Electric-field control of penetration of quantum-mechanical current density under semi-infinite potential barrier at the interference of the electron waves in semiconductor 2D nanostructures

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The influence of a constant transverse (along z – axis; z-axis being the axis of the quantization) electric field with strength F on penetration of quantum-mechanical current density ej_x (x, z) (e being an electron charge) under semi-infinite potential barrier in height V at the interference of the electron waves in semiconductor 2D nanostructures have been theoretically studied. We have considered a situation when in 2D nanostructure at the left, from region 1 (x < 0, QW_1) the electronic wave of unit amplitude with energy $E_x < V$ on such barrier in region 2 (x > 0, QW_2) falls. We have shown, that in a situation when the electron wave falls on the first quantum-confined electron subband in QW_1 and longitudinal energy E_x of the particle less than energy of the bottom of the second subband in this reg. 1 and reflection of the electron wave probably only on the same first subband the quantum-mechanical current density ej_x (x, z) in reg. 2 equal to zero. However, if energy of the particle in reg. 1 is more than energy of the bottom of the second quantum-confined electron subband in QW_1 a situation because of the interference of the reflected waves cardinally varies. The possibility of the exist of the reflected wave on the second subband on $x \to -\infty$ results to the situation, when under a barrier the quantum-mechanical current density $ej_x (x, z) \neq 0$ (penetration of quantum-mechanical current density) and its amplitude exponentially dumped at $x \to \infty$. Thus under a barrier there are two zones of distribution of the ej_x (x, z): the zone (2), in which ej_x (x, z) it is directed in a positive direction of the x- axis and zone (1), in which ej_x (x, z) has a return direction. On zone (1) there is an outflow of a charge from under a barrier. Distinction of potentials U_1 (z) and U_2 (z) localizing a particle along the z-axis in regions 1 (x < 0) and 2 (x > 0) respectively provide nonorthogonality of the transverse wave functions in these regions. It results to confuse of the electron subbands in different regions and to appearance of the electronic interference effects. Certainly, the complete probability current density (or the complete quantum-mechanical current density) along the x-axis $J_x = \int j_x (x, z)\, dz$ has no coordinate dependence from x. As is known [1], at falling of the free electron with energy E_x (the x-axis is the direction of propagation of the electron wave) on a rectangular potential wall in height V_0 (x> 0) under condition of $E_x < V_0$ the quantum-mechanical current density ej_x (x, z) in the reg. 2 is equal to zero, because of the real exponent of the wave function. Certainly, in this case exists exponentially dumped penetration of wave function of the particle into this region at x> 0.

We have calculated effect of penetration of a ej_x (x, z) in the reg. 2 for the 2D nanostructure with parameters GaAs. Width of the structure is 300Å, $F = 7 \cdot 10^5$ V/cm.

[1] L. D. Landau and E. M. Lifschitz, Quantum Mechanics (Non – Relativistic Theory), Pergamon Press, Oxford, 1977.