High-$T_c$ Superconductors – $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$

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Superconductors

Important Critical Properties:

- $T_c$ (Temperature)
- $H_c$ (Magnetic Field)
- $j_c$ (Current)
- Dependent on coherence length and penetration depth

Meissner Effect: perfect diamagnetism repels external magnetic fields

Zero DC electrical resistivity

Superconductor

Normal metal

Neutral defects

Phonons

$T_c$
Applications

• Maglev technology (transportation)
• High-powered magnets (accelerators, NMR, MRI, etc.)
• Resistance-less wires (highly efficient cables)
• Electronic devices (heavy current industry)
Material – Bi2212

- $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_{8+\delta}$
- Superconductor
  - Ceramic
  - High $T_c$ (~93K)
  - Type II
  - 2D superconductivity (CuO$_2$ layers)
- Doped with Pb and Y to control hole concentration
  - My (first) sample: $(\text{Bi}_{1.7}\text{Pb}_{0.4})(\text{Ca}_{0.95}\text{Y}_{0.05})\text{Cu}_2\text{O}_{8+\delta}$

Unit Cell of Bi2212 -
- $a=5.411(0)$ Å
- $b=5.384(5)$ Å
- $c=30.7799$ Å
Research Goals

• Create high quality, single crystal samples of Bi2212 usable for ARPES (Angle Resolved PhotoEmission Spectroscopy) measurement to investigate superconducting gap and pseudogap
Plan

• Produce Bi2212 powder
• Check purity (powder XRD)
• Grow single crystal
• Check alignment (Laue XRD)
• Analyze via
  • PPMS (resistivity, Seebeck coefficient, specific heat, magnetic susceptibility)
  • ARPES (k vs. E)
  • TEM (crystallinity, chemical analysis)
  • etc.

3 main phases of material – Bi-2201, Bi-2212, Bi-2223, respectively
Process – “Just Like Baking”

Raw Materials (Heavy Metal Oxides/Carbonates) → Dry (24h) and Mix → Grind and Decarboxylate (24h) → Grind and Heat (72h) → Take XRD

- High Purity?
  - Yes: Grow Single Crystal
  - No: Mix and Heat at Higher Temperature (72h)

Analysis (XRD, PPMS, ARPES, TEM, etc.)
XRD Data

- Shows appearance of characteristic Bi2212 (desired) peaks with increasing temperature
- Good sign that desired product was obtained and that purity is high
Plan

• Produce Bi2212 powder
• Check purity (XRD)
• Prepare single crystal
• Check alignment (XRD)
• Analyze via
  • PPMS (resistivity, Seebeck coefficient, specific heat, magnetic susceptibility)
  • ARPES (k vs. E)
  • TEM (crystallinity, chemical analysis)
  • etc.

3 main phases of material – Bi-2201, Bi-2212, Bi-2223, respectively
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References (Images)

1. http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/coop.html
5. Dr. Robert Sobota
Some definitely not staged photos of Dr. Sobota and I working with the floating zone furnace, PPMS, and TEM, respectively

Questions?
Origin of Superconductivity: Cooper Pairs

- Weakly bound electrons near Fermi energy
- Give rise to superconducting state

Reference 1
Reference 2, Tohoku University
Pseudogap – Mechanism Unknown!

- Found in cuprate superconductors
- Decreases density of states near Fermi energy (where Cooper pairs are formed)
- Competes with superconducting state -> decreases $T_c$

Pseudogap

Vishik et. al., *New Journal of Physics*, 2010