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Position-dependent temporal behavior of spin states in a Rashba–Dresselhaus nanoloop

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ABSTRACT

In this paper we study the spin states populations, as functions of time, for electrons in a quasi-1D Rashba–Dresselhaus quantum loop, in a strong perpendicular magnetic field. We also explicitly include a parabolic confining potential into the Hamiltonian. The Rashba–Dresselhaus Hamiltonian is shown to give rise to a fictitious magnetic field which depends on the location of the electron in the loop and may be forced to lie along the bisector of the first-third quadrant. We show that the spin precesses, *without* wobbulations, about this fictitious field. It is further demonstrated that at locations where this fictitious field vanishes, the spin precesses about the external field, *with* wobbulations.

1. Introduction

The manipulation, control and exclusion (filtering) of some electronic spin states play a major role in the construction of spintronic devices [1–5]. In spintronic devices, information is placed onto the electronic spin states, while its charge, containing no information, transfers such information [6,7]. Having no conventional counterparts, development of spintronics is anticipated, in most cases, to increase the speed and decrease the power consumption in information processing devices [8–10]. It is thus essential to explore means of controlling and manipulating the electronic spin states. A vivid candidate for the construction of spintronic devices and manipulation of spin states is semiconductor heterostructures. This is mainly due to the fact that fabrication of low-dimensional semiconductor structures has advanced during the last decade [11–13]. Consequently, the reduction of effective

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dimensions from three dimensional bulk, to quasi-two dimensional quantum wells, quasi-one dimensional quantum wires, and even quasi-zero dimensional quantum dots, has been possible [11–13].

In suitably chosen heterostructures with different band gaps, the conduction electrons form a two dimensional electron gas at the interface [14]. Moreover, choices of heterostructural materials, along with externally applied electric field, reduce the electronic motional freedom, confining it to nanowires, quantum dots, nanoloops, etc. [14,15]. Among the aforementioned apparatus, the nanoloop has provided new means for construction of quantum memories [16], switchable flux transformers [17], spin interferometers [18], quantum networks [19] and so on. Therefore, investigating the dynamical behavior of electronic spin states in a quasi-1D nanoloop is essential for the aforementioned applications.

It is well known that in a heterojunction, where the two-dimensional electron gas resides, two important effects arise: The Rashba [20] and Dresselhaus [21] spin–orbit couplings (SOC). The Rashba SOC is caused by structural inversion asymmetry [20], while the Dresselhaus SOC is due to the bulk inversion asymmetry [21]. It is also well established that the structural inversion asymmetry (consequently, the Rashba SOC) and the bulk inversion asymmetry (consequently, the Dresselhaus SOC) depend upon the band structure of the material, the electron density and the actual geometry of the sample [22]. It has been also demonstrated that the strength of Rashba SOC can be controlled with an electrostatic potential applied to a top gate terminal while that of the Dresselhaus SOC depends on the side-wise external gate potentials [23]. It is emphasized that for a nanoloop produced at the interface of GaAs/AlGaAs, both effects are present and may be tuned to be of equal strength in the range of $0\text{–}10 \times 10^{-12}$ eV m [24,25]. Equal Rashba and Dresselhaus parameters are of great interest in construction of spin-field-effect transistors [26]. It is also ordinary to apply an external magnetic field to remove spin degeneracy even at zero electronic momentum [27]. In what follows, therefore, we consider an electron, confined in a quasi-1D nanoloop, with a parabolic confinement, to which a uniform magnetic field is applied, taking into account both the Rashba and Dresselhaus SOCs. The model used here is schematically presented in Fig. 1. The confined electrons may be initially prepared, through an input beam, in some particular polarization state. It is clear from Fig. 1 that the injected electrons into the loop are not allowed to split in (counter) clock-wise beams as opposed to a ring [28–30]. Fabrication of such an apparatus, appears to pose subtle technological difficulties. However, with recent technological developments, construction of gated rings (loops) has become indeed feasible [31,32]. The dynamical behavior of electronic spin states, under these conditions, is of much interest for mainly two reasons. Firstly, the electronic spin provides a simple two level quantum entity (forming qubits) whose behavior is determined by spin orientation in space [33–36]. The dynamical behavior of spin, therefore, is of much interest in the development of encoding and decoding the qubits, with direct applications in quantum information processing. Secondly, the dynamics of electronic spin is much less sensitive to unavoidable electromagnetic noises [37].

In the present work, we report the dynamical behavior of electronic spin, in a GaAs/AlGaAs quasi-1D circular nanoloop, where both the Rashba and Dresselhaus SOCs are taken into account. In so doing, we first present the governing Hamiltonian, from which the time evolution of spin states is

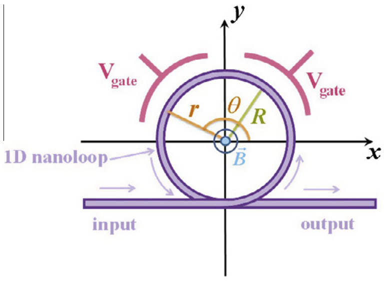

Fig. 1. A typical schematic representation of gated nanoloops. The initial electronic state is prepared through the injected beam and does not split at the entrance.