Spin-orbit Interaction of Electrons in Curved Low-dimensional Systems and Spintronic Applications

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The conventional non-magnetic 2D semiconductor systems are perspective for spin-electronic devices due to the presence of spin splitting. The application of longitudinal electric field leads to the orientation of electron spins [1-4] that gives a way to control spins electrically. High technological development of 2D systems permits to modify easily their properties in a wide range of parameters.

It is well known that the Hamiltonian for electrons confined near an oriented planar two-dimensional system contains linear in lateral momentum terms which describe the spin-orbit (SO) interaction [5-7]. This SO interaction is conditioned by the presence of crystal potential together with potential well and vanishes for free electrons in a planar potential well. In this paper we study the SO interaction of electrons confined near a curved semiconductor surface and in a curved quantum wire. We show that the curvature induces a novel mechanism of SO interaction which complements the known mechanisms occurring in planar systems. The systems under consideration are assumed to have transversal widths much less than curvature radii.

We have found the effective Hamiltonian of SO interaction. As an example the Hamiltonian for the curved 2D system is presented here. If the longitudinal wavelength of electrons is also less than the radius of surface curvature R, the SO Hamiltonian can be written in the small vicinity of a given point on the surface as

$$H_{SO}^{(n)}= -2\alpha[\, T_n(\sigma_x p_y \kappa_y - \sigma_y p_x \kappa_x) - (p_x^2 \kappa_x + p_y^2 \kappa_y)\,(\sigma_x p_y - \sigma_y p_x)/\,2m].$$

Here $H_{SO}^{(n)}$ is referred to the n-th subband of transversal quantization, α is the constant of basic SO interaction, T_n is the kinetic energy of transversal motion, $\sigma_{x,y}$ are the Pauli matrixes, $p_{x,y}$ are the components of the longitudinal momentum. The axes x and y in the tangent plane are chosen along the principal directions of curvature; $\kappa_{x,y}$ are principal values of curvature.

The specific cases of nanosphere and nanotube are considered and the electron spin-split spectra in these systems are obtained. For instance, the energy levels of electrons in nanotube with given projection of the total angular momentum $j_z=\pm 1/2, \pm 3/2...$ to the nanotube axis z and the longitudinal momentum p_z are

$$\varepsilon_n(p_z,j_z)=\{\, k^2+j_z^2+1/4 - \beta\,(1/4+3j_z^2-t_n) \pm[j_z^2[1+\beta T_n-\beta(j_z^2+3/4)]^2+\beta^2 k^2 (j_z^2+1/4)^2]^{1/2}\}/2mR^2.$$

Here $\beta=2\alpha/R^2$, $t_n=2mR^2T_n$ and $k=p_zR$.

The SO Hamiltonians for the planar and spatial curved quantum wires were found also.

The presence of spin-splitting terms in the Hamiltonian leads to the rotation of electron spin while electron travels along the curved surface or wire. The sign of spin-orbit interaction depends on the occupation of the subbands of transversal quantization. The strength of curvature-induced SO interaction can be governed by an external gate.

Possible spintronics applications of curved 1D and 2D systems are discussed.

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