PHYSICAL PROPERTIES OF SUPERCONDUCTOR COMPOUNDS CONTAINING YTTRIUM

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ABSTRACT

In this work the physical properties superconductor compounds containing yttrium were investigated and the effects of these properties were examined YBCO compounds are named as 1-2-3 superconductors. High temperature superconductivity is one of the most important research areas and YBCOs are the most studied compounds in this area. The purpose of physicist is to obtain high temperature superconductors at room temperature. If this is achieved, many technologies which will ease life in many fields such as transportation and energy disposition and attach great importance to disposition may be created. Yttrium in YBCO superconductor compounds have combined CuO_2 layers in these compounds and have increased the critical temperature. However, copper and oxygen has showed superconductor properties when combined with yttrium.

Key Words: Yttrium, YBCO, Cuprate superconductor

YİTRİYUM İÇEREN SÜPERİLETKEN BİLEŞİKLERİN FİZİKSEL ÖZELLİKLERİ

ÖZET

Bu çalışmada, yitriyum içeren süperiletken bileşiklerin fiziksel özellikleri üzerinde durulmuş, yitriyumun bileşiklerdeki etkileri araştırılmıştır. YBCO bileşikleri 123 süperiletkenleri olarak adlandırılır. Yüksek sıcaklık süperiletkenliği, günümüzün önemli araştırma alanlarından birisini teşkil eder ki bu alanda en yoğun çalışılan bileşiklerin başında YBCO lar gelir. Fizikçilerin en büyük gayretleri yüksek sıcaklık süperiletkeni olarak adlandırılan bu bileşikleri oda sıcaklığında elde edebilmek üzerine yoğunlaşmıştır. Eğer bu gerçekleşirse ulaşım kolaylığı ve enerji tasarrufu

gibi birçok alanda hayatı kolaylaştıracak, tasarrufu ön planda tutacak teknolojiler üretilebilecektir. YBCO süperiletken bileşiklerindeki yitriyum, bu bileşikte yer alan bakır oksit tabakalarıyla birleşerek kritik sıcaklık değerini daha yükseğe çıkarmaktadır. Bununla birlikte, bakır ve oksijenin, yitriyumla birleşik oluşturduğunda süperiletken özellik gösterdikleri görülmüştür.

Anahtar Sözcükler: Yitriyum, YBCO, Küprat Süperiletken

1. INTRODUCTION

1.1. Yttrium in Periodic Table:

Yttrium is a transition element symbolized by the letter Y and located in the 3rd group of the periodic table with atomic number of 39 and atomic mass number of 89,906 [1]. Many compounds (or alloys) formed by yttrium have superconducting properties. Although superconducting parameters for yttrium element could not be determined in normal state, superconductivity is more under high pressure or in thin films of compounds it forms. Some of the compounds developed by yttrium may be given as follows:

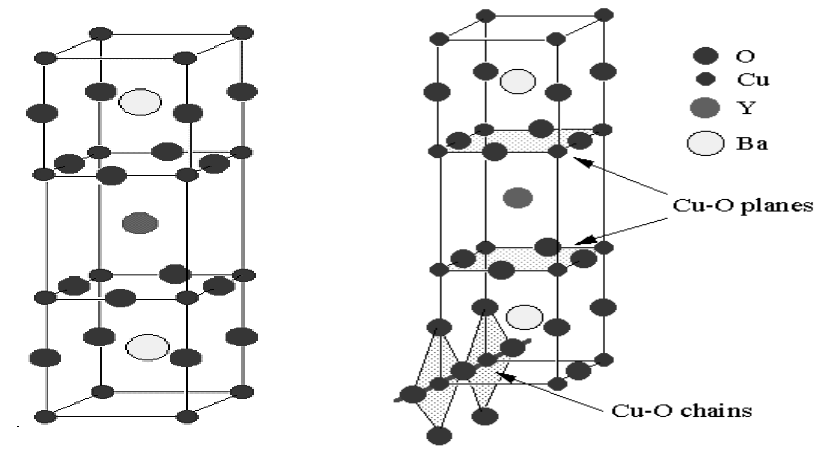
1	YBCO	9	$Y_{1-x}Ca_xBa_2Cu_4O_8$
2	$YBa_2Cu_3O_7$	10	$Y_{0,9}Ca_{0,1}Ba_2Cu_4O_8$
3	$YBa_2Cu_3O_6$	11	$Y_1Ba_1Cu_1O_5$
4	$YBa_2Cu_3O_{7-\delta}$	12	YFe_8Co_3Ti
5	$Y_1Ba_2Cu_3Cd_xO_y$	13	Y_2O_3
6	$Y_1Ba_2Cu_3O_{7-x}$	14	$Y_4Ba_3O_9$
7	$YFe_{11-x}Co_xTi$	15	$YBa_2Cu_{3,5}O_{7,5-x}$
8	$Y_1Ba_2Cu_3O_{7-\delta}$		

2. $YBa_2Cu_3O_{7-\delta}$, $YBa_2Cu_3O_7$, $YBa_2Cu_3O_6$ SUPERCONDUCTING COMPOUNDS

One of the most commonly used compounds is $YBa_2Cu_3O_{7-\delta}$ defined in short as YBCO. Here, the symbol δ represents a fraction value varying between $0 \le \delta \le 1$ [2].

YBCO is treated as 1-2-3 superconductors due to relative numbers of metal atoms in its chemical formula. Here, the yttrium atom and other trivalent atoms may replace each other. No remarkable difference is observed as a result of this change.

Upon the examination of the structure of $YBa_2Cu_3O_{7-\delta}$ compound, we may simplify the situation by the assumption that each Cu and O atoms in the crystal structure of $YBa_2Cu_3O_{7-\delta}$ are two dimensional systems of insulated CuO_2 plane. Therefore, they significantly affect the conductivity of high T_c superconductors of these planes. $YBa_2Cu_3O_{7-\delta}$ superconductors also include the chain structures formed by alternative Cu and O atoms (Figure 1) [3]. Full understanding of superconductivity properties of $YBa_2Cu_3O_{7-\delta}$ completely depends on considering its complex three-dimensional structure.



(a) (b)

Figure 1. (a) $YBa_2Cu_3O_6$ (a) and $YBa_2Cu_3O_7$ (b) crystal structures of superconductor compounds

Electric resistance of $YBa_2Cu_3O_{7-\delta}$ in normal state is anisotropic, that is to say depending on the direction. Resistance is higher when flowing towards z- direction and lower when flowing on xy- plane. This situation asserts that the conduction predominantly depends on conveyors on CuO_2 plane. It may be useful to see what happens when oxygen amount in $YBa_2Cu_3O_{7-\delta}$

compound is changed. First, $YBa_2Cu_3O_6$ compound is obtained for δ=1. Oxygen atoms on CuO chain concerning this material do not appear at all. Thus, x- direction is no different than y- direction and the crystal structure is tetragonal (a=b≠c, α=γ=90°). $YBa_2Cu_3O_6$ is electrically insulating under normal conditions. It may be accepted that CuO_2 plane in this material is approximately formed by Cu^{+2} and O^{-2} ions. Cu^{+2} ions have 9 pieces of 3d electrons on the outer shell and their total spins are ½. Cu spins have been antiferromagnetically arranged at Neel temperature just above 400 K. O^{-2} ions; on the other hand, they display no magnetic properties as their 2p orbits on the outer shells are full. Once oxygen is added in $YBa_2Cu_3O_6$ compound, the additional atoms randomly fill the regions determined as O(4) and O(5). Therefore, the structure remains as tetragonal. The added oxygen atoms act as receptor impurities in semiconductors and increase the number of holes in crystal. Some of these holes are situated on CuO_2 planes, but no conduction is observed with low concentration levels. As a result, $YBa_2Cu_3O_{7-\delta}$ is in an antiferromagnetic and insulating state when δ value equals to 0,6. Thus, there are five pieces of 2p electrons on the outer shell of oxygen atoms on CuO_2 planes and their spins are s=1/2. The settlement of holes shows that the electron-electron interaction is significant on CuO_2 planes [2]. Two important changes take place when δ value of the added oxygen comes close to 0,6 value:

1) The tetragonal symmetry of the crystal structure turns into orthorhombic (a≠b≠c, α=β=γ=90°). (a≠b≠c, α=β=γ=90°).
2) An insulating metal transition occurs.

The reasons for these changes are still unknown. The reason for the change in crystal structure is the preference of O (4) over O (5) region. Thus, the xy symmetry is broken and CuO chain starts to develop. Conduction occurs as a result of unlocalized holes. It is claimed that one of the following reasons cause this situation to happen. However, there is no certainty.

1) It occurs as a result of conduction holes passing from one oxygen atom to another.
2) It may occur in connection with the energy band occurring due to hybridization of the 3d state of copper and the 2p state of oxygen.

Metallic $YBa_2Cu_3O_{7-\delta}$ compound experiences a transition to superconductivity at an approximate level of 40 K for δ values just below 0,6. However, T_c increases as δ decreases and T_c equals to 92 K at about $\delta \approx 0,1$. But it is not possible to prepare $YBa_2Cu_3O_{7-\delta}$ material for values of δ lower than 0.1. Antiferromagnetic arrangement of Cu atoms is completely removed during the insulating metal transition. However, there is a possibility that antiferromagnetic interaction among Cu spins may have a role in transition to superconductivity [2].

$YBa_2Cu_3O_{7-\delta}$ superconductivity is basically accepted to be two-dimensional. The reason is the properties of $YBa_2Cu_3O_{7-\delta}$ which are rather anisotropic. For instance, although the critical flow is rather high when the flow is on xy-plane, it is lower at z- direction. High T_c value and small Fermi rate of $YBa_2Cu_3O_{7-\delta}$, and coherent length determining the magnitude of Cooper pair's wave function are smaller compared to sizes of unit cells. However, low conveyor density shows that the magnitude of effect is greater.

$YBa_2Cu_3O_7$ are multilayer peroxides with orthorhombic structure ($a \neq b \neq c$). There is a direct relationship between the number of copper-oxygen layers of these compounds and the critical temperature. The addition of copper-oxygen layers until the structure periodically repeats itself increases T_c. Thus, the valence of copper in CuO and CuO_2 layers and the role of chemical bond direction are being investigated [4].

There is rather much interest in mechanical processing of a superconducting oxide like $YBa_2Cu_3O_{7-\delta}$ found on wire, tape or spirals. The reason is that these types of geometries enable the production of superconductors as handy compounds.

Rounding, tension and stress processes are usually carried out by powder in tube method for manufacturing wire or tape. The use of these mechanical deformation methods is put forward when YBCO particles and the cross sectional area of friction wire between these particles and Ag atoms decrease. Mechanical deformation may be explained by means of rupture compression and ambient stress among YBCO-YBCO and YBCO-Ag pairs, and thus superconductors are expected to break. Parameters like friction coefficient, rupture toughness and hardness are important parameters as they determine the characteristics of deformation and the superconductor.

YBCO is a fragile material with microhardness of 4-10 Gpa and rupture toughness of 0,7-1,0 Mpa $m^{1/2}$. Friction coefficients of YBCO-YBCO and YBCO-Au pairs vary from 0,12 to 1 and 0,15 to 1,1 respectively which are measured by means of the ball test [5][6][7].
It was found out that the abrasion is directly proportional with the normal force in a linear way and the abrasion ratio is between the ranges 7 x 10^{-2} $mm^3N^{-1}m^{-1}$ which is measured by on-disk adhesion test. Besides, Verkin and other scientists found that friction coefficient decreases with increasing force and this value decreases from 0,3 to 0,2 for forces between 2,5 and 15 N at 273 K and from 0,1 to 0,02 for changing forces between 2,5 and 25 N at 77 K [8].

Friction coefficients of YBCO-YBCO and YBCO-Ag superconductor pairs change with the number of impacts and the related behavior may be divided into two:

1) First state (Formation with force): Friction coefficient changes with the number of impacts due to the first surface roughness, the related field and other variables. Upon examination, it is stated that the period formed by the help of force is 1500 impacts and this formation period decreases with increasing temperature.

2) Second state (Static state): Friction coefficient reaches to a constant value after some impacts and maintains this value for the rest of the study. The change in friction coefficients of YBCO-YBCO and YBCO-Ag pairs in static state is lower than 15% [7].

The basic difference in friction coefficient is humidity related to gas containing media and surface reactions. Surface films may be formed by triple chemical reactions and therefore there is a relation between the third construction material and the intermediate phase. Thus, friction coefficient of YBCO-YBCO pair decreases with increasing humidity.

YBCO may react with water at room temperature as follows:

$$3H_2O + 2YBa_2Cu_3O_7 = Y_2BaCuO_5 + 3Ba(OH)_2 + 5CuO + 1/2O_2 \qquad (1)$$

and $Ba(OH)_2$ may react with CO_2 in air in order to form carbonate.

$$Ba(OH)_2 + CO_2 = BaCO_3 + H_2O \quad (2)$$

The formation of films depends on humidity as well as temperature. The film on YBCO's surface could not be repaired after breaking due to vaporization of humidity in laboratory conditions at temperatures above 100 °C and triple chemical reactions could not maintain during the experiment. Thus, friction coefficient of YBCO-YBCO pair decreases between the room temperature and 100 °C under laboratory conditions.

Deformations generally caused by humidity and changing temperatures have been observed in silicon, silicon nitrite, silicon carbide and aluminum. Both friction coefficient and abrasion ratio decrease after the abraded debris forms round figures [9][10][11][12][13].

It was found out that the friction coefficient changes as the function of impact loops and average friction coefficient of YBCO-YBCO in static state varies between 0, 90 and 0, 26 and that of YBCO-Ag varies between 0,8 and 0,26 depending on the temperature.

Friction coefficient reaches to minimum values at 400 °C. Friction coefficient of YBCO-YBCO at room temperature under laboratory conditions changes from the maximum value to static state with a factor of 2 and shows a transition at 100 and 200 °C in humid conditions. Humidity dependent transition occurs by means of the debris abraded in the formation of cylinders [14].

Superconducting properties of yttrium are not affected much when it replaces various rare surfaced elements with high moments. Partial relocation of copper in YBCO alloys with third transition metal ions has a substantial effect on its transition properties. Cu_2O is a p-type semiconductor with 1,19 and 1,33 eV deep trap level. These trap levels occur as a result of the ionization of oxygen holes one by one or in pairs. These two trap levels disappear by doping into cadmium containing Cu_2O and hardening and cooling it at 500°C. Thus, the material shows low specific resistance. Filling oxygen holes with cadmium leads to this result [15][16].

3. $Y_1Ba_2Cu_3Cd_xO_y$ SUPERCONDUCTING COMPOUNDS

$Y_1Ba_2Cu_3Cd_xO_y$ samples displayed superconducting properties with x=0,05; 0,1; 0,2; 0,3; 0,4 and 1,0 values of Cd concentration at temperatures higher than 77 K. Upon x- ray powder diffraction measurements of samples, it was proved that samples were single-phase with values of x=0,05; 0,1 and 0,2 [15]. Samples with values of x=0,3; 0,4 and 1,0 display the single-phase and a small amount of CdO. The replacement of 1-2-3 ceramic superconductors of cadmium affects the transition temperature T_c a little. The temperature is arranged from 89K to 93,5K in the samples examined. When the results of X-ray diffraction measurements and measurements of specific resistance to temperature of $Y_1Ba_2Cu_3Cd_xO_y$ samples are compared, it is claimed that there exists a second phase for x>0,2 and the reason for that is the small amount of CdO available in samples. Thus, the critical value of x for oxygen holes filled with cadmium is x≤0,2. A more systematic study for obtaining a higher value of T_c requires cadmium concentration with x<0,1 and lower specific resistance, if possible [17].

It is well known that the Fermi level of undoped material is close to the valence band and is scattered around. The level of irregularities in doped materials increases and falls to states localized to the Fermi level, and an insulating metal transition occurs. This transition may be explained by means of thermally activated conductivity and may also be analyzed by ρ(T) specific resistance curves located in the field where semiconducting behavior exists. The mentioned conductivity is characterized by the Mott Law.

$$\rho(\exp)\ \alpha\ [(T/T_0)^{1/4}]$$

$$T_0=\lambda a^3/k\rho_0$$

T_0 stands for the characteristic temperature and a stands for a coefficient of exponential decrease of localized situations. ρ_0 is the consistency of Fermi level. λ is a nondimensional constant with an approximate value of 16 and k is the Boltzman constant.

The equation of $\rho_0=10^{21}cm^{-3}$ eV forms where localization does not occur. Only these three samples display semiconducting behavior within the temperature range of 100 K and 300 K. Low critical flows in volume materials and all well-developing thin films may be the results of poor connections among particles occurring on particle boundaries due to interactions upon the atmospheric contamination on surface porosity.

$Y_1Ba_2Cu_3Cd_xO_y$ samples showed that there are small amounts of CdO available in samples of Cd concentration formed for x=0,3; 0,4 and 1,0 values upon X-ray diffraction measurements. The surplus CdO leads to a transition from metal to insulator by becoming close to copper oxide planes and chains like the increase in x. Budhani claimed that it is not possible for a^{-1}, with an higher value than 1,6 nm, to cause deformation of plait as he only indicated the orthorhombic structure for high values of x in x-ray diffraction measurements. On the other hand, there is no indication of CdO in samples for $x \leq 0,2$ and it is also stated that T_c fills the oxygen holes of cadmium after it changes when compared to 1-2-3 undoped superconductors [15].

4. $Y_{1-x}Ca_xBa_2Cu_4O_8$ SUPERCONDUCTING COMPOUNDS

It was stated that 124 high T_c superconductor is successfully synthesized under oxygen pressure in $Y_{1-x}Ca_xBa_2Cu_4O_8$. 124 high temperature superconductor Y 124 was first discovered in the decomposition of Y 123 and as a misstructuring in inhomogeneous Y 123 thin films [18][19][20].

The first synthesis of this superconductor in body phase was performed under high oxygen pressures varying from 40 Mpa at 1040 °C to 3,5 Mpa at 930 °C [9]. This superconducting material maintains its stability in terms of thermal properties during heating up and cooling of oxygen content up to 850 °C and nonatomic tetragonal-orthorhombic phase changes are not observed while scanning Y 123 in the widest scale during the cooling process. These properties of the material make it rather attractive [21].

Therefore, no small cracks will develop upon reduction of oxygen during phase transition occurring so as not to require oxygen supply during thermal process in the production of body superconducting materials. The most important application field is believed to be copper coated superconductor wire production. Because it is no longer a necessity to provide oxygen supply in thermal processes and thus the adverse effects of copper oxidation caused by oxygen supply are eliminated [21].

5. CONCLUSION AND DISCUSSION

YBCO compounds consist of yttrium, barium, copper and oxygen, and are called (123) compounds in short. In the crystal structure of $YBa_2Cu_3O_{7-\delta}$, which is one of these types of compounds, there are CuO_2 planes formed by copper (Cu) and oxygen (O) atoms and it is observed that these planes play an important role in the conductivity of superconducting materials. Electric resistance of that kind of an alloy is anisotropic. Alteration of δ in $YBa_2Cu_3O_{7-\delta}$ compound changes the amount of oxygen.

The change in oxygen amount also changes the properties of the compound. When δ value in $YBa_2Cu_3O_{7-\delta}$ equals to 0,6, the material is an antiferromagnetic insulator. If oxygen is added to that kind of an alloy, the tetragonal symmetry of crystal structure turns into orthorhombic structure as the value of δ closes to 0,6 and an insulating metal transition occurs.

It is a well known fact that maximum values of superflows are high on copper-oxygen planes and very low at vertical directions to these planes. In fact, considering 10^{10} A/m^2 critical flows on the copper oxygen plane in $YBa_2Cu_3O_{7-\delta}$ thin films, flows in the c- direction are quite low. This means that the flow should be two dimensional. Unfortunately, flow density of voluminous ceramics is much lower due to factors like boundary effects. For instance, the critical flow density of $YBa_2Cu_3O_{7-\delta}$ samples with multi-crystal structure is between 10^5 and 10^7 A/m^2.

Superconducting properties of yttrium are not affected much by means of its replacement with various rare surfaced elements with high moments. On the other hand, partial relocation of copper in YBCO alloys with third transition metal ions has a substantial effect on its transition properties.

Transition temperature is less affected by the replacement of 1-2-3 ceramic superconductors of cadmium. This temperature is arranged form 89 K to 93,5 K.

The fact of superconductivity is also critically dependent on sintered ceramics containing oxygen. High density materials are sources for both mechanical properties and valid critical flows.

A superconducting material maintains its thermal stability during heating and cooling of oxygen content and it attracts attention as nonatomic tetragonal orthorhombic phase changes are not observed while scanning Y 123 in the widest scale during the cooling process. Therefore, there will be no need for oxygen supply during thermal process in the production of body superconductors and no cracks will develop upon reduction of oxygen during phase transition.

Friction coefficients of ceramic superconductors decrease at transition temperature as temperature increases and increases above the transition temperature as temperature increase. Friction coefficient is also dependent on surface reactions of gas containing media. Because surface humidity ratios formed by various gas containing media are different. Thus, friction coefficients change depending on the humidity [22].

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