Possible High $T_c$ Superconductivity in the Ba - La- Cu- O System

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Metallic, oxygen-deficient compounds in the Ba—La—Cu—O system, with the composition $\text{Ba}_x\text{La}_{5-x}\text{Cu}_3\text{O}_{5-\delta}$, have been prepared in polycrystalline form. Samples with $x=1$ and $0.75$, $\delta>0$, annealed below 900 °C under reducing conditions, consist of three phases, one of them a perovskite-like mixed-valent copper compound. Upon cooling, the samples show a linear decrease in resistivity, then an approximately logarithmic increase, interpreted as a beginning of localization. Finally an abrupt decrease by up to three orders of magnitude occurs, reminiscent of the onset of percolative superconductivity. The highest onset temperature is observed in the 30 K range. It is markedly reduced by high current densities. Thus, it results partially from the percolative nature, but possibly also from $2D$ superconducting fluctuations of double perovskite layers of one of the phases present.
Paper Summary

• Published in 1986

• Resulted in Nobel Prize, Awarded in 1987

• Reported Discovery of High Temperature Superconductivity
The Achievement

- Growth of BaLaCuO
- Superconducting Critical Temperature in 30 K Range
- Paved Way for Further High Temperature Superconductivity Research
Comparison to previous work: experimental

- “At the extreme forefront of research in superconductivity is the empirical search for new materials.” – Michael Tinkham

- Attempt to find high superconducting critical temperatures

**Timeline of critical temperature for superconductors**

(Courtesy: University of Cambridge)
Comparison to previous work: theoretical

- Strong electron-phonon interaction (For High $T_c$)
  Attractive interaction in BCS theory

- Mechanism for the interaction
  - Polaron formation
  - Jahn-Teller distortion
The Experiment

1. Sample Preparation and Characterization
   • Coprecipitation method oxalates
   • Heated at 900°C for 5h, pressed at 4kbar, reheat at 900°C

2. X-Ray Analysis: Three different Phases discovered
   1. Perovskite structure (K$_2$NiF$_4$)
   2. Cubic (Ba concentration)
   3. Oxygen-deficient perovskite
The Experiment

3. Conductivity Measurements

*Schematic of the four point resistivity measurement method*

Fig. 1. Temperature dependence of resistivity in $\text{Ba}_2\text{La}_{5-x}\text{Cu}_x\text{O}_{5+y}$ for samples with $x(\text{Ba})=1$ (upper curves, left scale) and $x(\text{Ba})=0.75$ (lower curve, right scale). The first two cases also show the influence of current density.
Low temperature conductivity measurements

Fig. 2. Low-temperature resistivity of samples with $x$(Ba) = 1.0, annealed at $O_2$ partial pressure of 0.2 bar (curve ①) and $0.2 \times 10^{-4}$ bar (curves ③ to ⑦).

Fig. 3. Low-temperature resistivity of a sample with $x$(Ba) = 0.75, recorded for different current densities.
Conclusions

1. Speculation: metal-to metal structural phase transition

2. The size of the superconducting grains is 100Å

3. The way the samples have been prepared seems to be of crucial importance to superconductivity
• 848 in 1987 (Nobel Prize Year)
• 1272 in 1988
• Avg. 314 Citations per year
The major players: Before 1986

Kammerlingh Onnes
1911

Walther Meissner
1933

Vitaly Ginzburg
1950

John Bardeen
1957

Leon Cooper
Robert Schrieffer
The rise of superconductivity

The diagram shows the progress in superconductivity from 1900 to 2000. Key milestones include:

- **Nov. 1986**: LaBaCuO$_4$
- **Feb. 1987**: boiling temperature of liquid helium
- **Jan. 1988**: Nb$_3$Sn
- **Jun. 1991**: BiCaSrCu$_2$O$_9$
- **Apr. 1993**: HgBaCaCuO

The diagram also indicates the boiling temperature of liquid nitrogen and the year of discovery for various superconductors.
The impact

Cover Page, Time Magazine (May 11, 1987)
The major players: After 1986

- Alexei Abrikosov (small q phonons)
- Bob Laughlin (competing phases)
- Phil Anderson (RVB; interlayer tunneling)
- Karl Mueller (bipolarons)
- Bob Schrieffer (spin bags)
- Tony Leggett (interlayer Coulomb)

(Courtesy: Michael Norman)
Current status of the theory of high temperature superconductivity

- Classic BCS theory not enough
- 2 e⁻ pairs in real space – Analogous to Cooper pairs in the BCS theory
- The pairs are d-wave \((L=2, S=0)\)
- Quasiparticles exist below \(T_c\)
- Still an open-ended problem
Thank you!

QUESTIONS?