Mapping the electronic structure of each ingredient oxide layer of high-$T_c$ cuprate superconductors

Can-Li Song (宋灿立)

Department of Physics, Tsinghua University

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Bi-2201 samples: Lin Zhao, Xing-Jiang Zhou...

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High-$T_c$ Cuprate Superconductors

Unsolved issues of high-$T_c$ superconductors:

1) Electron pairing mechanism: spin fluctuation?

2) Various sorts of charge orders and their interplay with superconductivity?

3) The nature of non-Fermi liquid behavior (strange metal)?

4) Pseudogap and its connection with superconductivity as well as broken-symmetry states?
Pseudogap of Cuprates by STM

Renner, PRL 80, 149 (1998)

Nakano, JPSJ 67, 2622 (1998)

Spectral depletion at $E_F$ above $T_c$

$T^*$ versus $p$: linear behavior

$T_c$ versus $p$: dome-shaped behavior
Possible Origin for Pseudogap

1) Precursor pairing

2) A non superconducting related pseudogap, e.g. various broken-symmetry states

- Checkerboard

- Fluctuating Stripes
  - Parker, Nature 468, 677 (2010)

- Static Striped DOS

- CDW

- Electronic cluster glass

- “Nematic” and “Smectic”
Challenges and Opportunity

◆ Strongly correlated electron systems

◆ Structural complexity
  Superconducting CuO$_2$ layer, charge reservoir building layer (for example, BiO/SrO in Bi-2212)

◆ Unattainable CuO$_2$ layers
  Surface-sensitive measurements on the vacuum cleaved BiO planes: the properties of superconducting CuO$_2$ planes?

Possible path to address the challenges

Atomic-layer-resolved spectral study of cuprates

Argon-ion sputtering and annealing (IBA)
MBE + LT STM/STS + magnetic field + IBA

A precise control of growth flux

Metal sources (99.999%) :
evaporated from standard Knudsen cells

STM/STS: 0.4 K, 4.3 K, 78K
Magnetic field: 11 T
Vacuum: 5x10^{-11} Torr

Ozone-assisted MBE

To MBE

Ozone system
(Fermi Instruments)
Increasing IBA cycles

Deeper and deeper atomic layers of Bi-2212 are exposed with increasing IBA.
STS spectra on as-sputtered Bi-2212

- Contrasting spectral feature between BiO and CuO$_2$
- A substantial loss of near-surface oxygen dopants during IBA
- Asymmetric gap of CuO$_2$ planes, neither superconducting gap nor pseudogap

Misra, PRL. 89, 087002 (2002)
Post-anneal under Ozone Flux

A precise control of oxygen stoichiometry!
Atomic-Layer-Resolved Spectra of Bi-2212

BiO(I)

Single dominant pseudogap

Sample bias (meV)

dl/dV (arb. units)

Bi Sr Cu Ca O
Atomic-Layer-Resolved Spectra of Bi-2212

SrO(I)

![Diagram showing SrO(I) and Van Hove singularity](image)

Sample bias (meV)

Van Hove singularity
Atomic-Layer-Resolved Spectra of Bi-2212

Robust VHS on SrO planes!
Atomic-Layer-Resolved Spectra of Bi-2212

CuO$_2$(I)

Two-gap spectral feature
Atomic-Layer-Resolved Spectra of Bi-2212

CuO$_2$(II)

Two-gap spectral feature
Atomic-Layer-Resolved Spectra of Bi-2212

BiO(II)

Single dominant pseudogap again
Pseudogap: a property of BiO

Pseudogap on MBE-grown BiO$_x$ islands
Robust two-gap feature on CuO$_2$

The smaller gap becomes invisible near $T_c$

$\Delta$ follows a dome-shaped behavior, like $T_c$

$2\Delta/k_B T_c = 3.8 \pm 1.0$

Preparation and direct measurements of CuO$_2$ Superconducting layers are so essential!!!
$d$-wave Pseudogap in Noncuprate Compounds

La$_{1.2}$Sr$_{1.8}$Mn$_2$O$_7$ manganites

Meatllic nickelate R$_{2-x}$SrNiO$_4$ (R=Nd, Eu)

Fermi arc and $d$-wave gap are not unique to cuprates


Uchida, PRL 106, 027001 (2011)
Summary and Perspective

- Atomic-layer-resolved electronic structures of cuprates

Pseudogap and VHS: possibly a property of oxygen-doped oxides
Real superconducting gap in CuO$_2$ layer
SrO/BiO: VHS and acts carrier reservoir for CuO$_2$

- Bottom-Up (MBE) & Top-Down (IBA) strategies

Thank You Very Much!