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BOOK OF ABSTRACTS

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I.O11

PECULIAR PROPERTIES OF 0-π TRANSITION IN SF-F-FS VARIABLE THICKNESS BRIDGES

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Recently, interest has been renewed in the study of Josephson structures of variable thickness bridges. The calculations carried out in Refs. [1–3] indicated the possible prospect of their use as basic elements of digital and analog superconducting devices.

Josephson variable thickness bridges were first proposed by Likharev [4] and were intensively studied both theoretically [5–9] and experimentally [10–14] until the end of the 80s. The structure (see Fig. 1) consists of two superconducting (S) electrodes with a thickness d_S connected by a structured film of a weak link material with a thickness d_F.

In SN-N-NS and SF-F-FS Josephson junctions the final interface transparency leads to violation of the rigid boundary conditions used in the above estimates [15] and delocalization of the weak coupling region [1]. In the limit $L_b \ll \xi$ both critical current I_c and I_cR_N product are mainly determined in these junctions by suppression parameter γ_{BM} rather than on bridge geometrical factors L_b and W. There is no need for additional structuring of the width of the bridge film [1]. Its width may coincide with the width of the composite electrode and be determined by the requirements for the line width of a technological process.

To find the required dependencies $I(\varphi)$ and $J_{Fx}(x, \varphi)$, it is necessary to solve in the F-film the Usadel equations. In case of low film thickness, $d_F \ll \xi_F$, Usadel Green's functions Φ independent of the coordinate y. Figure 2a shows the dependence of the current, $I(x)$, in the F,N-layer for different values of the normalized on πT_c exchange energy H. It can be seen that there are Josephson junctions with positive (0-junction) and negative (π-junction) critical current ($I_c = I(0)$). In addition, the presence of a vortex can be observed in both cases. It makes the existence of junctions with the bistable phase-current relation.

From Usadel equation in the S-electrodes it follows that in this approximation phases of order parameter $\Delta(x,y)$ and anomalous Usadel Green's functions, $\Phi_s(x,y)$ coincide with each other, while their modules equal to their equilibrium values in a superconductor at a given temperature, T: $\Phi_s(x,y) = \Delta(x,y) = \Delta\exp\{\chi(x,y)\}$. Here Δ is normalized on πT_c magnitude of superconductors order

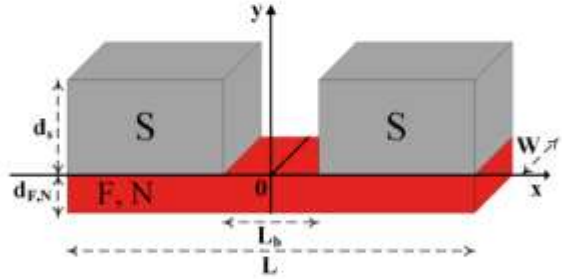

Figure 1. Sketch of SF-F-FS Josephson junction with variable thickness bridge geometry.

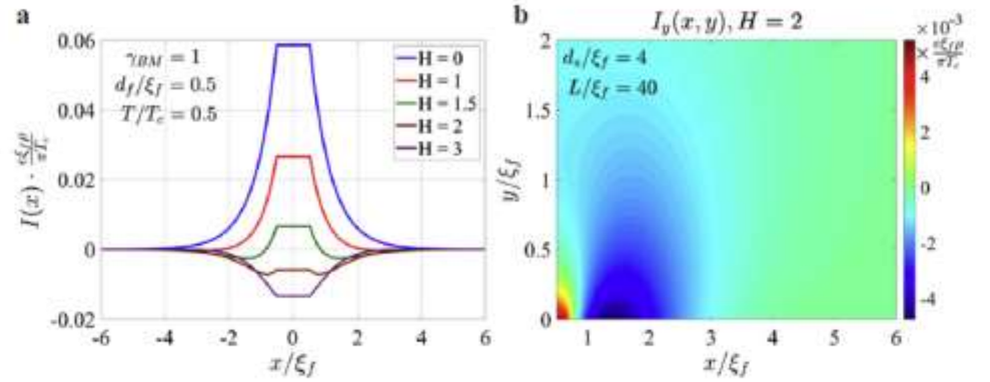

Figure 2. **a** Dependence of the current, $I(x)$, in the F,N layer for different values of the normalized exchange energy H; **b** Spreading of the y-component of the current, I_y, in the superconducting electrode S for $H = 2$.

parameter. The phase $\chi(x,y)$ obeys the Laplas equation with Neumann boundary conditions. Figure 2b shows the calculation of the spreading of the y-component of the current, I_y, in the superconducting electrode S for $H = 2$. In the vicinity of F-FS corner the vortex character of current spreading in the S-electrode is observed. When moving away from the bridge by a value of about $3\xi_F$ the current is evenly distributed along of coordinate y.

In summary, we assert that SF-F-FS junction with variable thickness bridge geometry can have a different sign of the critical current (0 or π junctions). In addition, we have shown that in the presence of Zeeman splitting in a weak link material, these supercurrent configurations can be even of a vortex nature. Another important feature is the absence of the critical current oscillations when the film thickness d_F or the S electrode thickness d_S changes.

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1. I. Soloviev, S. Bakurskiy, V. Ruzhickiy, N. Klenov, M. Kupriyanov, A. Golubov, O. Skryabina, and V. Stolyarov, Phys. Rev. Applied, **16**, 044060 (2021).
2. P.M. Marychev and D.Y. Vodolazov, Beilstein J. Nanotechnol., **11**, 858{865 (2020).
3. V. Bosboom, J.J.W.V. der Vegt, M.Y. Kupriyanov, and A.A. Golubov, Supercond. Sci. Technol., **34**, 115022 (2021).
4. K.K. Likharev, Zh. Eksp. Teor. Fiz., **61**, 1700 (1971).
5. K.K. Likharev, Pis'ma Zh. Tekh. Fiz., **2**, 29 (1976), [Sov. Tech. Phys. Lett., **2**, 12 (1976)].
6. M.Y. Kupriyanov, K.K. Likharev, and V.F. Lukichev, Zh. Eksp. Teor. Fiz., **83**, 431 (1982), [Sov. Phys. JETP, **56**, 235–240 (1982)].
7. A.A. Golubov, M.Y. Kupriyanov, and V.F. Lukichev, Soviet Microelectronics, **12**, 180 (1983).
8. P. Dubos, H. Courtois, B. Pannetier, F.K. Wilhelm, A.D. Zaikin, and G. Schon, Phys. Rev. B, **63**, 064502 (2001).
9. J.M. Warlaumont, J.C. Brown, T. Foxe, and R.A. Buhrman, Phys. Rev. Lett., **43**, 169 (1979).
10. R.B. van Dover, A. de Lozanne, and M.R. Beasley, J. Appl. Phys., **52**, 7327 (1981).
11. O. Liengme, P. Lerch, W. Liu, and P. Martinoli, IEEE Tran. Magn., **19**, 995 (1983).
12. H. Nakano and T. Aomine, Jap. J. Appl. Phys., **26**, 304 (1983).
13. J. Sauvageau, R. Ono, A. Jain, K. Li, and J. Lukens, IEEE Tran. Magn., **21**, 854 (1985).
14. Y. Baryshev, A. Dmitriev, A. Krivospitsky, V. Lukichev, A. Orlikovsky, and K. Valiev, Microelectronic Engineering, **9**, 385 (1989).
15. V.K. Semenov, Y.A. Polyakov, and S.K. Tolpygo, IEEE Trans. Appl. Supercond., **29**, 1302809 (2019).