Doping evolution of the Cooper pairs density in cuprates

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Electronic Raman Scattering (ERS) in metals

Raman shift: $\omega_R = \omega_i - \omega_s$

Transfered momentum: $Q = k_i - k_s$

$\Delta Q \approx \frac{1}{l_m} \quad \rightarrow \quad \Delta \omega_R = \frac{\hbar}{\tau}$
ERS in Superconductors

- \((u_k v_k)^2\) condensation probability of the Cooper Pairs (de Gennes, Superconductivity of metals and Alloys, 66)

- \(\sum_{k} (u_k v_k)^2\) density of Cooper Pairs around \(E_F\) (Legett, Quantum Liquids in Condensed Matter systems, 2006)
ERS is a momentum probe

Real space

K-space

AN

\( \pi \), 0

« axes of the BZ »

\( \pi \), \( \pi \)

« diagonal of the BZ »

B\(_{1g}\)

B\(_{2g}\)

d-wave gap

\( \chi''(\omega) \)  arb.units

\( \omega \)

\( \omega \)/2\( \Delta_0 \)

A- Nodal

\( \Delta_{AN}/\Delta_N = 1.2 \)

Nodal

\( \Delta_{AN}/\Delta_N = 1.2 \)

\( \Delta_{AN}/\Delta_N = 1.2 \)
Our objective is to define the evolution of the nb of Cooper pairs in the Nodal and A-Nodal regions with doping. Absolute Raman measurements in order to quantitatively evaluate the changes of the area under the SC peak for each doping level.
Absolute Raman measurements

- Easily cleaved
- Large homogeneous surface (mm²)
- Optical constants (ellipsometry)

Bi-2212

\[ T_{\text{max}}^c = 92 \text{ K} \]

G. Gu, BNL, USA

S. Blanc et al., 09

Change in intensity less than 5% for two samples with the same doping level
Intrinsic ERS spectra vs doping level

S. Blanc et al. Submitted to PRL 2009
Density of mobile pairs vanishes at $T_c$

$\chi''(\omega)$ (cts/s.mW) vs Raman Shift (cm$^{-1}$)

Normalized area vs Temperature $T/T_c$

S. Blanc, not yet published, 09
SC gap and pseudo gap

W. Guyard et al. 2008, not yet published
SC and PS gaps

ERS

STM

W. Guyard et al. not yet published, 09

C. Renner et al. PRL 98
Over-doped

Under-doped

FT-STS: Bogolubov arcs

ARPES: coherent spectral weight

Y. Khosaka et al. Nature 454, 08
A. Pushp et al. Science DOI: 10.1126/science.1174338

T. Kondo et al. Nature 457, 09
$\Delta_N$ and $\Delta_{AN}$ vs $T$

$\Delta_N(T) / \Delta_N(10 \, K)$

$T / T_c$

W. Guyard PRL 101, 097003 (08)  
W. Guyard et al. PRB 77, 24524, 2008
Depletion of Cooper Pairs at the A-Nodes with underdoping

Concomitant with the temperature deviation of the A-Nodal peak from the BCS behaviour

Concomitant with the appearance of two energy scales with underdoping

What is the origin of the 2 energy scales detected in SC? Fermi arcs or Fermi pockets?