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The theoretical analysis of the new microwave detector based on a Josephson heterostructure

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High-sensitivity superconducting microwave detectors of various types are widely used now in a number of applications [1]. Among the most important theoretical results achieved in this field in the last few years was the creation of theories [2,3], taking into account the quantum nature of microwave radiation absorption in these detectors as well as excited quasiparticles relaxation and multiplication. These theories have obtained the limits of sensitivity of such popular microwave detectors, as CEB (cold electron bolometer) detector and KID (kinetic inductance bolometer) detector. The results of [2,3] clearly demonstrate, that principles of operation of CEB and KID do not permit to achieve the values of sensitivity, relevant for the present radio-astronomy applications. On the other hand, recent calculations of non-equilibrium fluctuations, arising in normal diffuse metal strip under microwave irradiation [4], and the response of Josephson S-I-N-I-S (superconductor-insulator-normal metal-insulator-superconductor) heterostructure on microwave power [5], allow us to hope that THZ frequency range microwave detector, having the sensitivity, suitable for the radio-astronomy applications, can be created.

In this work, we consider theoretically signal and noise properties of the new type of a high-sensitivity detector, based on a S-I-N-I-S Josephson junction, in which the electron energy distribution function $f(\varepsilon)$ in the nanoscale normal metal N_region is nonequilibrium due to the capacitive coupling of this region with a receiving antenna [5]. The deviation of $f(\varepsilon)$ from the equilibrium distribution function leads to a change in the critical current I_c of the junction, i.e., in fact, to its inductance $L = \Phi_0/2\pi I_c$ ($\Phi_0 \approx 2.07*10^{-15}$ Wb is the magnetic flux quantum), which is the output signal of this device. We also show that this device has a number of advantages as compared to the recently proposed bolometer based on a long S-N-S (superconductor–normal metal–superconductor) Josephson junction [6] and is free from a number of inherent drawbacks of the S-N-S bolometers. Up to now there was no calculation of the noise properties of S-I-N-I-S Josephson junction bolometer, taking into account non-equilibrium form of electron distribution function $f(\varepsilon)$ in the normal metal absorber of this detector. Based on results of [4,5], we make this calculations and demonstrate, that noise parameter NEP of this detector is lower, than in others modern microwave detectors.

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The theoretical analysis of electronic thermal properties of the interfaces between multiband superconductors and a normal metal

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Investigations of the electronic thermal properties of the interfaces between a normal metal and high-temperature superconductors are important for correct design of modern low-temperature electronic refrigerators and bolometers [1,2]. Multiband superconductivity, recently discovered in ferropnictides [3] and in magnesium diboride [4], is the suitable choice due to isotropic order parameter in it, in contrast with strongly anisotropic d-wave superconductivity in high-Tc cuprates, which is destructive for electronic refrigeration and bolometric applications [2]. Moreover, recent calculations of Andreev spectra and subgup bound states in ferropnictides [5], taking into account coherent multiband interference effects in $s_{\pm}$ sign-reversal order parameter model [6], predict possible suppression of Andreev reflection for clean boundaries between ferropnictides and a normal metal. This Andreev reflection suppression can improve electronic refrigerator quality, in a similar way as additional ferromagnetic layer, suggested in [7]. Up to now there was no calculation of electronic thermal properties of the interfaces between a normal metal and novel multiband superconductors. In this paper we calculate the thermal flux and electron thermal conductivity of the boundary between normal metal and novel multiband superconductors. In this calculations both s_{++} and $s_{\pm}$ sign-reversal order parameter models [6] for multiband superconductor is used, taking into account coherent multiband interference effect [5]. We suggest, that the interface is smooth in an atomic scale and clean, so BTK model [8] for transmission and reflection probabilities of the interface is used. The possible microrefregerating and bolometric application of this structures is discussed.

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Microscopic theory of thermal phase slips in diffuse superconducting wires

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The investigations of the phase slips phenomenon are important for deriving the answer on a fundamental question, important for the superconducting electronics: up to what value it is possible to reduce the width of a superconducting strip, that it keeps the ability to carry a current without dissipation. Per the last few years new theoretical results [1-3] was obtained, which essentially improved our understanding of this problem, in comparison with the first theories [4,5].These new theoretical results include calculations of quantum phase slip rate [1], essential for extremely low operating temperatures, the correction of McCumber-Halperin result [4] for the preexponential factor in phase slip frequency, obtained via reconsideration of phase-slip center problem with the aid of the imaginary time effective action technique [2], as well as the calculation of free-energy barrier versus supercurrent dependence in clean superconducting wires at arbitrary temperature, using Eilenberger equations [3]. But up to now there was no calculation of free-energy barrier value versus supercurrent dependence in the whole temperature range for the case of diffuse superconductor, which is the most important for the comparison with the experimental results.

In this work we consider the phase slip process for the case of diffuse superconductor in a framework of Usadel equation in Matsubara technique. We calculate numerically coordinate-dependent Green functions corresponded to saddle point in the configuration space and obtain the dependence of the free-energy barrier on the supercurrent.

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Transport properties of josephson junctions with ferromagnetic layers

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The novel S-FN-S and S-FNF-S types of Josephson junctions (S - superconductor, F - ferromagnet, N - normal metal) suggested in [1-3] provide the opportunity for solution of several challenging problems, which still exists in SFS spin valve devices. They are the problem of enhancement of the decay length of critical current, I_C, and the problem of realization of control upon the junction parameters by changing the mutual orientation of magnetization vectors of ferromagnetic films. The results obtained in [1-3] are essentially based on the assumption that the thickness, d_F, d_N, of all the films in FNF multilayer are small compared to their decay lengths (ξ_F, ξ_N). In real structures the requirement $d_N \ll \xi_N$ can be easily fulfilled, while the inequality $d_F \ll \xi_F$ is difficult to achieve due to the smallness of ξ_F and finite roughness of NF interfaces. Therefore the solution of two dimensional problem is needed.

In this work we will concentrate on properties of a S-FN-S junction and perform the calculation of its critical current beyond the limits of small F and N film thicknesses for two dimensional geometry. We have considered that NF interface has finite transparency and that N and F metals have different transport parameters. The critical current of S-FN-S Josephson junctions is calculated in the framework of linearized Usadel equations. The dependence of I_C on the distance, L, between superconductors and thicknesses of ferromagnetic and normal layers is analyzed. We discuss practically interesting parameters of the structure. These results are important for possible applications of S-FN-S and S-FNF-S Josephson junctions as spin valve Josephson devices.

Also the conductance of ferromagnetic conductor is studied in the presence of induced long-triplet correlations from SF bilayer for the case of noncollinear vectors of magnetization of F layers.

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Critical temperature of SF and SFS multilayres with arbitrary electron mean free path in F and S films.

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In the last few years there is a considerable interest to the structures composed from superconducting (S) and ferromagnetic (F) interlayers [1-3]. Among the most important results achieved in this field there were the experimental evidence of so-called reentrance behavior of superconductivity in SF bilayers [4,5], as well as the observations of non-monotonic dependence of critical temperature of SF and FSF structures upon a thickness of ferromagnetic layers (see, e.g. [6]). The problem of theoretical calculations of critical temperature of SF and FSF structures has been also intensively analyzed (see e.g. [7-14]). Most of calculations had been done in a dirty limit and only in a few publications the clean limit had been also studied [9-12].

Up to now there was no calculation of T_C for SF bilayer and SFS trilayer under arbitrary mean free path in both S and F films. In this work we will attack this problem by developing a method, which has permitted to transfer the problem of T_C evaluation from solution of integro-differential Eilenberger equations in both S and F films to sufficiently more simple integral equation for a parameter $B(\theta)$. This parameter is a function of the angle θ between SF interface normal and the direction of Fermy velocity v_f in F metal and relates via boundary conditions the Eilenberger functions in F and S materials at SF interface.

Two types of SF interfaces have been considered. They are the interfaces having small transparencies or them, which are transparent and smooth in an atomic scale and connected the metals having essentially different Fermy velocities, $v_s >> v_f$.

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