Rashba electron transport in 1D quantum waveguides

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The properties of Rashba wave function in the planar one-dimensional waveguide are studied, and the following results are obtained. Due to the Rashba effect, the plane waves of electron with the energy E divide into two kinds of wave with the wave vectors $k_1 = k_0 + k_\delta$ and $k_2 = k_0 - k_\delta$, where k_δ is proportional to the Rashba coefficient, and their spin orientations are $+\pi/2$ (spin up) and $-\pi/2$ (spin down) respect to the circuit, respectively. If there is gate or ferromagnetic contact in the circuit, the Rashba wave function becomes standing wave form $\exp(\pm ik_\delta l)\ \sin[k_0(l-L)]$, where L is the position coordinate of the gate or contact. Unlike the electron without considering the spin, the phase of the Rashba plane or standing wave function depends on the direction angle θ of the circuit. The travel velocity of the Rashba waves with the wave vector k_1 or k_2 are the same $\hbar k_0/m^*$. The boundary conditions of the Rashba wave functions at the intersection of circuits are given from the continuity of wave functions and the conversation of current density. Using the boundary conditions of Rashba wave functions we studied the transmission and reflection probabilities of Rashba electron moving in several branch structures, and found the interference effects of the two Rashba waves with different wave vectors caused by ferromagnetic contact or the gate. At last we derived the general theory of multiple branches structure. The theory can be used to design various spin polarized devices.

The eigen states of the closed circular and square loops are studied by using the transfer matrix method. The transfer matrix $M(E)$ of a circular arc is obtained by dividing the circular arc into N segments, and multiplying the transfer matrix of each short straight segment. The energies of eigen states in the closed loop are obtained by solving the equation $\det(M(E)-I)=0$. For the circular ring, the eigen energies obtained with this method are in agreement with those obtained by solving the Schrödinger equation. For the square loop, the analytic formula of the eigen energies is obtained first. The transport properties of the A-B ring and A-B square loop, double square loop are studied using the boundary conditions and the transfer matrix method. In the case of no magnetic field, the zero poins of the reflection coefficients are just the energies of eigen states in closed loops. In the case of magnetic field, the transmission and reflection coefficients all oscillate with the magnetic field, the oscillating period is $\Phi_m=hc/e$, independent of the shape of the loop, Φ_m is the magnetic flux through the loop. For the double loop the oscillating period is $\Phi_m=hc/2e$, in agreement with the Koga's experimental result. At last, we compared our theoretical results with Koga's experiment.

Rashba wave function, one-dimensional waveguide, boundary condition

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Supported by the special funds for Major State basic Research Project No. 069c031001 and National Natural Science Foundation No. 60521001.