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Spin-dependent electron transport in a nonmagnetic nanostructure with both Dresselhaus and Rashba spin-orbit terms

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The spin-dependent electron transport is numerically studied in a nonmagnetic nanostructure in the presence of both Dresselhaus and Rashba spin-orbit interactions. It is shown that the large spin polarization can be achieved in such a structure mainly due to the Rashba spin-orbit term induced splitting of the resonant level. It is also shown that the spin polarization strongly depends on the well width and the thickness of the middle barrier as well as the height of the middle barrier.

1. Introduction

In recent years, due to the feasibility of spin polarization and spin filtering within a two-dimensional electron gas (2DEG) which was proposed by Papp and Peeters [1,2] based on the combination of hybrid magnetic-electric barrier structure, the significant progresses have been made in both theoretical and experimental investigations of spin-dependent tunneling through magnetic nanostructures [3–7]. The use of ferromagnetic metal (FM)-semiconductor (SC) junctions as spin-polarization devices has been widely considered [8–12]. However, these systems suffer from rather poor spin-injection efficiency arising from the conductance mismatch between the FM and SC materials [13,14].

Recently, extensive studies of spintronics begin to focus more on the tunneling through nonmagnetic semiconductors after it is pointed out that the large spin polarization can be achieved in such a

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structure due to the spin-orbit coupling interaction [15–20] being responsible for the experimentally observed zero-field spin-splitting [21,22]. Comparing to the tunneling through magnetic junctions, spin-dependent tunneling through nonmagnetic semiconductors has several inherent merits. For example, it opens the door to orienting, detecting and manipulating electron spin through electrical ways and avoids the conductance mismatch between the FM and SC materials which would strikingly reduce spin injection efficiency.

More recently, Glazov et al. [23] investigated the spin-dependent resonant tunneling through symmetric double-barrier structure in the presence of the Dresselhaus spin-orbit term and found that the transmission coefficient was strongly dependent on the spin orientations and the wave vector of the electrons. Then, the spin-dependent tunneling through double-barrier heterostructure with the influence of in-plane magnetic field and the Dresselhaus spin-orbit coupling [24] or through a periodic nonmagnetic heterostructure with both Dresselhaus and Rashba spin-orbit effects [25] was numerically studied by Lu et al. Motivated by these brief reports, we will investigate the spin-dependent tunneling through nonmagnetic three barriers of strained heterostructure with zero-field, in which the effects of both Dresselhaus and Rashba spin-orbit interactions are taken into account.

2. Theoretical method and formulas

We consider the transmission of electrons with the initial wave vector, $\boldsymbol{k} = (\boldsymbol{k}_{\|}, k_z)$, through a three-barrier structure, InP/InAs/InP/InSb/InP/InAs/InP, grown along zVert [001] direction as depicted in Fig. 1. Here $\boldsymbol{k}_{\|}$ is the in-plane wave vector, $\boldsymbol{k}_z$ denotes the wave vector along the growth direction, i.e., z axis, a and V_1 denote the thickness and the height of the left or right barrier, respectively, c and V_2 stand for the thickness and the height of the middle barrier, respectively, and b gives the well width. Then the electron Hamiltonian including both Dresselhaus and Rashba spin-orbit terms is

$$\widehat{H} = -\frac{\hbar^2}{2m_i^*}\frac{\partial^2}{\partial z^2} + \frac{\hbar^2 k_{\|}^2}{2m_i^*} + V_{1/2} + \widehat{H}_D + \widehat{H}_R, (i = 1, 2 \text{ } and \text{ } 3) \tag{1}$$

where m_1^*, m_2^* and m_3^* denote the electron effective masses of materials InP, InAs and InSb, respectively. $\hat{H}_D$ is the spin-dependent k^3 Dresselhaus term and $\hat{H}_R$ is in-plane Rashba term, both describing the spin splitting of conduction electrons in zinc-blende-lattice semiconductors. We assume that the kinetic energy of electrons is substantially smaller than the barrier height $V_{1/2}$. The Dresselhaus term [26,27] can be simplified to

$$\widehat{H}_D = \gamma(\hat{\sigma}_x k_x - \hat{\sigma}_y k_y)\frac{\partial^2}{\partial z^2}, \tag{2}$$

and in the asymmetrical quantum wells in-plane Rashba term exists with non-zero α due to hetero-potential asymmetry

$$\widehat{H}_R = \alpha(\hat{\sigma}_x k_y - \hat{\sigma}_y k_x), \tag{3}$$

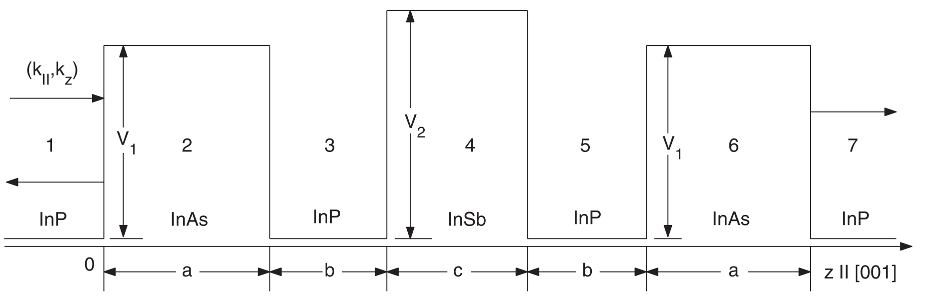

Fig. 1. Electron transmission through [001]-grown asymmetrical three-barrier heterostructure.