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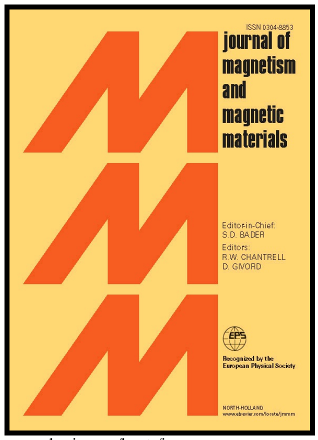

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Coulomb interactions-induced perfect spin-filtering effect in a quadruple quantum-dot cell

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Abstract

A quadruple quantum-dot (QQD) cell is proposed as a spin filter. The transport properties of the QQD cell were studied in linear response regime on the basis of the equations of motion for retarded Green's functions. The developed approach allowed us to take into account the influence of both intra- and interdot Coulomb interactions on charge carriers' spin polarization. It was shown that the presence of the insulating bands in the conductance due to the Coulomb correlations results in the emergence of spin-polarized windows (SPWs) in magnetic field leading to the high spin polarization. We demonstrated the SPWs can be effectively manipulated by gate fields and considering the hopping between central dots in both isotropic and anisotropic regimes.

Keywords: Spin filter, Quantum interference, Fano-Feshbach resonance, Coulomb correlations
PACS: 73.63.Kv, 73.21.La, 73.23.Ra, 81.07.Ta

1. Introduction

The generation of tunable highly spin polarized current is vital for spintronic applications [1, 2]. To achieve this aim the variety of systems has been already proposed from semiconductor heterostructures to mesoscopic samples [3, 4]. In the former the electron spins are controlled by the Rashba spin-orbital coupling (SOC) [5, 6]. The strength of the SOC in turn can be regulated by an electric field perpendicular to 2D electron gas [7]. Along with the SOC in mesoscopic devices, having at least a few Feynman paths, quantum interference in phase-coherent transport regime plays important role [8]. In some works it was demonstrated that the interplay between the Aharonov-Bohm (AB) flux [9] and the Rashba SOC results in a substantial spin-polarized conductance [10, 11]. However, the experimental implementation of such low dimensional nanosystems, in particular, varying the SOC strength by electric field or penetrating the AB ring with magnetic field seems to be rather difficult.

It is known that the structures having the AB geometry or the networks consisting of quantum dots (QDs) are able to exhibit the Fano-Feshbach resonance [12, 13] in their transport characteristics as well. As a result, the Zeeman splitting of spin-dependent conductances in the region of such an asymmetric peak leads to the emergence of so-called spin-polarized window (SPW) when there is high probability of tunneling for the electrons with spin σ and close-to-zero one for the electrons with spin $\overline{\sigma}$ [14, 15, 16, 17]. For the QD-networks previously proposed as spin-filter prototypes in [15, 16, 17] it is highly preferable to have many QDs considering the Coulomb correlations inside each QD but not between them. In this article we will show that the nanosized diamond-shaped cell composed of just four QDs, a quadruple quantum-dot cell (QQD cell), can display perfect spin filtering properties. This behavior is achieved by taking into account both intra- and interdot Coulomb interactions. It is shown that its spin polarization can be effectively manipulated by different kinetic processes in the cell and gate fields. It is important to note that the transport properties of the cells containing three and four QDs have been already considered earlier [18, 19, 20, 21]. In particular, Ozfidan et al [21] showed that the QQD cell having the same geometry can experience the spin blockade (SB) since the spin of the three- and seven-electron states becomes $3/2$ under certain conditions. Thus, SB can serve as an indicator of spin polarized state of the QQD cell. As it will be seen below, our results are based on another, more general definition of SB when the transmission for electrons of one spin direction is strongly suppressed relative to the other due to Zeeman splitting [22].

2. The model

The system under consideration is a QQD cell between paramagnetic contacts in external magnetic field H depicted at figure 1. It is modeled by the Hamiltonian $\hat{H} = \hat{H}_L + \hat{H}_R + \hat{H}_D + \hat{H}_T$. The term $\hat{H}_{L(R)}$ describes the left (right) lead,

$$\hat{H}_{L(R)} = \sum_{k\sigma} \xi_{k\sigma} c^{+}_{L(R)k\sigma} c_{L(R)k\sigma}, \qquad (1)$$

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