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Short Communication

Novel Phase $YBa_2Cu_3O_5$ derived from the High Tc Superconductor $YBa_2Cu_3O_{7-x}$

Danijel Djurek*

Alessandro Volta Applied Ceramics (AVAC), 49247 Zlatar Bistrica, Augusta Šenoe 14, Croatia

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***Corresponding author:** Danijel Djurek, Alessandro Volta Applied Ceramics (AVAC), 49247 Zlatar Bistrica, Augusta Šenoe 14, Croatia, Email: danijel@avac.hr

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Abstract

The orthorhombic unit cell of high Tc oxide superconductor $YBa_2Cu_3O_{7-x}$ is indicated by two-dimensional CuO_2 planes spanned in a-b directions. Partial removal of oxygen, down to x > 1, creates an insulating state and randomly distributed oxygen vacancies. An attempt has been made to increase the concentration of vacancies up to some critical value when their ordering could take place, while balance with copper cations will still maintain the original tetragonal structure. Removal of two oxygen atoms per unit cell results in the $YBa_2Cu_3O_5$ compound and formation of linear $Cu^{1+}-O$ chains. The novel phase is an insulator, and doping in a low (50 –200 mbar) oxygen atmosphere at T < 800 K converts it to a conducting state.

Introduction

Discovery of the superconductivity (SC) at 93 K in a mixed phase $Y_{1.2}Ba_{0.8}CuO$ [1] sparked worldwide tremendous research in a good hope [2] that superconductivity at Room Temperature (RT) will be discovered in near future. Cava and co-workers [3] revealed the formula $YBa_2Cu_3O_{7-x}$ (Y–123) and orthorhombic unit cell of dimensions a = 0.3822 nm, b = 0.3891 nm and c= 1.1677 nm. The unit cell is presented in Figure 1. Cu-O planes in a-b directions exhibit (super)conductivity, while the removal of one oxygen atom per unit cell results in an insulating tetragonal compound $YBa_2Cu_3O_6$ (Y-6), indicated by oxygen vacancy disorder. Such a result leaves little space for further stoichiometric manipulations which could possibly open the road to a novel kind of metallic oxides and superconductivity [4]. However, novel metallic compounds, derived from a highly reduced Y-123, may surpass the scope of the known SC cuprates, while effects of more general importance may appear in an ordered oxygen vacancy environment balanced by linear Cu-O chains. Novel one-dimensional (1D) structures, doped in a low-pressure oxygen atmosphere, may result in spin-charge separation, an effect intensively studied by modern experimental and theoretical methods.

In this respect, it is of great importance to remove two oxygen atoms in the unit cell Y-123 and creation of the ordered 1 D phases in the novel compound $YBa_2Cu_3O_5$ (Y-5), as denoted by x-x and y-y in Figure 1.

Experiment

Y-123 powder was supplied by Sigma-Aldrich, and the structure was verified by X-Ray Diffraction (XRD). Powdered samples were pressed into pellets 8 mm in diameter and 0.8 mm - 1 mm in thickness. In order to measure electric resistance, four gold wires, 0.1 mm in diameter were introduced into the pellet. The reduction of Y-123 was performed in a home-developed device based on the Taconis effect [5] and Knudsen resonant cell (TK), as described in a previous paper [6]. The efficiency of such a device was clearly demonstrated in three cases; Y-123 decomposes to a green phase Y_2BaCuO_5 at 1213 K, but at 985 K in TK, magnesium oxide MgO, highly resistant to all reducing agents, converts to pure Mg at 886 K, CuO is reduced to copper already at 613 K.

Results and discussions

The oxygen defect in the final Y- 5 sample was evaluated by weight, and by subsequent decomposition at 673 K in a 2

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bar hydrogen atmosphere. X-Ray Diffraction (XRD) analysis reveals the tetragonal unit cell dimensions; a = 0.38605 nm and c = 1.1845 nm. Figure 2 shows XRD data: (a) the starting phase Y-123, (b) Y-5 and (c) Rietveld refinement of the Y-5 phase.

The oxygen doping of reduced Y–123 phases Y-6 and Y-5 was performed in a high-quality ceramic cell, previously filled with argon, in order to evaluate the temperature dependence of the pressure in the cell. At 1370 K cell was evacuated and possible residual ingredients were removed. The starting pressure of oxygen at RT ranged from 50 –200 mbar and absorption of 0.18 moles finishes at 980 K giving unit formula $YBa_2Cu_3O_{5.18}$, while RT resistivity was 0.07 ohm·cm. Temperature dependence of the oxygen pressure is shown in Figure 3 and it is evident an absence of absorption in the Y-6 sample.

Novel insulating compound $YBa_2Cu_3O_5$ is highly sensitive to the application of small oxygen pressures at temperatures T < 900 K, in contrast to $YBa_2Cu_3O_6$ indicated by negligible absorption rate. In this respect Y–5 may be a basis for a novel set of metallic phases with electric conductivity proceeded along the oxidized Cu^{1+}–O chains, and the result is complementary with recent theoretical and experimental achievements of many groups. Fuchs and co-workers [7] evaluated the properties of the strongly correlated spin-electron 1 D system and proposed experiments in ultra-cold atomic chains. An application of theoretical models in experiments was put forward by Shi and co-workers [8]. Experiments show that ultra-cold atoms confined to periodic potentials in one dimension [9,10] obey the Tomonaga-Luttinger liquid model and spin-charge excitations were spotted.

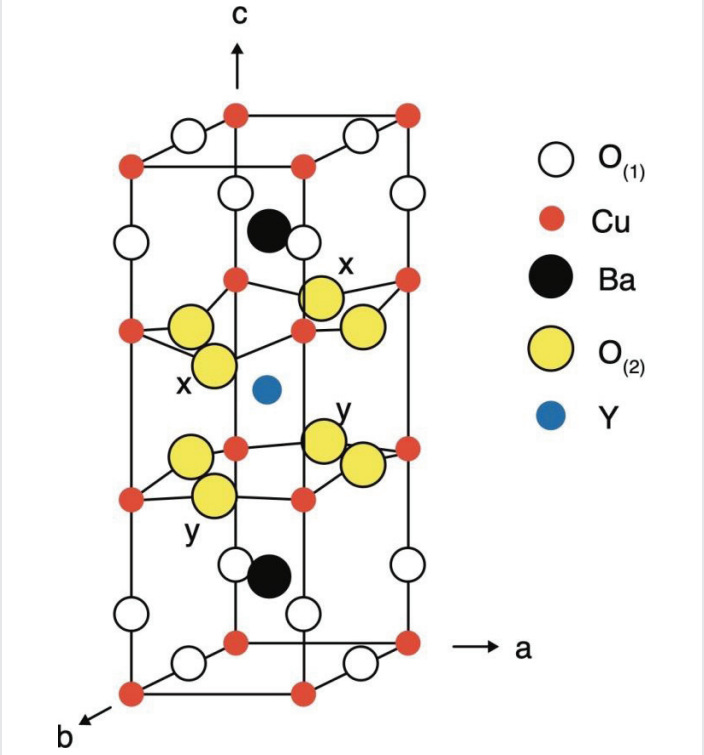

Figure 1: A unit cell of High Tc superconductor $YBa_2Cu_3O_{7-x}$.

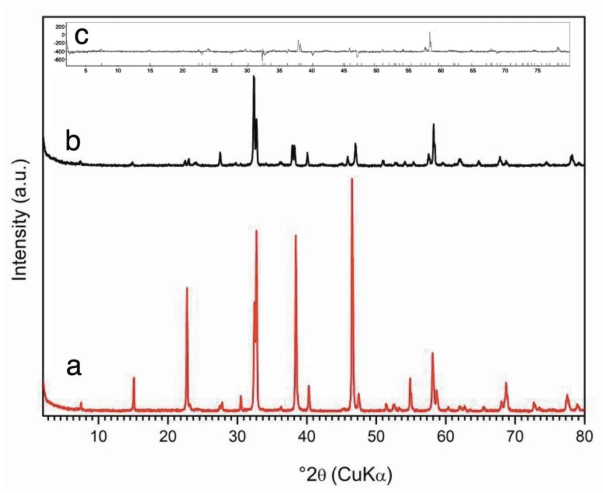

Figure 2: XRD analysis; (a) original SC phase Y-123, (b) Y-5, (c) Rietveld refinement of Y-5.

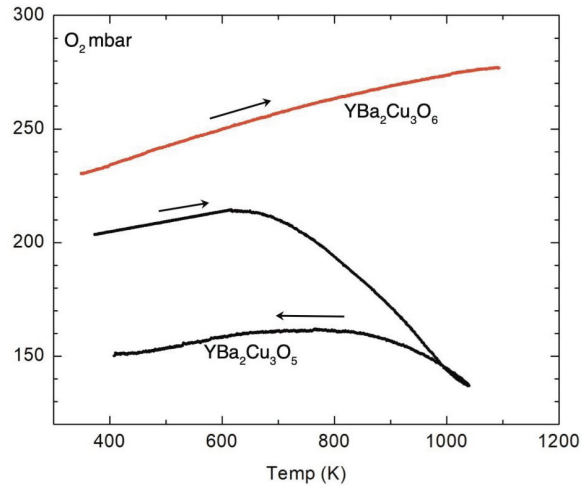

Figure 3: Temperature dependence of doping oxygen pressure in $YBa_2Cu_3O_6$ and $YBa_2Cu_3O_5$.

Conclusion

This brief review states that the removal of two oxygen atoms from the unit formula of the superconductor $YBa_2Cu_3O_{7-x}$ is possible. Also, the Y-5 compound offers a true 1 D system at ambient temperatures and provides additional opportunities for dealing with electric conductivity.

Data availability statement

Data are available on the request.

Acknowledgment

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