflection [8] at Majorana-type bound states.

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