STRIKING PROPERTIES OF JOSEPHSON JUNCTIONS WITH FERROMAGNETIC LINK AND NONUNIFORM INTERFACE

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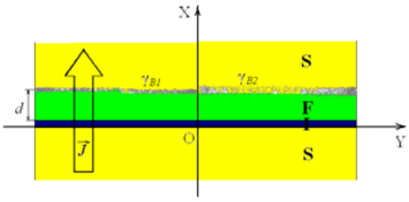
SIFS Josephson Junction with nonuniform S/F boundary



The damping parameter is equal to γ_{B1} at $y>0$, and γ_{B2} at $y<0$. $\gamma_{B1,2}$ are proportional to the boundary resistance of the corresponding region.

The boundary problem

The conditions of the "dirty" limit are fulfilled. And we assume that γ_{B1} and γ_{B2} are large enough to neglect by the proximity effect in superconducting banks and to use linealized Usadel equations:

$$\xi_F^2\left[\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right]\Phi_F-\frac{\tilde{\omega}}{\pi T_C}\Phi_F=0$$

here $\tilde{\omega}=\omega+iE$

The boundary condition at S/F interface ($x=d$):

$$\gamma_{B1(2)}\frac{\xi_F}{\tilde{\omega}}\frac{\partial}{\partial x}\Phi_F+\frac{G_0}{\tilde{\omega}}\Phi_F=G_0\frac{\Delta\exp(i\varphi/2)}{\omega}$$

The boundary condition at the interface covered by the dielectric layer ($x=0$):

$$\frac{\partial}{\partial x}\Phi_F=0$$

At the free ends of the Josephson junction $y=\pm L/2$:

$$\frac{\partial}{\partial y}\Phi_F=0$$

The solution of the boundary problem is substituted into the expression for the critical current:

$J(\varphi)=J_C(y)\sin(\varphi)$

$$J_C(y)=\frac{\pi T}{eRS}\sum_{\omega=0}^{\infty}\frac{\Delta}{\sqrt{\omega^2+\Delta^2}}\mathrm{Re}\left[\Phi_F(0,y,\omega)\right]$$

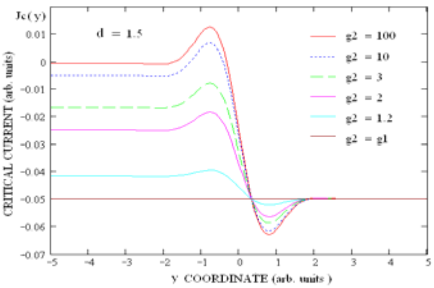
Full critical current through the junction in the external magnetic field was found from the Ferrell-Prange type equation:

$$\lambda_J^2\frac{\partial^2\varphi(y)}{\partial y^2}-\frac{J_C(y)}{J_{C0}}\sin\left[\varphi(y)\right]=0$$

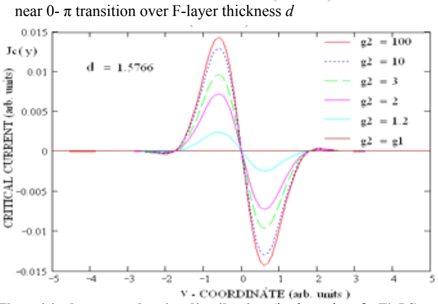
here λ_J is the Josephson penetration depth. In the limit $\xi_F<<L<\lambda_J$, the solution of the equation: $\varphi(y)=\varphi_0+hy$ where $h\sim H$ the external magnetic field.

Critical current density distribution

Far from 0- π transition

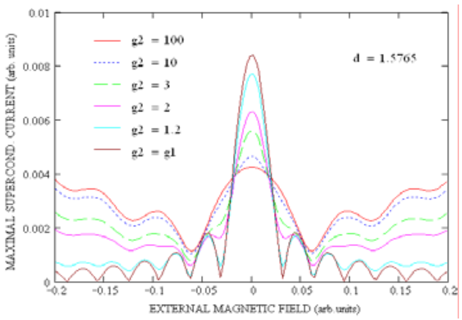


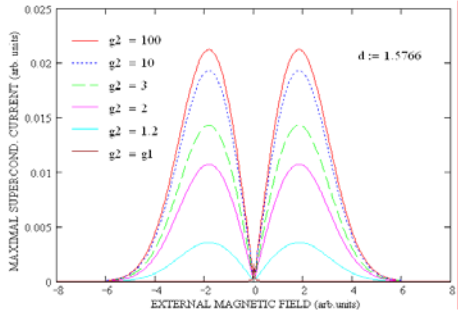
near 0- π transition over F-layer thickness d



The critical current density distribution (in the units of $\pi T/eRS$) **along the nonhomogeneous Josephson junction.** y-coordinate is in the units of the ferromagnetic coherence length ξ_F. The temperature T=0.1T_C, the exchange magnetic energy E=25πT_C, γ_{B1}=1,

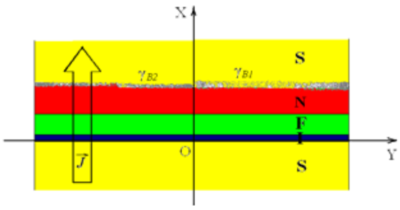
Dependence of the critical current of the junction on external magnetic field

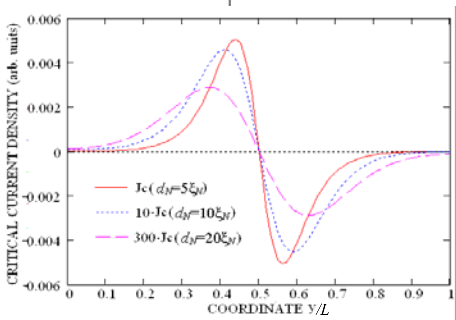




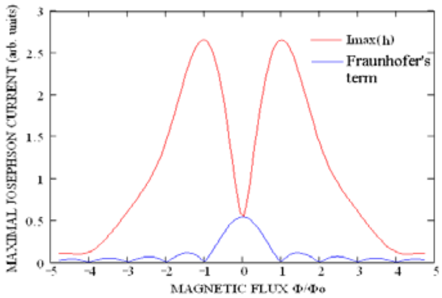
The junction critical current (in the units of $\pi T/eR$) **as a function of the external magnetic field near the point of 0- π transition at various S/F boundary damping parameter γ_{B2} .**
Two different scales (small and extra large field).
The temperature is T=0.1T_C, the exchange magnetic energy is E=25πT_C

SIFNS Josephson junction with the additional normal metal layer



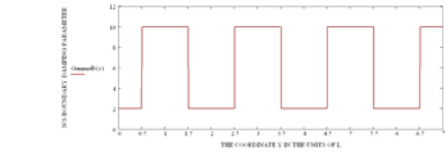


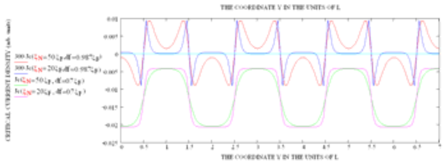
The critical current density distribution along the junction has the other scale, much longer than in SIFS. The scale depends on ξ_N. It is a consequence of the proximity effect. The junction length L=3000 ξ_F



Maximal Josephson current through the junction (in the units of $2\pi T/eR$) **vs. the magnetic flux** (in the units of Φ_0) in the vicinity of 0-π transition

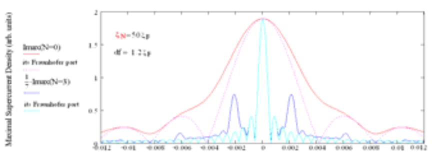
SIFNS junction with periodically changed transparency of N/S interface



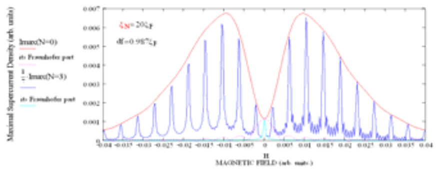


Critical current density at various values of ξ_N in the vicinity and far from 0-π transition

Far from 0- π transition



near 0- π transition



The maximal current through the junction as a function of the external magnetic field for 1 and 3.5 steps of N/S boundary transparency.

Conclusions

The boundary inhomogeneity inside the Josephson junctions with ferromagnetic weak link leads to inhomogeneous distribution of the critical current density along the junction.

It may yield to a formation of a nonuniform mini-contact inside the structure in the vicinity of the point of their 0-π transition. Characteristic scale of this object is of the order of coherence length ξ_F or ξ_N depending on the type of the structure.

It seems to be technologically possible to create an array of junctions with periodically step-like changes of the boundary transparency between their layers due to big scale of critical current inhomogeneity.

The dependence of the maximal Josephson current on external magnetic field for these structures is essentially different from the Fraunhofer pattern typically observed in usual Josephson junctions.

These structures would be used for the creation of sensitive magnetic sensors or superconducting filters.

Some literature:

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