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Josephson φ-device based on complex nanostructures with normal metal/ferromagnet bilayer

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The φ-junction is the Josephson device with nontrivial ground state phase ($0 < \varphi_g < \pi$). It provides a lot of possible applications starting from double-well potential formation in quantum detectors and silent qubits, development of metamaterials and ending with self-biasing one-photon detectors.

However, φ-junction is unavailable on the base of conventional Josephson structures due to inappropriate shape of current phase relations (CPR) in them. To avoid this restriction it was proposed to use arrays of parallel 0 and π junctions[1] or SFS junctions with step-like ferromagnetic interlayer[2]. Unfortunately, these devices haven't been fabricated experimentally yet.

In this work we have demonstrated that the structures composed from longitudinally oriented normal and ferromagnet films in the weak link region can be used as reliable φ-device. To prove it, in the frame of Usadel equations we solved two dimensional boundary problem for different geometries of the structures and found analytical criteria of φ-state existence. In case of the ramp type S-FN-S structure (Fig.1a) these criteria have form of the limitations on geometrical and material parameters

$$1.00 < \sqrt{\frac{H}{2\pi T_C}}\frac{L}{\xi_F} < 2.52, \qquad (1)$$

$$0.12 < \frac{\gamma_{BF}}{2}\sqrt{\frac{H}{\pi T_C}}\frac{d_N}{d_F} < 0.2, \qquad (2)$$

where H – exchange field, T_C – critical temperature, ξ_F – ferromagnetic coherence length, γ_{BF} – transparency parameter of SF interface and temperature $T \to 0$. Also we took into account the FN-interface impact which terminates scalability of φ-junction and determines minimal thickness

$$d_N > \frac{\xi_F}{\gamma_{BFN}}\frac{\pi T_C}{H}\left(1+\frac{\rho_N}{\rho_F}\frac{1}{\gamma_{BFN}}\sqrt{\frac{\pi T_C}{H}}\right). \qquad (3)$$

The SN-FN-NS structure (Fig1.b) is founded to have significant advantages, including wider φ-state area and effective independence from N-layer thickness.

Furthermore we numerically estimated and showed φ-junction with scale in order of 100 *nm* and critical current reaching 1 *mA*.

1. A. Buzdin and A.E. Koshelev, Phys. Rev. B, **67**, 220504, 2003.
2. N.G. Pugach, E. Goldobin, R. Kleiner, D. Koelle, Phys. Rev. B, **81**, 104513, 2010.

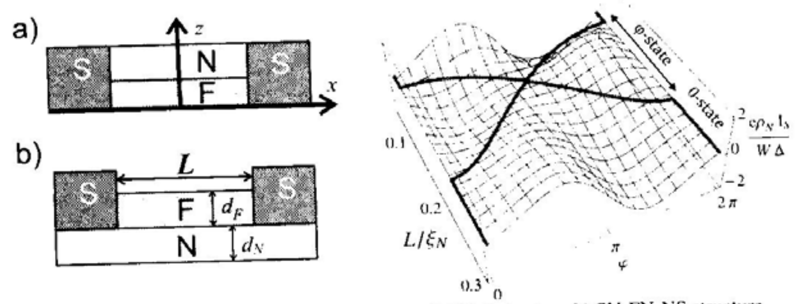

Figure 1: Different geometries of Josephson junctions: a) S-FN-S structure b) SN-FN-NS structure.
Figure 2: Supercurrent I_S versus Josephson phase φ and electrode spacing L in SN-FN-NS structure (d_N=0.64ξ_N, d_F=1.45ξ_N). Each section at certain L is a CPR. The thick lines mark ground state phase φ_g.

Manifestation of long-range triplet superconducting correlations in F1-SF1F2-F1 structures

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Artificial SF structures (S-superconductor, F- ferromagnetic metal) are under great interest nowadays. This interest is due not only to bunch of effects corresponding to similar to FFLO [1] phenomenon that was for the first time observed experimentally in SFS artificial structures [2, 3], but also due to recent experimental observations [4, 5] of supercurrents in structures with thick ferromagnetic layers; these supercurrents are believed to be a manifestation of an odd-frequency equal spin triplet superconducting correlations predicted theoretically for bulk materials in [6].

We propose and theoretically explore other possible structures in which odd-frequency equal spin triplet superconducting correlations can be observed experimentally. We investigate correlations in F1-SF1F2-F1 structures that represent a long thin ferromagnetic wire F1 connected with thick superconducting film S on the top of wire and thin ferromagnetic film F2 on the bottom of the wire (the lengths of S and F films are identical). Magnetization vector of the long ferromagnetic wire is constant and directs along the F1F2 interface. Magnetization vector of the short ferromagnetic film F2 is declined from the first vector on an angle α thus providing conditions for realization of equal spin triplet superconducting correlations in the structure. Odd-frequency equal spin triplet superconducting correlations are insensitive to the value of exchange energy, so they can penetrate ferromagnetic material at longer distance. So, these correlations can be observed in the long ferromagnetic wire F where the other singlet and short-range triplet correlations are already suppressed due to exchange energy.

Here we present results for Dos and differential conductance along F1 film calculations in F1-SF1F2-F1 structure with noncollinear magnetizations of ferromagnetic layers that also differs with values of exchange energies. The calculations were done in the limit of 'dirty' metals in the framework of Usadel equations for both linear and nonlinear cases. We show how Dos depends on angle α in the vicinity of SF1F2 part of the structure and how Dos transforms to Dos corresponding to long-range triplet correlations part only in the F1 wire far from SF1F2 part. Also we present differential conductance dependence on angle α. We show that maximum value of differential conductance is achieved not at $\alpha = \pi/2$ but for some intermediate angle that depends on difference between values of exchange energies of F films. As it was shown in [7] there are interesting effects form suppression parameter γ_B at F1F2 interface due to phase slip. We also investigate influence of parameter γ_B on the shape of Dos and differential conductance.

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1. P. Fulde and R.A. Ferrell, PRB, **135, p.**A550, 1964; A.I. Larkin and Y.N. Ovchinnikov, Zh. Eksp. Teor. Fiz., **47**, p.1136, 1964.
2. V.V. Ryazanov, V.A Oboznov, A.Yu. Rusanov, A.V. Veretennikov, A.A. Golubov, J. Aarts, Phys. Rev. Lett., **86**, p.2427, 2001.
3. T. Kontos, M. Aprili, J, Lesueur, F. Genet, B. Stephanidis, R. Boursier, Phys. Rev. Lett., **89**, p.137007, 2002.
4. J.W.A. Robinson, J. Witt, M. Blamire *et al.*, Science, **329** pp.59-61, 2010.
5. T.S. Khaire, M.A. Khasawneh, W.P. Pratt, Jr., and N.O. Brige, Phys. Rev. Lett., **104**, p.137002, 2010.
6. V.L. Berezinskii, JEPT Lett., **20**, p.287, 1974.
7. T.Yu. Karminskaya, A.A. Golubov, M. Yu. Kupriyanov, Phys. Rev. B, **84**, p.064531, 2011.