THIN NS-SANDWICHES PROXIMITY EFFECTS

A. I. D'yachenko, I. V. Kochergin

*Donetsk Physico-Technical Institute of the Ukrainian Academy of Sciences, str. R. Luxemburg, 72, Donetsk, 340114, the Ukraine

In the WKB approximation the self-consistent solution of the Bogolyubov–Gor'kov equations for Green functions of thin NS sandwich is obtained. The self-consistent account was taken of the coordinate dependence of the order parameter both in N and S metals as well as of elastic scattering from impurities. It is concluded that the essential distinction of conduction electron parameters of N and S metals leads to the same effect on the tunnel density of states as a thin tunneling barrier on the interface of both layers in the McMillan model.

Equation for the order parameter at NS boundary. After high-temperature superconductors discovery an interest for proximity effect has become stronger because tunneling investigations of these materials are complicated by an imperfect metalceramic surfaces [1]. The aim of our calculations is a strict (within the limits of WKB-approximation [2]) self-consistent solution of the Bogolyubov–Gor'kov equations for Green functions $G(E,x)$ of NS-sandwiches. The solution was obtained in an explication if the quasi-onedimensionality of this spatial inhomogeneous task has been used since first steps of solving. The thin NS-sandwich with geometry parameters ($d \geq l_N$, ξ_N, $a \geq l_S$, ξ_S) was considered according to coordinate and frequency dependence of the order parameter $\Delta_i(x,E)$, $i = N,S$.

The solution is found in the case of perfect NS-interface with essential distinction of electron concentrations in sandwich layers ($k_{FN} \neq k_{FS}$; $v_{FN} \neq v_{FS}$) and accounting for the elastic scattering in the layers. The results obtained confirm the well developed McMillan model applicability to NS–sandwiches even if primary conditions put in this model are not fulfilled. Our equation system is more complicated, but it so much resembles the McMillan one (in the case of $\alpha = k_{FN}/k_{FS}$):

$$\Delta^N_{-d} = \frac{\Delta^{N,ph}_{-d} + i\Gamma^N_{-d}\Delta^N_0/\Omega^N_0}{1 + i\Gamma^N_{-d}/\Omega^N_0}, \qquad \Gamma^N_{-d} = \frac{\hbar}{\tau_N Z^{N,ph}_{-d} \cos(\Delta k_N d)}$$

$$\Delta^N_0 = \frac{\Delta^{N,ph}_0 + i\Gamma^N_0\Delta^S_0/\Omega^S_0}{1 + i\Gamma^N_0/\Omega^S_0}, \qquad \Gamma^N_0 = \frac{\hbar\alpha}{\tau_N Z^{N,ph}_0}\left(2i\frac{\cos(\Delta k_S a)}{\sin(\Delta k_S a)} - 1\right)$$

$$\Delta^s_0 = \frac{\Delta^{s,ph}_0 + i\Gamma^S_0\Delta^N_0/\Omega^N_0}{1 + i\Gamma^S_0/\Omega^N_0}, \qquad \Gamma^S_0 = \frac{\hbar\alpha}{\tau_S Z^{S,ph}_0}\left(2i\frac{\cos(\Delta k_S a)}{\sin(\Delta k_S a)} - 1\right)$$

$$\Delta_a^S = \Delta_a^{S,ph} - \Gamma_a^S \frac{\Omega_a^S\left(\Delta_0^S - \Delta_0^N\right) + \Omega_0^S\left(\Delta_a^S - \Delta_0^N\right)}{\Omega_0^N \Omega_0^S},$$

$$\Gamma_a^S = \frac{\hbar\alpha}{\tau_S Z_a^{S,ph} \sin\left(\Delta k_s a_s\right)}.$$

Here

$$\Delta k^N d \equiv \int_{-d}^{0} dx\, R_N Z_{ph}^N \Omega^N(x), \quad \Delta k^S a_s \equiv \int_{0}^{a_s} dx\, R_S Z_{ph}^S \Omega^S(x),$$

$$\Omega^{N,S}(x) = \left(E^2 - \Delta_{N,S}^2(x)\right)^{1/2}, \quad R_N = \frac{2d}{\hbar v_{FN}}, \quad R_S = \frac{2a_s}{\hbar v_{FS}},$$

d, a_s are the thicknesses of N- and S-layers, respectively $v_F(x)$ is the Fermy velocity. Quasi-one-dimensional character of the task of finding the NS-sandwich density of states allowed us to use the standard WKB-approximation. This makes it possible to take account of the slow coordinate dependence of any parameters in the task, so in the formulae given above one can use any phenomenological expressions for $\Delta_{S,N}(x)$ and $v_F(x)$ for the spatially-non-uniform N-S region, which can be realized at the surface of superconducting metal ceramics [3].

Conclusion. As a result of the calculations it was concluded that the essential distinction of electron concentrations lead to the same shape as a thin tunneling barrier on the interface of both layers. To all appearance this fact is caused by a weak assumed exchange of layer properties on the NS–interface (in the McMillan case there is a tunneling barrier, for our case — the small parameters α). Besides Γ, parameters inferred on microscopic level may apply to an analysis of proximity experiments, especially to T_c, order parameter calculations and shape of a tunneling spectrum near the gap.

The authors thank A. N. Omelyanchouk, V. M. Svistunov and V. Yu. Tarenkov for helpful discussions.

1. *Deutscher G.*, Physica C185/189, 216 (1991).
2. *D'yachenko A. I.*, *Kochergin I. V.*, J. Low Temp. Phys. 84, 197 (1991).
3. *Iguchi I.*, Physica C 185/189, 241 (1991).