Suppression of the Kondo Effect in T-Shaped Double Dots System

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Abstract

We calculate the tunneling conductance through a system of double dots in parallel geometry, in which only the first dot is connected to the leads whereas the second dot to the first one. Transport properties are considerably affected by tunable parameters of the second dot. In particular, we find the suppression of the conductance in the Kondo regime, which is due to the interplay of the Kondo effect and the interference effect.

Key words: Kondo effect; interference effect; double dots

Electron transport phenomena through quantum dots have been studied intensively in recent years. In particular, the Kondo effect due to local electron correlations has been observed in a single-dot system[1,2]. This discovery demonstrates the importance of electron correlations in quantum dot systems. Furthermore, the Kondo effect has been observed in coupled quantum dots[3–5], in which several microscopic parameters are tunable, enabling us to systematically study a variety of quantum phenomena caused by the Kondo effect.

In this report, we study transport phenomena through a system of two coupled quantum dots in specific parallel-geometry, shown in Fig.1, which is regarded as a single-dot system decollated by the second dot. We show that the additional dot gives rise to the interference effect, resulting in the nontrivial suppression of the conductance in the Kondo regime at low temperatures.

The model we consider here is a T-shaped double-dots system, which is described by the following Hamiltonian,

$$H = \sum_{i,\sigma} \epsilon_i d^\dagger_{i\sigma} d_{i\sigma} + V \sum_{i \neq j} d^\dagger_{i\sigma} d_{i\sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow} + \sum_{k\sigma\alpha} \epsilon_{k\sigma\alpha} c^\dagger_{k\sigma\alpha} c_{k\sigma\alpha} + \frac{1}{\sqrt{2}} \sum_{k\sigma\alpha} (W_l c^\dagger_{k\sigma\alpha} d_{l\sigma} + h.c) \quad (1)$$

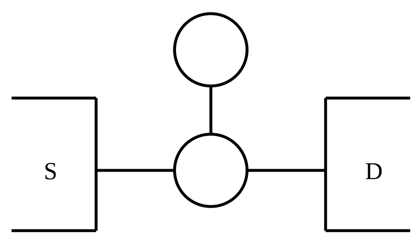

Fig. 1. T-shaped double-dots system

where $d^\dagger_{i\sigma}$ creates an electron in the lower ($i = l$) or upper dot ($i = u$) with the energy ϵ_i and spin σ, and $c^\dagger_{k\sigma\alpha}$ creates an electron in the source ($\alpha = s$) and drain ($\alpha = d$) with the energy $\epsilon_{k\sigma\alpha}$ and spin σ. Here, V (W_l) is the tunneling amplitude between dots (between the dot and the leads). The intra-dot Coulomb repulsion is assumed to be sufficiently strong to exclude double occupancy of electrons in each dot. We use two methods to treat such strong correlations: (i) non-crossing approximation (NCA)[6,7], which may give reasonable results at temperatures larger than the Kondo temperature; (ii) slave-boson mean-field approximation (SBMF)[8], which gives complementary results to NCA at low temperatures.

Shown in Fig. 2 are the results calculated by NCA at finite temperatures T as well as those by SBMF at zero temperature, where we have chosen the parameters corresponding to the Kondo regime with small

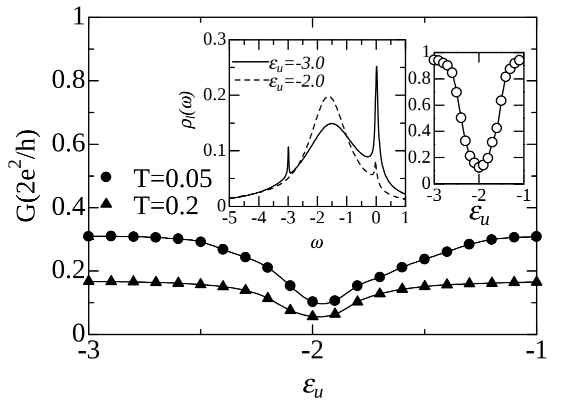

Fig. 2. Conductance computed by NCA as a function of the upper-dot level ϵ_u for $\epsilon_l = -2.0$ and $V = 0.1$. Left (right) inset shows the density of states for the lower-dot (the conductance computed by SBMF).

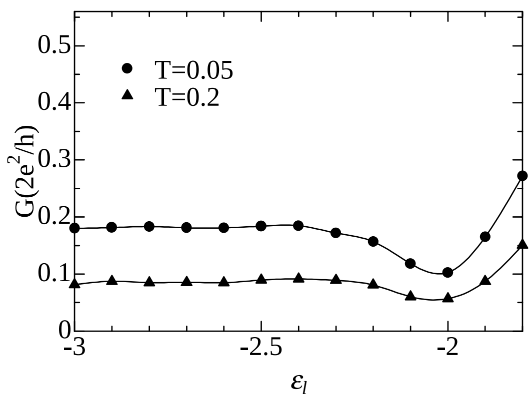

Fig. 3. Conductance computed by NCA as a function of the lower-dot level ϵ_l for $\epsilon_u = -2.0$ and $V = 0.1$.

inter-dot coupling V. We take the bare resonance width of the lower-dot, Γ, as the unit of the energy.

When the upper-dot level ϵ_u is deep below ϵ_l, the conductance is enhanced as the temperature decreases. Such enhancement is also observed when ϵ_u is higher beyond ϵ_l. These effects are indeed caused by the formation of the Kondo resonance in the lower dot. It is to be noticed, however, that there is nontrivial suppression of the conductance, when two bare dot-levels coincide with each other. This is observed both in the NCA results as well as the SBMF results (right inset) around $\epsilon_u \sim -2.0$. The suppression of the conductance is caused by the interference between two distinct channels, i.e. the direct Kondo resonance of the first dot and the indirect resonance via both of the first and second dots.

We can see the origin of the interference effect from the local density of states (DOS) shown in the left inset of Fig. 2. When two localized levels are separated, the DOS of the lower dot has a shape similar to that for the single-dot model, which is slightly modified around ϵ_u by the hybridization term V. Therefore the conductance is dominated by the Kondo resonance of the lower dot in this case. On the other hand, when two levels are close to each other energetically ($\epsilon_u = \epsilon_l = -2.0$), the lower- and upper-dot states are mixed up and lift the degeneracy. This change around the bare levels causes the suppression of the Kondo peak around the Fermi level, as seen from the left inset in Fig. 2 for $\epsilon_u = -2.0$. As a result, this causes the decrease in the conductance. We have confirmed that this type of dip structure also appears when the lower-dot level is varied, as seen from Fig. 3. It is to be noticed that such an interference effect occurs when the dot level is changed in the energy range of the order of the bare resonance width Γ, while the relevant temperature range, in which such an effect may be observable, is given by the effective Kondo temperature. We also note that the interplay of the Kondo effect and the interference effect appears only for small V, and is smeared when V becomes large (e.g. $V = 1$ in the present case).

In summary, we have calculated the tunneling conductance for a system of T-shaped double-dots. It has been shown that electron transport is considerably affected by the additional dot. In particular, we have found the suppression of the conductance by the interference effect in the Kondo regime at low temperatures. This effect may be observed experimentally around or below the Kondo temperature by properly tuning the gate voltage. In real double-dots systems, the inter-dot tunneling may be rather small, which may be suitable to observe the interference effect discussed here. The detail of the calculation will be published elsewhere [9].

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