MOTIVATION

To understand the physics of Transition-Edge Sensors made of normal metal – superconductor (NS) bilayers. To quantitatively characterize the interface transport parameters of NS bilayers by fitting experimental data of Ir/Au to a transition temperature calculation model.

APPROACH

The $T_C$ of an NS bilayer can be calculated with the equations (1) – (4) below (Wang et al., IEEE Trans. on Appl. Supercon., 27, 2100405 (2017)):

$$\ln \left( \frac{T_C}{T_{CS}} \right) = -\int_0^{\hbar \omega_D} \frac{dE}{E} f_A \tanh \left( \frac{E}{2k_B T_C} \right)$$   \hspace{1cm} (1)

$$f_A = \frac{f_1}{1 + f_2}$$   \hspace{1cm} (2)

$$f_1 = \frac{1 + \frac{\hbar^2}{(2\pi)^2} \frac{d\rho}{d\omega} \lambda_T^2}{1 + \frac{\hbar^2}{(2\pi)^2} \frac{d\rho}{d\omega} \lambda_T^2}$$   \hspace{1cm} (3)

$$f_2 = \frac{1 + \frac{\hbar^2}{(2\pi)^2} \frac{d\rho}{d\omega} \lambda_T^2}{1 + \frac{\hbar^2}{(2\pi)^2} \frac{d\rho}{d\omega} \lambda_T^2}$$   \hspace{1cm} (4)

where $T_{CS}$ is the transition temperature of a bare superconducting film, $\hbar \omega_D$ is the Debye cutoff energy, $\tau$ is the electron spin relaxation time in the normal metal ($\tau = \infty$ for Au), $d_N, d_S$ are the thicknesses of the normal metal and superconductor respectively, $N_{NS}$ are the densities of states of normal metal and superconductor respectively. The parameter characterizing the transport properties of an NS interface is $a_\perp$ in equation (4). It is related to the specific interface resistance $R_b$ of an NS interface, i.e., $a_\perp = 4m^2 \ln^2 Z$ with $G = e^2 / h$.

The temperature-dependent specific interface resistance is $R_b(T) = F^* d\rho / 2 + 1 / hNS$, where $F^*$ is the quasiparticle injection efficiency, which is defined in the BTK model (Blonder et al., Phys. Rev. B, 25, 4515, (1982)). The first term on the right is due to charge imbalance (M. Tinkham and J. Clarke, Phys. Rev. Lett., 28, 1966, (1972)). The tunneling conductance of an NS interface is

$$g_{NS} = g_0 \frac{e^2}{\hbar} \left( \frac{d\rho}{d\omega} \right) \left( 2A(E) + C(E) + D(E) \right) dE,$$   \hspace{1cm} (5)

where the tunneling conductance constant $g_0 = 2N_se^2V_F$, $V_F$ is Fermi velocity. $f_0$ is electron distribution function at equilibrium. $A$, $C$ and $D$ are summarized in the BTK model, and contain a hidden parameter, $Z = H / (h V_F)$ which characterizes the NS interface barrier strength $H$.

RESULTS

Model vs. experiment of the reduced transition temperature $T_C / T_{CS}$ of Ir/Au bilayers. $T_{CS}$ is the transition temperature of the bare Ir films. Experimental data are from Nagel et al., J. Appl. Phys., 110, 063919, (1994). Blue circles are the best fit results with reduced $\chi^2 = 0.95$ using temperature-independent $R_b$. The red squares are the best fit results with reduced $\chi^2 = 0.78$ using temperature-dependent $R_b$. The red line is for visual guide.

The specific interface resistances of Ir/Au bilayers estimated by fitting measured $T_C$ to its calculation model. The blue circles are for the temperature-independent $R_b = 0.82 \Omega m^2$ obtained from a least $\chi^2$ fit. The red triangles are for the temperature-dependent $R_b$ obtained from a least $\chi^2$ fit with two contributions: charge imbalance; and BTK tunneling model with $g_0 = 635.1 T S / m^2$, and $Z = 0.02$, which means a metallic contact between the Ir film and the Au film.