Probing spins in spin interferometer with superconducting lead

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Recently the spin-orbit interaction (SOI) in semiconductors has attracted great attention as it plays a very intriguing role in semiconductor spintronics. SOI can couple the spin degree of freedom of electrons to their orbital motion and vice versa, therefore giving a useful handle for manipulating and controlling the electron spin by external electric field or gate voltages [1]. In general, SOI is very strong in narrow gap semiconductors such as InAs and InSb [2].

In this work, using the superconducting lead, we study the relation between the asymmetric Andreev bound state and a spin current generated by the SOI in an interferometer containing a quantum dot (QD) as shown in Fig. 1. It is argued that the spin current is generated under the condition when the SOI is finite, a QD has an on-site Coulomb interaction, and an interferometer is out of equilibrium [3,4]. We employ the Schwinger-Keldysh nonequilibrium Green's function method based on Nambu-Gor'kov formalism. First we consider the situation without superconducting lead, namely t_S=0 in Fig. 1, and discuss the mechanism of spin current generation. We show that the generated spin current depends on whether the nonequilibrium situation is created by the source-drain bias voltage or thermal gradient applied to two normal leads (L,R). Depending on the condition for the QD energy level and the strength of SOI, even for finite thermal gradient, we may have no spin current. On the contrary, for finite source-drain bias voltage, the spin current always occurs. Next we discuss the detection scheme of the spin current using the superconducting lead whose voltage is zero. The local density of states (LDOS) in the system shows the peak splitting corresponding electron and hole in an Andreev bound state. When the spin current is not generated, those peaks in the LDOS are symmetric with respect to energy. As the source-drain bias voltage, on-site Coulomb interaction, or SOI increase, those peaks become asymmetric. This result shows that there is the relation between a finite spin current and the asymmetry in LDOS. This property in LDOS appears in the tunneling current from the left lead to right lead through a QD. Therefore, we can detect the spin current generation from the transport property through a QD.

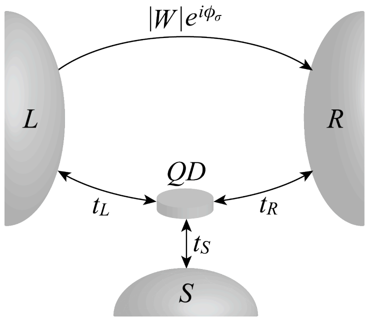

Figure 1: Schematic diagram of an interferometer containing a QD which couples to two normal leads (L,R) and a superconducting lead (S). $\phi_\sigma=\sigma\phi_{SO}$ is spin-dependent phase due to SOI, where ϕ_{SO} is proportional to the strength of the Rashba SOI. t_ν is the tunneling amplitude between the QD and the reservoir ν and W indicates the direct transmission between two normal leads.

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