Thickness dependence of critical temperature in Mo/Au bilayers

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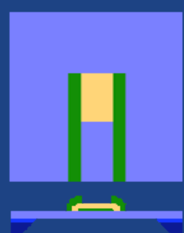
ABSTRACT

We report on the sensitivity of the superconducting critical temperature (T_C) to layer thickness, as well as on T_C reproducibility in Mo/Au bilayers. Resistivity measurements on samples with a fixed Au thickness (d_{Au}) and Mo thickness (d_{Mo}) ranging from 50 to 250 nm, and with a fixed d_{Mo} and different d_{Au} thickness are shown. Experimental data are discussed in the framework of Martinis model, whose application to samples with d_{Au} above their coherence length is analysed in detail. Results show a good coupling between normal and superconducting layers and excellent T_C reproducibility, allowing to accurately correlate Mo layer thickness and bilayer T_C.

FABRICATION PROCESS

- High quality, strain-free Mo layers are deposited by RF sputtering at Room Temperature in an UHV chamber on LPCVD Si_3N_4 layers deposited on Si (100) single crystal substrates.
- Protective Au layers of 15 nm are deposited insitu by DC sputtering
- The total Au thickness is obtained by ex situ electron beam evaporation of a second Au layer in another UHV chamber
- Further details can be found in References [1,2]



Schematic layout (not to scale) of a lithographed bilayer showing top view of the device and a cross section through the central point

MARTINIS MODEL

One of the main problems in achieving T_C reproducibility in the Mo/Au system is to control the quality of the interface ➔ this quality can be checked through the Martinis model [3].

This model predicts T_C from simple physical parameters: superconducting layer thickness, d_S, normal metal layer thickness, d_M, and the quality of the interface, represented by a transmission parameter, t, ranging from 0 to 1.

For arbitrary thick layers:

$$T_C = T_{C0}\left[\frac{d_S}{d_0}\frac{1}{1.13(1+1/b)}\frac{1}{t'}\right]^b$$

$$\frac{1}{d_0} = \frac{\pi}{2}k_B T_{C0}\lambda_f^2 n_S$$

$$b = d_M n_M / d_S n_S$$

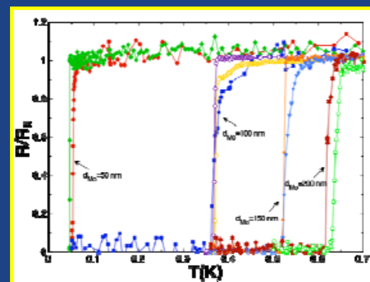
Eq. 1

$$\frac{1}{t'} \rightarrow \frac{1}{t} + \frac{1}{3}\left(\frac{d_S}{0.013\mu m}\frac{\rho_S}{\rho_{S0}} + \frac{d_M}{0.084\mu m}\frac{\rho_M}{\rho_{M0}}\right)$$

Problem: This model does not reproduce the expected T_C saturation for $d_M > \xi_M$[4]

BILAYER CRITICAL TEMPERATURE AS A FUNCTION OF d_{MO}

- Bilayers with normal metal layer thickness of d_{Au}=215 and 115 nm and variable superconducting thickness, d_{Mo}, are fabricated.
- Excellent T_C reproducibility ($\Delta T_C \approx 20$ mK) which allow accurate determination of T_C as a function of d_{Mo}
- No change in T_C is observed when d_{Au} is increased between 115 nm and 215 nm ➔ $\xi_{Au} \leq 115$ nm.



R(T) curves of some of the studied samples. Bold symbols represent samples with d_{Au}=215 nm, while empty symbols are used for bilayers covered by d_{Au}=115 nm.

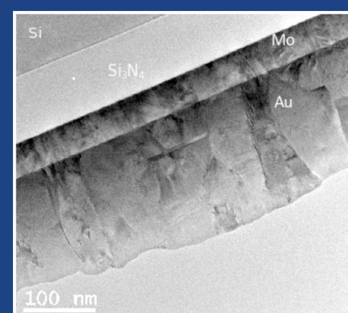
ξ_M can be estimated as [5]:

$$\xi_M = \sqrt{\frac{h v_M^f l_M}{6\pi k_B T_S}}$$

Au grain size is governed by the Mo one [5]➔l_M can be estimated as ~20 nm [1]

$\xi_M \sim 107$ nm

When fitting experimental data to Eq. 1 different interface transparency values are found for d_{Au}= 115 nm and 215 nm: t decreases as d_{Au} increases



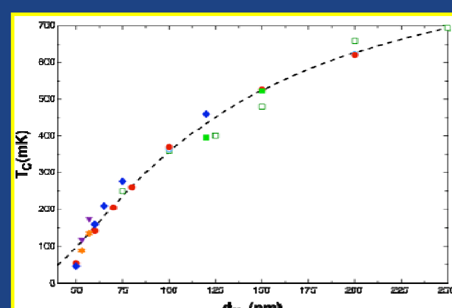
Cross section TEM image of a 50/200 nm Mo/Au bilayer

HRXTEM images show changes neither in interface nor in grain size as a function of Au layer thickness ➔ the necessary change in t that has to be introduced in (1) to fit experimental data has no physical meaning. This indicates that some assumption have to be done in order to validate the model for thick films.

Since the Au thickness above ξ_M is not influencing T_C, to used Eq.1 in bilayers of arbitrary thickness we propose that Martinis Eq. can be used when **$d_{Au} > \xi_M$** simply by substituting **d_{Au}** by **ξ_M**

Under this assumption, a unique fit to $T_C(d_{Mo})$ and a unique t value can be obtained for different **d_{Au}** :

$t \sim 0.45 \pm 0.08$



T_C of Mo/Au bilayer as a function of the superconductor thickness for a normal metal thickness of 115 nm (empty symbols) and 215 nm (full symbols). Each symbol corresponds to a set of bilayers. Dash line correspond to the fitting of the data to Eq. 1.

Our samples are extremely reproducible, and display and excellent coupling between the involved layers.

Conclusions

- Fabricated Mo/Au thermometers display excellent coupling, T_C and reproducibility.
- To avoid an underestimation of the transparency factor, only the *"active"* metal thickness ($d_{Au}=\xi_M$) has to be considered.
- For thick layers ($d_M \geq \xi_M$) The following constrain $d_{Au}=\xi_M$ has to be applied in order to apply the model developed by Martinis et al.[3].
- Since $d_M \geq \xi_M$, R_N can be tunned through variations of d_M without affecting T_C

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