Pseudogap effects on the ferromagnetic transition of \( \text{YBa}_2\text{Cu}_3\text{O}_y \) and \( \text{SrRuO}_3 \) bilayers

or

Do pre-formed pairs exist above \( T_c \) ?

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Outline

- Background - the pseudogap and the pre-formed pairs scenario
- Motivation & Methodology of how to design the experiment
- Results and discussion
- Conclusions
$T^*$ from $R$ vs. $T$ measurements


Wuyts, Moshchalkov, and Bruynseraede PRB, 53 9418 (1996)
$T^*$ on the phase diagram
Motivation

To look for a signature of pre-formed pairs via a proximity effect in S/F bilayers of YBa$_2$Cu$_3$O$_y$/SrRuO$_3$ where the YBCO is in the pseudogap regime.

Standard PE:  \( \text{For } T < T_c \)

PG/F PE:  \( \text{For } T_c < T < T^* \)

Where  \( F \) is the probe.
As the ferromagnetic layer (F) we chose SrRuO₃ (the “probe”)

![Graph showing a plot of dR/dT vs. T (K) and R vs. T (K) with data points labeled 5nm SRO and BLR1004, with SRO symbol indicated.](image-url)
Show the $dR/dT$ relation to $dM/dT$ & sensitivity issues

![Graph showing $dR/dT$ and $|dM/dT|$ for $T_p = 144K$](image)

- $dR/dT$ (Ω/K)
- $|dM/dT|*10^6$ (A m$^2$)
- $T_p = 144K$

200 nm SRO film

<Z-Moment> (A m$^2$)
Preparation of the bilayers and reference films

10nm c-axis YBCO

5 nm SrRuO$_3$

(100) SrTiO$_3$
Preparation of a bilayer and its reference film on the same wafer by the use of a shadow mask

10nm c-axis YBCO

5 nm SrRuO$_3$

(100) SrTiO$_3$
Simple patterning & contacts config.
Where did we work on the P.D. and why?

For YBa$_2$Cu$_3$O$_y$:

- For the $T_C = 30$ K phase
- For the $T_C = 60$ K phase
- For the $T_C = 90$ K phase

$T_{Curie}$ of SrRuO$_3$ is 150 K

$T^* \approx 230$ K

$T^* \approx 180$ K

$T^* \approx 110$ K
Results at different doping levels

data on 10x10 mm$^2$ films

- 5nm SRO
- 7.5nm c-axis YBCO / 5nm SRO / (100) STO
  - □ Bilayer 30K
  - △ Bilayer 60K
  - ◄ Bilayer 90K
**Temperature derivatives of the Resistance**

A 7.5 nm thick YBCO layer is too thin to shift the $T_p$ of SRO
10nm YBCO on 5nm SRO

Test the contributions of the separate layers
And the interaction between them

$pseudogap$

$T^* \sim 170 - 200 \, K$

$dR/dT \, (\Omega / K)$

5 nm SRO

10 nm YBCO

norm. calculated BL

norm. measured BL
A large $T_p$ shift when the YBCO is at 30 & 60 K

The 90 K phase peak is too broad and small to determine $T_p$. But we have better data.
A BL & a reference layer on the same wafer

![Graph showing normalized dR/dT vs. T (K)]

- Are the conjectured preformed pairs injected into the SRO layer lowering its $T_p$?
Control experiments in BL with cuprates out of the pseudogap regime ($T^*<120$ K)

- No shift of $T_p$ for both YBCO & LSCO in this case

No effect by the injection of normal electrons from the SC above $T^*$ into the SRO
A control experiment in a bilayer with an antiferromagnet (Cr)
10 nm Cr/ 5 nm SRO

1. Injection of electrons with opposite spins into the SRO leads to only a 2 K shift down of $T_p$

2. An inverse PE can lead to loss of itinerant electrons in the SRO, thus lowering its $T_p$
Comparison of the main results

• Large $T_p$ shifts – only when the YBCO is in the PG regime!
• A small $T_p$ shift – by injection of electrons with opposite spins
• Thus only the injection of correlated electrons with zero spin yields a large effect – these might be the preformed pairs
Conclusions

• Large Tp shifts – necessitates correlated electrons injection

• This is consistent with the preformed pairs scenario, but is not a definitive proof of their existence

• But...

• If it looks like a duck, sounds like a duck and walks like a duck, it is a duck!!