$YBa_2Cu_3O_{6+\delta}$: From Synthesis to Spectroscopy

An Interdisciplinary Approach to Research in High-Temperature Superconductivity

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Ongoing motivation for the investigation of YBCO: a material that has been discovered 30 years ago

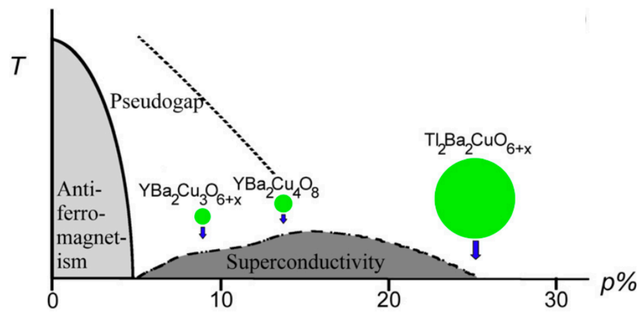
1991: Discovery of superconductivity by *H. Kamerlingh Onnes*
1986: Discovery of high-T_c superconductivity in cuprates by *G. Bednorz* and *K. A. Müller* (NP 1987)

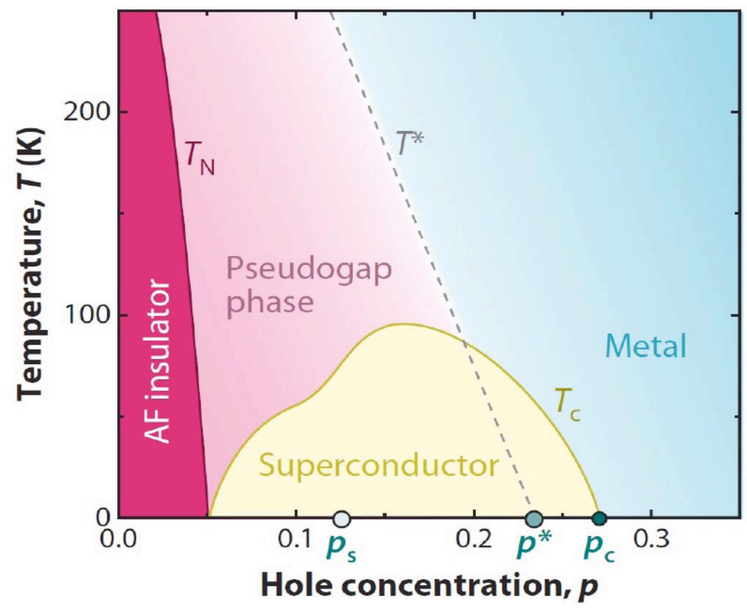
- The electronic structure of $YBa_2Cu_3O_{6+\delta}$ has been heavily debated for decades
- Much remains unclear in the understanding of its phase diagram.

→ Pseudogap Phase
- Precursor to hidden ordered state with broken symmetry?
- Precursor to Mott insulator?

→ Fermi surface reconstruction
- Large in overdoped regime
- Small in underdoped regime

What are the causes of the reconstruction and what is its implication on high-T_c superconductivity? [1, 2]



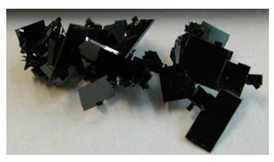


Timeline and milestones

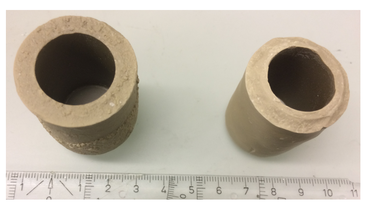
3 major steps:
(1) Self-flux crystal growth in crucibles (2) Removal of twins (3) Annealing in order to obtain specific doping

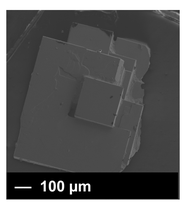
Crystal Growth

- Best quality single crystals: self–flux method. SM: Y_2O_3 and a BaO–CuO melt
- Crucible material: $BaZrO_3$ or ZrO_2 crucibles. [3]



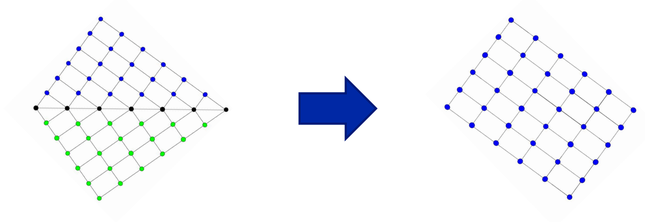
Current status
- Crystal growth of high-quality YBCO in ZrO_2 crucibles.
- Fabrication of $BaZrO_3$ crucibles.





Detwinning

- YBCO has orthorhombic structure → formation of structural domains "twinned"
- Detwinning procedure removes domain → monodomain sample "detwinned"
- Application of uniaxial pressure → 143 MPa at 250°C [4]

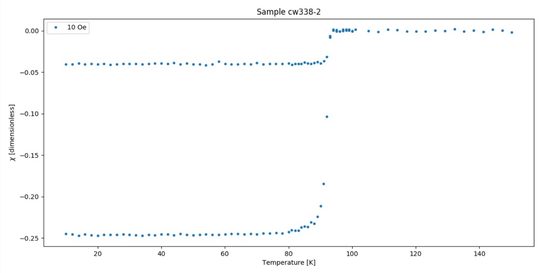


Annealing

Superconductivity in YBCO emerges in the underdoped and optimally doped regimes

Oxygen annealing:
- control of the hole doping
- post crystal growth.

The exact hole doping can be verified by the Tc (SQUID) and the change of the unit cell parameter *c* (SXRD). [5]



End Product

- Desired doping through annealing
- Twinned or detwinned

ARPES (Angle–resolved Photoemission Spectroscopy)

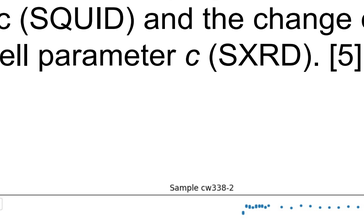
- Detailed information on band dispersion and Fermi surface
- Detection and measurement of the emitted photoelectrons at different emission angles

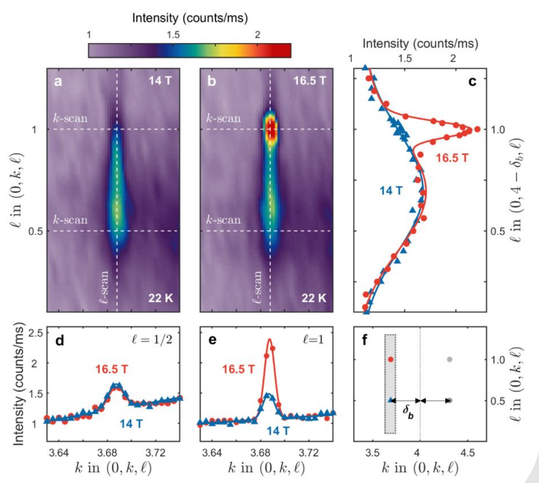
Research in YBCO:
Get an understanding of the Fermi surface reconstruction through the study of the three-dimensional electronic structure at different doping levels

X-Ray Diffraction

- Working principle based on Braggs law : $2d \sin\vartheta = n\lambda$
- Direct measurement of the structure

Research in YBCO:
Detection of charge density waves induced by field [5] and pressure [6]





Conclusion and outlook

The synthesis of high quality (pure and homogenous) single crystals is the crucial step for fundamental studies on the mechanism of superconductivity.
We have successfully grown and detwinned high purity singe crystals of optimally doped YBCO in ZrO_2 crucibles and will proceed with the growth in homemade $BaZrO_3$ crucibles. In a next step, we will tackle the annealing to obtain crystals in the underdoped regime. Meanwhile, spectroscopy experiments are in planning for 2020.

References

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[2] M. Horio *et al*., Phys. Rev. Lett. 2018, 121.
[3] R. Liang, D. Bonn, W. N. Hardy, *Phys. C Supercond.* 2000, *336*, 57–62.
[4] S. Jöhr, J, Chang, Bachelor Thesis, 2018
[5] R. Liang, D. A. Bonn, W. N. Hardy, Phys. Rev. B 2006, 73, 180505.
[6] J. Choi et al., arXiv:1909.09359 [cond-mat], 2019
[7] H. Kim et al., Science, 362, 6418, p1040, 2018