Interplay of Superconductivity and Magnetism in Oxy-Chalcogen Cuprates $\text{YBaSrCu}_3\text{O}_x\text{Se}_y$

Armen Gulian, presenter

*Chapman University, Institute for Quantum Studies, Advanced Physics Laboratory, Burtonsville, MD 20866, USA*

Vahan Nikoghosyan

*Chapman University, Institute for Quantum Studies, Advanced Physics Laboratory, Burtonsville, MD 20866, USA*

Also: *Physics Research Institute, National Academy of Sciences, Ashtarak, 0203, Armenia*

Vadim Grinenko

*Leibniz Institute IFW-Dresden, PF 270116, Dresden D-01171, Germany*
Motivation:

Belief:
Exploration of the oxychalcogens is a valuable step towards testing the proposed theories of HTSC


Intention:
Replace in YBa$_2$Cu$_3$O$_7$ superconductors:
1) one atom of Ba by Sr
2) one oxygen atom by Se.

Outcome:
This double substitution results in:
1. two SC transitions: at 34K and 18K;
2. the re-entrant Wohlleben effect;
3. setting up of ferromagnetic interaction at 4K.
Standard Synthesis Routes

$\text{Y}_2\text{O}_3$, SrCO$_3$, BaCO$_3$, and SrSe in stoichiometric proportions for YBaSrCu$_3$O$_x$Se composition.
Calcinating at 900$^\circ$C for 100 min.
Re-grinding, pelletizing, baking at 950$^\circ$C for 30 min. Continued at 650$^\circ$C for 80 minutes.
Initial Findings: Doubly Re-entrant Magnetization

While resistive transition takes place at ~35K, diamagnetic transition which started at the same T is suppressed by the re-entrant paramagnetism at cooling down, which itself is suppressed by the re-entrant diamagnetism at further cooling down!
What is going on?

1) How many phase transitions?
2) What is causing the jumps?
3) Any effect on resistivity?
4) Crystalline structure
5) Composition
Surface morphology and Structure

[Graphs and images showing surface morphology and structure analysis.]
Wohlleben Effect (PME)
Two SC transitions as indicated by heat capacity
Two SC phases in resistivity?

![Graph showing resistance vs. temperature with different magnetic fields and currents.](image)

- Resistance, $R$ (Ohm)
- Temperature, $T$ (K)
- Magnetic fields: $H = 5$ Oe, $H = 100$ Oe
- Currents: $I = 1$ mA, $I = 0.1$ mA, $I = 0.01$ mA
Two SC phases in resistivity?
Fitting by the Curie-Weiss law

- $\mu_{\text{eff}} \sim 2/3 \mu_B$ per Cu atom
- Enhanced correlations are responsible for magnetism.

\[
\chi = \chi_0 + C/(T - \theta_{\text{CW}}), \quad \theta_{\text{CW}} \approx 4K
\]

Other constants: $\chi_0 \approx -3 \times 10^{-4}$, $C \approx 0.5$
Various magnetic fields: $H=0$, 100 Oe, 1000 Oe

$f=3333\text{Hz}$; measurements at other frequencies yielded similar results.
Re-entrant resistive state

In some samples only
Does Se stay in composition?

TEM analysis (Hitachi-USA)
Quantitatively?
In the lattice?

Kikkuchi pattern with simultaneous EDX
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