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RESISTANCE OF HIGH-TC SUPERCONDUCTORS: REVIEW ARTICLE

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ABSTRACT. The origin of resistance and its relation to the superconducting mechanism remain a profound, unsolved mystery. Currently, model parameters used to fit normal state properties are specific and vary arbitrarily from one doping. This short review illustrates the electrical resistivity of ceramic high temperature superconductors copper oxides. The article gives a summary of the prevailing arguments of researchers to relate the material to ceramic HTS compounds.

Keywords: *superconductivity, HTC ceramic compounds, resistivity.*

INTRODUCTION

The discovery of superconductivity at 40 K by Bednorz and Muller and at 90 K by Wu and Chu, in the ceramic oxides, has generated a tremendous amount of work in the field of high temperature superconducting materials. Superconductors with high critical temperatures are extremely complex and it remains difficult to synthesize high quality samples. In this regard, the materials and crystallographic aspects, drawing together the fields of structural chemistry and physics, solid state chemistry and physics, and applications and properties, both for cuprate and organic superconductors, play a vital role in our understanding of the phenomenon. Since the realization of electrical conducting properties of HTC ceramic compounds, there have been extensive investigations in to their transport properties. The significant progress of ceramic materials has been attracted attention of a lot of scientists in various disciplines and encouraging their entry into field. The synergy of diverse scientific senses brings further spread of the study of these materials.

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Electrical resistance of ceramic HTC compounds

Ceramic HTS compounds can be considered as grain systems coupled to each other by Josephson junctions. Some of these junctions behave as weak intergranular bonds (WLs) as shown in the literature. These lead to increased contact resistivity ρ_{ct} between the grains, and the electrical conduction is of the percolative type (mobile load carriers move on the roads where they meet the lowest values for ρ_{cti}). Because inside the grains we also have a percolative conduction along the CuO_2 layer (ab plane), the intragranular coupling between two crystallites will be in relation with the match between the CuO_2 layers at their boundary. When the CuO_2 planes make large angles between them or if they break at the contact limit of the granules ρ_{ct} grow.

For Bi: 2212 compounds with optimal gap doping in the CuO_2 layers (therefore maximum T_C) the electrical resistivity changes depending on the temperature as in Figure 1 [1].

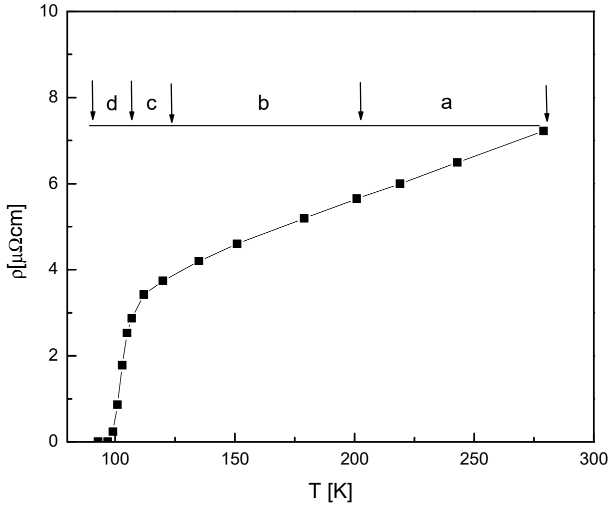

Fig. 1. *Electrical resistivity as a function of temperature for the superconducting system Bi: 2212*

We find the presence of four dependent regions $\rho(T)$: a) the "metallic" region; b) region of excess conductivity; c) the region of transition from the normal state to the superconducting state; d) the region of dissipative processes in the vortex system of the mixed state.

a) "Metallic" region

In this region the resistivity varies linearly depending on the temperature:

$$\rho = \rho(0) + \mathrm{aT}$$

where $\rho(0)$ is the residual resistivity (obtained by extrapolating to T=0K the linear dependence) and $a = \frac{d\rho}{\mathrm{dT}}$ it is the slope of the right. This region is usually between temperatures $\mathrm{T}^* \approx 2\mathrm{T_C}$ and room temperature. Electrical conduction is called the "metallic" type because of the dependence $\rho(T)$ is formally described by a law similar to that encountered in metals: $\rho(T) = \rho(0) + \rho_{\mathrm{ph}}(T)$, where $\rho_{\mathrm{ph}}(T) = \alpha T$ is the phonon contribution in the limit of high temperatures, and $\rho(0)$ is the temperature-independent residual resistivity.

In the case of metals, $\rho(0)$ comes from the scattering of electrons on impurities or static imperfections of the network and $\rho_{\mathrm{ph}}(T)$ from the scattering of electrons on the phonons of the network. Because the two scattering processes are not coherent, the scattering probabilities (which are proportional to the inverse of the relaxation times) add up:

$$\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_i} \quad .$$

In this expression τ_r and τ_i are the relaxation times of the electrons following the scattering of photons in the network, respectively impurities. We notice that $\rho_{\mathrm{ph}} \approx \frac{1}{\tau_r}$, and $\rho(0) \approx \frac{1}{\tau_i}$. Due to the inconsistency of the two scattering processes responsible for the resistivity of metals, there is no link between $\rho(0)$ and $\rho_{\mathrm{ph}}(T)$ or $\alpha = \frac{d\rho_{\mathrm{ph}}}{\mathrm{dT}}$.

Compared to the situation presented above, we find major differences in HTS compounds. If in homogeneous metals the conduction is three-dimensional (3D), in HTS compounds the behavior of "metal" type is generally found for the two-dimensional conduction (2D) in the CuO_2 layers. Another difference is given by the fact that between the slope $\alpha_{\mathrm{ab}} = \frac{d\rho_{\mathrm{ab}}}{\mathrm{dT}}$ (describing the linear dependence of the resistivity in the plane (ab) as a function of temperature: $\rho_{\mathrm{ab}}(T) = \rho_{\mathrm{ab}}(0) + \alpha_{\mathrm{ab}} T$

and value ρ_{ab} measured at 100K there is a linear correlation [2]. This was highlighted in a set of 5 single crystals of $YBa_2Cu_3O_7$ with the same value for the critical temperature, T_C = 91K, but different values for α_i and $\rho_{\mathrm{ab}}(100)$. The explanation of this behavior can be given based on the model of percolative conduction in single crystals. This model considers that:

$$\rho_{\mathrm{ab}}(T) = p(\rho_i(0) + \alpha_i T)\,.$$

At the ideal crystal, without defects, it is expected as $\rho_i(0) \rightarrow 0$, and $p \rightarrow 1$. Changing the slope of the linear dependency, $\alpha_{\mathrm{ab}} = p\alpha_i$, is therefore directly related to the current percolation parameter. The defects in the plane (ab) caused by the disorder of the oxygen atoms, the small angles between the planes (ab), respectively their twinning, change the value of p.

In the case of HTS ceramics, dependence $\rho(T)$ can be written as:

$$\rho(T) = p\left[\rho^i_{\mathrm{ab}}(T) + \rho_{\mathrm{ct}}\right]$$

where $\rho^i_{\mathrm{ab}}(T)$ is the intrinsic resistivity of the single crystal $(\rho^i_{\mathrm{ab}}(T) = \rho_i(0) + \alpha_i T)$ and ρ_{ct} is the contact resistivity between the granules.

In the case of polycrystalline ceramics, it was considered that the dependence of resistivity as a function of temperature is mainly determined by $\rho_{\mathrm{ab}}(T)$, because resistivity ρ_c after the direction c is a few orders of magnitude larger than in the plane (ab) [3]. Resistivity ρ_{ct} independent of temperature is the average resistivity due to structural inhomogeneities of much larger dimensions than the size of the distances characteristic of the system (coherence length, average free path, distance between atomic layers, etc.). Such inhomogeneities occur at the contact of two grains or two untouched domains. For easier interpretation of percolative processes, p is used instead $\frac{1}{q}$. The low values of q suggest a sharp decrease in the cross section through which the electric current can pass due to the porosity of the sample and the decrease in the length of the percolation path between the granules due to the random orientation of the planes (ab) at the junction of neighboring granules. For these reasons the resistivity increases strongly. When the planes (ab) in the neighboring granules make small angles between them and engage well, then $q \rightarrow 1$. In general, the values of q are between zero and the unit $0 < q < 1$. important ρ_{ct} and p (or $\frac{1}{q}$) that characterize the ceramic samples can be estimated based on the determination from the experimental data of the values $\rho(0)$ and $a=\frac{d\rho}{dT}$ intrinsic $\alpha_i = \frac{d\rho_{ab}}{dT} \cong 0,5\mu\Omega cmK^{-1}$ and $\rho_i(0)$ of the monocrystalline sample.

b) Excess of conductivity region

This region begins at $T^* = 2T_C$ where the deviation from the linear metallic type dependence appears and ends at the CT. To characterize this area, the experimentally measured resistivity ρ_m is compared, with the one extrapolated from the linear temoerature dependence of ρ . At the temperature T <T * we observe that $\rho_m < \rho$, so the measured conductivity $\sigma_m = \frac{1}{\rho_m}$ is greater than $\sigma = \frac{1}{\rho}$ [1]. The difference $\Delta\sigma = \sigma_m - \sigma > 0$ it is called excess conductivity. This phenomenon was first demonstrated experimentally by Glover in measurements of electrical resistivity in amorphous bismuth thin films [4].

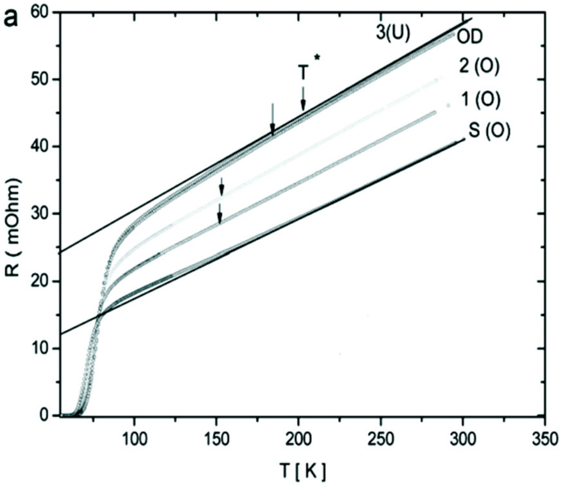

Fig. 2. *The in-plane resistance R vs. temperatures T for overdoped states of Bi-2212 with x = 0.02 Zn*

D. Marconi et al. shows that the temperature dependence of in-plane electrical resistance R = R_{ab}, of epitaxial Bi-2212 film with x = 0.02 Zn, in different doping states obtained after removing oxygen from in situ state S (O). Critical transition temperature Tc obtained from the maximum of first derivative dR/ dT data shows that OD is the optimal doped state (with maximum value of Tc), states S (O), 1 (O), 2 (O) are small overdoped states, and state 3 (U) is a small underdoped state (very close to OD). The resistance increases steadily with decreasing oxygen content. The typical high T-linear behavior followed by a less rapid decrease of R(T) at lower temperatures and a slight upward curvature of R(T) in the overdoped state S (O), can be seen in Figure 2. [23].

c) The transition region from the normal state to the superconducting state

This region is characterized by a sudden decrease in resistivity as the temperature decreases. The critical temperature TC is considered in the position of the inflection point of the curve $\rho(T)$ through the transition zone where the numerical derivative $\frac{d\rho}{\mathrm{dT}}$ is canceled. An evaluation of the TC value can be done by the "midpoint" method. This method approximates with a straight line the curve AB $\rho(T)$ from the transition area (Figure 3).

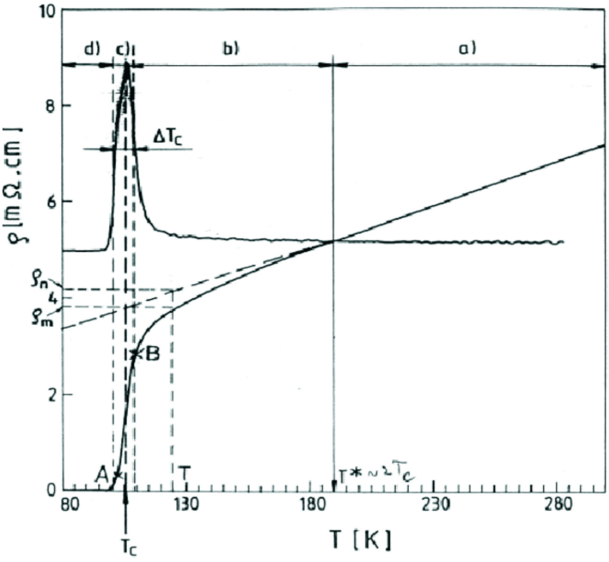

Fig. 3. *Electrical resistivity as a function of temperature for (Bi, Pb): 2223 superconducting system [1].*

A and B points are usually in the positions defined by the values 10% ρ_0 and 90% ρ_0 . The width of the transition is defined in this case as straight $(T_A - T_B) = \Delta T_C$, and the critical temperature T$_C$ is in the middle of this range: $T_C = T_B + \frac{\Delta T_C}{2}$. The exact value of the transition width is given by the width ΔT of the peak of the numerical derivative $\frac{d\rho}{\mathrm{dT}}$ measured at half its height [1].

d) Broadening of superconducting transition

As an example of the widening of the resistive transition in the magnetic field we will show in Fig.4 data from Palstra et al. [5-8] for $Bi_2Sr_2CaCu_2O_{8+\delta}$ configuration $(j \perp c, B \parallel c)$. It is observed that by increasing the magnetic field there is a decrease in temperature for which the resistance is zero T$_{c0}$, and the width of the transition increases.

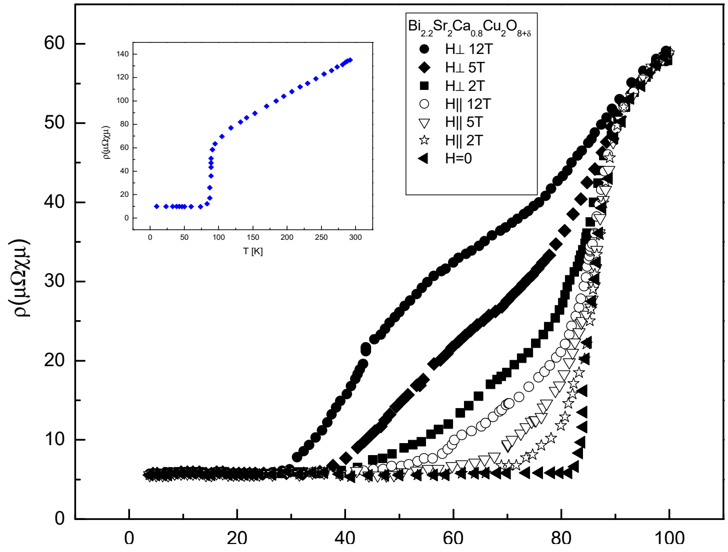

Fig. 4. *Temperature resistivity for different magnetic field values. The applied magnetic field is: parallel to the c-axis (symbols open on the graph) or perpendicular to the c-axis (symbols closed on the graph)*

Broadening the transition $\Delta T_c(B) = T_c(0) - T_c(B)$ In the presence of the magnetic field strongly depends on the value of the ratio ρ/ρ_n (ρ_n represents the temperature-dependent resistivity of the normal state). Transition width $\frac{\Delta T_c}{T_c} = 1 - \frac{T}{T_c}$, varies nonlinearly with the magnetic field according to a law of the type:

$$1 - T/T_c \sim B^{\nu}$$

exponent ν varies in different studies, however it is often close to $2/3$ [9, 10-12]. This behavior is the result of the shape of the irreversibility line and shows that the width of the resistive transition and the appearance of the irreversibility line are related. Results similar to those in Fig. 4 have been found for crystals, epitaxial films and polycrystals from all major HTSC families. To $La_{2-x}Sr_xCuO_4$; $YBa_2Cu_3O_{7-\delta}$; [13,12,14,1] systems based on Bi [15-17,1,18-20] and Tl [21,22].

e) Thermally activated resistivity

The bottom of the resistive transition $(\rho/\rho_n \approx 10^{-6} - 10^{-2})$ was studied in detail by Palstra et al. They found the thermally activated resistivity [5,7,8] to be of the form:

$$\rho = \rho_0 \exp\left[-\frac{U}{k_B T}\right] \tag{1}$$

then the characteristics IV become linear for both configurations (j c, B c) and (j c, B || c). We present the results for $Bi_2Sr_2CaCu_2O_{8+\delta}$ (B || c) in Fig.5 in the representation of Arhenius ln ρ depending on 1 / T. The slope in this representation is interpreted as the activation energy U. It is of the order of 103K for $Bi_2Sr_2CaCu_2O_{8+\delta}$ [18-20] and decreases with increasing magnetic field. factor ρ_0 it is found to be a few orders of magnitude larger than the resistivity of the normal state. Similar results were reported for Tl-coated superconductors and for the 60K phase of $YBa_2Cu_3O_{7-\delta}$ [7].

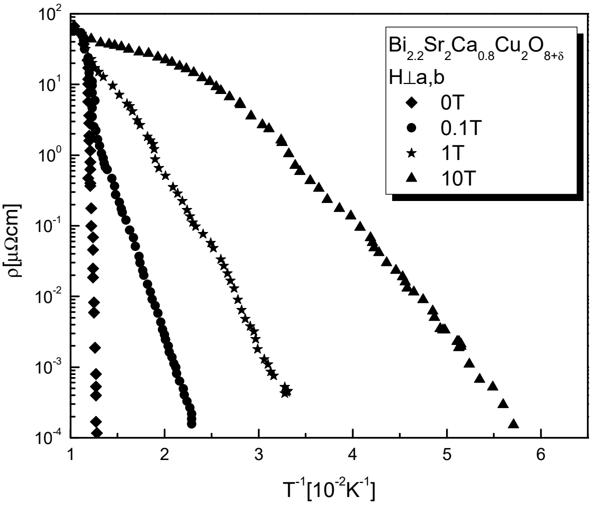

Fig. 5. *Representation of Arhenius for the data in Figure 4 in the case of the superconductor* $Bi_2Sr_2CaCu_2O_{8+\delta}$ *and B || c*

SUMMARY

In conclusion, in the presented material were discussed some experimental results obtained for electrical resistance of ceramic HTC compounds. We show and detailed the presence of four temperature dependent regions of electrical resistivity: a) the "metallic" region; b) region of excess conductivity; c) the region of transition from the normal state to the superconducting state; d) the region of dissipative processes in the vortex system of the mixed state.

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