COHERENT QUANTUM TRANSPORT IN MESOSCOPIC SUPERCONDUCTING HETEROSTRUCTURES WITH DEGRADED INTERFACES

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Due to the particle-wave duality, the concept of quantum coherence in time and space may be applied to quasiparticles in solids as well. In the following, we study interference processes of quasi-electron and quasi-hole excitations within a normal (n) sheath of the thickness $d_n$ at the surface of a superconductor (S) which is put in contact with an ultra-thin insulating (I) barrier and a metallic counter-electrode. It is shown that such interference can give rise to superposition phenomena produced by ordinary and Andreev-like scatterings from I/n and n/S interfaces in the planar heterostructure.

In this work, we analyze the effect of the bound states within the superconducting energy gap $\Delta$, that are formed in the n sheath, on conductance and shot-noise spectra of N(S)-I-n/S junctions. To find the lowest bound level $\varepsilon = E - E_F$, we use the Bohr-Sommerfeld quantization rule that requires an electron wave-function phase accumulation along an enclosed propagating loop inside the n interlayer to be an integer multiple of $2\pi$. Thus, $\varepsilon$ can be found from the relation $\varepsilon(\theta) = (\hbar v_F / 2d_n)\arccos[(\varepsilon(\theta)/\Delta)\cos \theta$ where $v_F$ is the Fermi velocity, $\theta$ is the incident angle, and the s-wave symmetry of the superconducting gap is assumed. It means that a strong peak in the conductance-vs-voltage characteristic at $V_\Lambda = \Delta/e$ (in the traditional N-I-S configuration) will be shifted to lower voltages and, besides it, a pronounced dip slightly below $V = V_\Lambda$ as well as an additional hump structure above $V = V_\Lambda$ should appear in measured curves. We generalize the above result to the case of the $d$-wave order-parameter symmetry and compare our numerical simulations with those obtained by tunneling spectroscopy experiments on low- and high-temperature superconductors as well as with alternative interpretations of anomalous subgap features in transport characteristics of mesoscopic superconducting multilayers. In order to get additional arguments supporting the proposed explanation of the unexpected features, we suggest shot-noise experimental investigations of multilayered devices with one or two superconducting films. It is shown that such combined measurements of conductance and noise characteristics could provide new information on kinetics of transport processes in the heterostructures. In particular, we show that, in contrast to conductance measurements, those of noise spectra should exhibit local maximums just at biases $V_\Lambda = \Delta/e$ independently on the presence of a normal sheath at the surface of a superconductor.

Next, we apply the scattering technique to the study of superconducting and dissipative characteristics of Josephson heterostructures where the normal n-interlayer is introduced artificially or appears due to the degradation of electrode surfaces. In particular, we discuss design of the junctions with enhanced temperature stability at about 4.2 K, i.e., a comparatively weak dependence of the critical supercurrent $I_c$ on temperature $T$ in the working range. To realize it, a concave upward $I_c$-vs-$T$ curve is required. To reveal the needed conditions, we have analyzed the shape of this curve in two limiting cases, (i) comparatively thin n interlayers with an induced mini-gap and (ii) thick n films remaining normal in proximity with an S film. Numerical simulations were performed for an n-film with the thickness of the order of the superconducting coherence length $\xi$. We demonstrate a crucial contribution of related bound states into the charge transport across S-I-n/S junctions and show that required concave upward $I_c$-vs-$T$ curves can be obtained only when $d_n$ is less than $\xi$ but of the order of its value.

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