THE THERMAL POWER AND CONDUCTIVITY OF SUPERCONDUCTING $Bi_2Sr_2Ca_{0.4}Zn_{0.6}Cu_2O_y$

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The temperature dependence of the resistivity and thermoelectric power of bismuth $Bi_2Sr_2Ca_{0,4}Zn_{0,6}Cu_2O_y$ superconductor in the range 77-320K is carried out. The experimental results on thermoelectric power are analyzed within the framework of the Xin's two-band model and the band gap of Bi-O layers is determined as E_g=0.059 eV.

Keywords: superconducting material, specific resistivity, thermal power.
PACS: 74.62.Bf; 74.25.F

1. INTRODUCTION

The discovery of high-temperature superconductors $La_{2-X}(Ba/Sr)_XCuO_4$ and $YBa_2Cu_3O_{7-X}$ with critical superconducting transition temperatures T_c~40K and T_c~90K, respectively, led to an intensive search for new oxide superconductors with even higher T_c. Michel et al. [1] reported the discovery of superconductivity between 7 and 22K in Bi-Sr-Cu-O, which was not a rare earth element. However, due to the great interest in yttrium superconductors with a critical temperature of 90 K, this report did not generate wide interest. However, the addition of the element Ca to the Bi-Sr-Cu-O cuprate system led to the discovery of bulk superconductivity at 85K and the proof of superconductivity up to 110K in the Bi-Sr-Ca-Cu-O system [2].

It is known that in bismuth superconductors there are phases with different numbers of CuO (n) atomic planes [3, 4]. With an increase in the number of planes to n=3, the critical temperature increases to Tc =110K.

Investigation of the transport properties of bismuth superconductors $Bi_2Sr_2CuO_6$ (n=1), $Bi_2Sr_2CaCu_2O_8$ (n =2) and $Bi_2Sr_2Ca_2Cu_3O_{10}$ (n=3) have been devoted to many works [1-7]. However, there is still no consensus on the mechanism of HTSC superconductivity. The transport properties of the normal state of HTSC, namely, the linear temperature dependence of the resistivity in a wide temperature range, as well as the strong dependence of the thermoelectric power on the hole concentration in the CuO_2 layers are unusual.

It is known that the coherence length of HTSC is rather small. This leads to the fact that structural inhomogeneities such as double boundaries, defects, grain boundaries, etc., will affect the transport properties of the superconductor in the normal state. The introduction of various impurities and various modes of synthesis affect both the phase formation and the physical properties in this system. On the other hand, atomic-crystal defects arising due to distortions of superconducting CuO_2 layers, as well as point defects in layers formed by calcium atoms when they are replaced with various elements, are pinning centers in Bi based high-temperature superconductors. Therefore, it is of interest to replace the element Ca by others, in particular, zinc.

This paper analyzes the results of studying transport properties, such as resistivity and thermoelectric power of $Bi_2Sr_2Ca_{0.4}Zn_{0.6}Cu_2O_8$.

2. EXPERIMENTAL RESULTS AND DISCUSSION

The investigated superconducting composition $Bi_2Sr_2Ca_{0.4}Zn_{0.6}Cu_2O_8$ was obtained by solid-phase synthesis, mixing in a stoichiometric proportion of highly pure powders Bi_2O_3, $CaCO_3$, $SrCO_3$, ZnO and CuO. The sample was annealed for 10 hours at a temperature of 840^0C, then cooled at a rate of 1.5^0C/min to room temperature.

X-ray structural analysis was carried out on a Brucker-D2 Phaser at room temperature with a resolution of $\Delta(2\theta)=0.05^0$in the range $5^0 \leq 2\theta \leq 80^0$. The obtained result is shown in Fig. 1. Some structural parameters of the investigated sample were determined from the data of X-ray structural analysis.

It was found that $Bi_2Sr_2Ca_{0,4}Zn_{0,6}Cu_2O_y$ consists of two phases. The main phase corresponds to the orthorhombic Pnnn group with lattice parameters a=5,429, b=5,431, c=30,840 Å. And the other phase is the tetragonal I4/mmm group with lattice parameters a=3.8097, c=24.607 Å, respectively. According to the intensities of the diffraction peaks, the tetragonal phase prevails.

The crystallographic structure of bismuth high-temperature superconductors is given in [8, 9]. The crystal structure can be considered as a three-dimensional packing of $Bi_2Sr_2CaCu_2O_8$along the c axis, the main feature of which is the presence of two Bi-O layers separated by 3.0 Å and shifted relative to each other (crystallographic shift) in the diagonal direction of the perovskite subcell. Tarascan et al. [10] showed that the 100K phase has the formula Bi-2:2:2: 3 and its structure contains three CuO_2 layers. The three phases Bi-Sr-Ca-Cu-O can be represented by the general formula $Bi_2Sr_2Ca_{n-1}Cu_nO_y$ (n =1, 2 and 3) and have a pseudo-tetragonal structure (Fig. 2), which can be described as the packing of the basic block $Bi_2Sr_2CuO_6$ with zero, one or two inserted $CaCuO_2$ plates.

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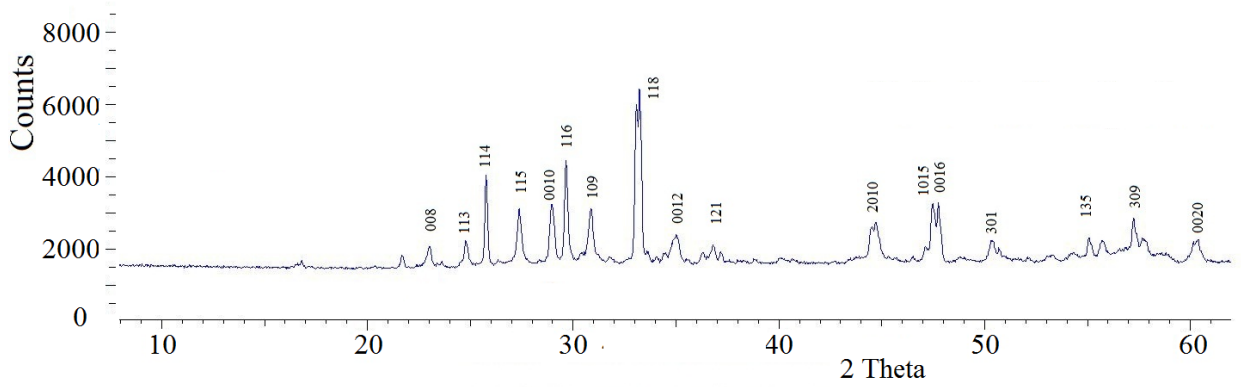

Fig.1. X-ray diffractogram of $Bi_2Sr_2Ca_{0.4}Zn_{0.6}Cu_2O_8$.

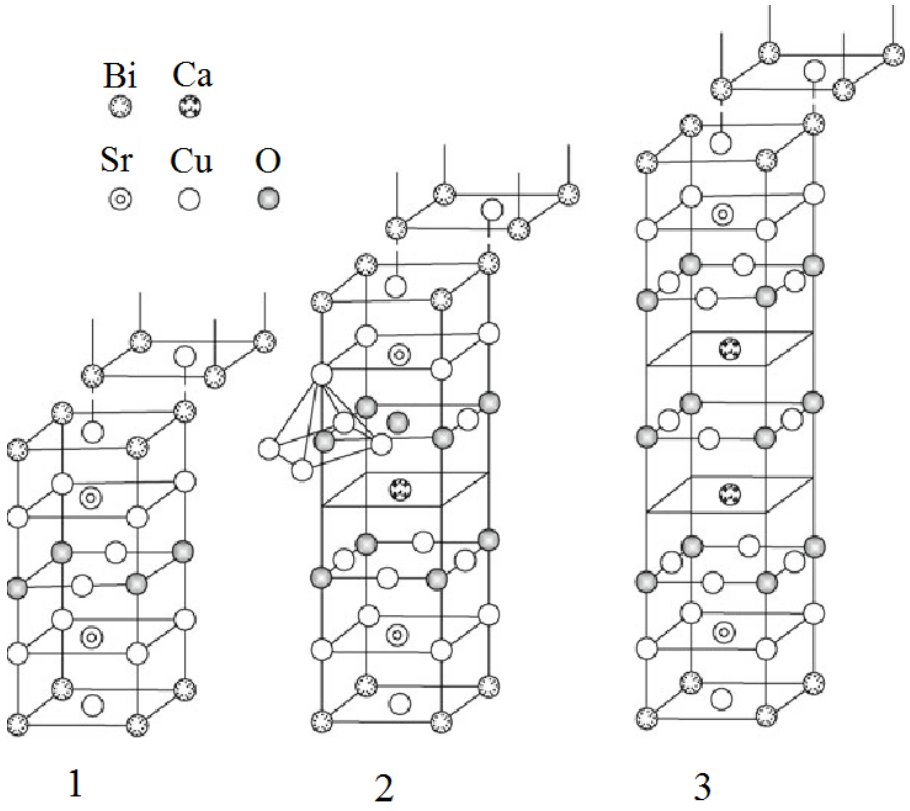

Fig. 2. Crystallographic structure of bismuth superconductors: 1-$Bi_2Sr_2CuO_{6+y}$ (c=24.6 Å); 2- $Bi_2Sr_2CaCu_2O_{8+y}$ (c=30.7 Å); 3- $Bi_2Sr_2Ca_2Cu_3O_{10+y}$ (c=37.1Å) [11].

The lattice parameter - c increases from 24.6 to 30.6 Å and finally to 37.1 Å when going from n = 1 to 2 and 3. This increase is the result of the gradual addition of 2×1 and 2×2 (doubled from - due to crystallographic shift) $CaCuO_2$, each with a thickness of about 3 Å, packing sequence in a unit cell. For $Bi_2Sr_2CaCu_2O_8$, the folding sequence is Bi-Sr-Cu-Ca-Cu-Sr-Bi. In $Bi_2Sr_2Ca_2Cu_3O_{10}$ the sequence of layers is Bi-Sr-Cu-Ca-Cu-Ca-Cu-Sr-Bi.

As can be seen from the crystal structure, the element Ca plays an essential role in the critical temperature of a bismuth superconductor. Naturally, it was interesting to determine the effect of the substitution of zinc for the element calcium on the conductivity and thermo power.

Figures 3 and 4 show the temperature dependences of the resistivity and thermoelectric power of the investigated superconductor. As can be seen from the figure, the temperature dependence of the resistivity in the normal state has a linear course and decreases with temperature. This indicates that the concentration of charge carriers increases with temperature. The superconducting critical temperature of $Bi_2Sr_2Ca_{0.4}Zn_{0.6}Cu_2O_8$ was Tc=78.2K. The temperature coefficient of specific resistivity is $d\rho/dT=1{,}2\cdot10^{-6}$Ohm·cm/K.

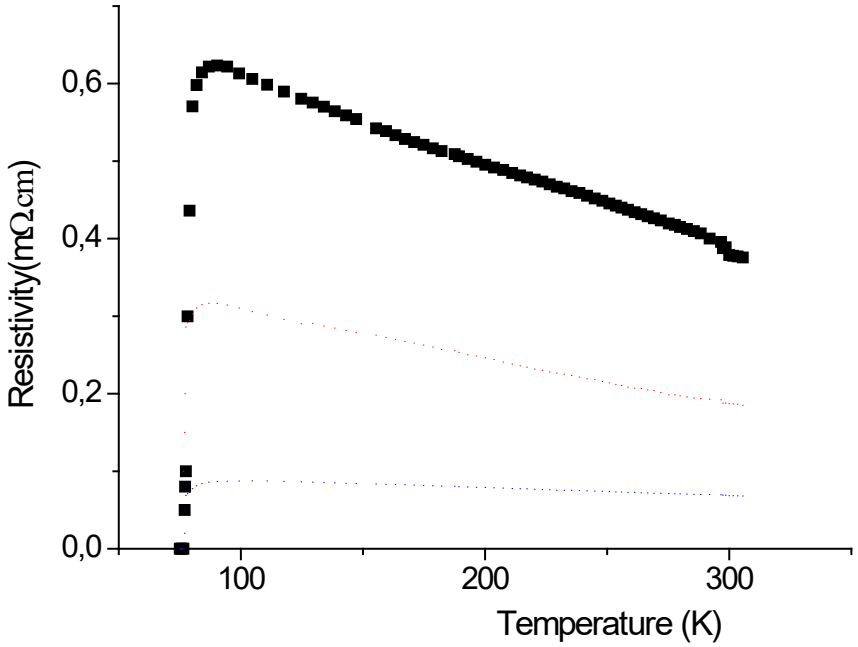

Fig.3. The temperature dependence of specific resistivity of $Bi_2Sr_2Ca_{0.4}Zn_{0.6}Cu_2O_8$.

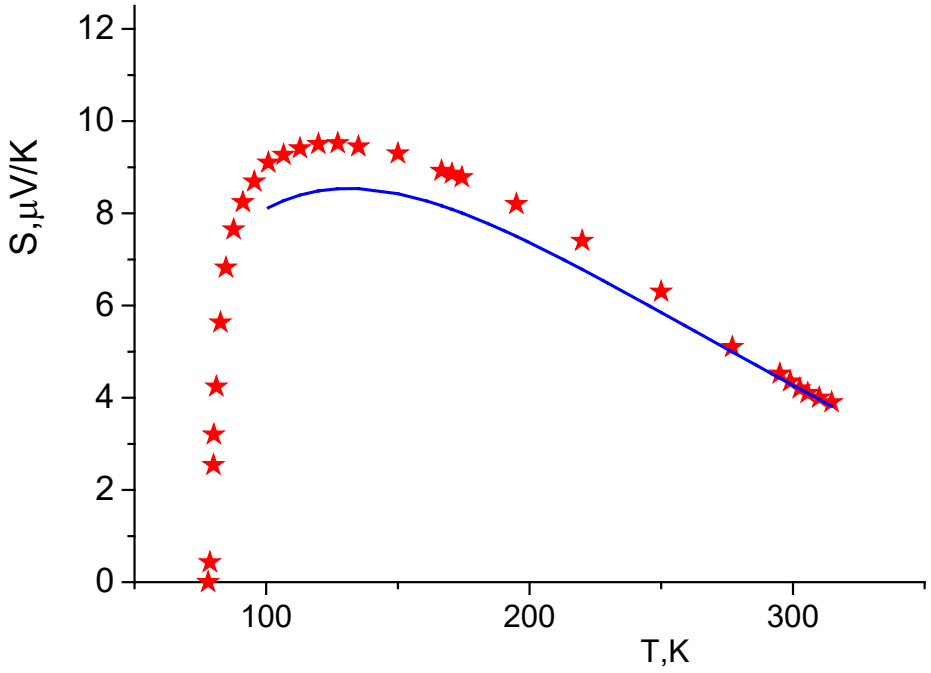

Fig..4. The temperature dependence of thermal power of $Bi_2Sr_2Ca_{0.4}Zn_{0.6}Cu_2O_8$.

In the entire investigated temperature range, the thermopower has a positive sign corresponding to the hole type of conductivity. The S(T) dependence passes through a maximum before the phase transition and sharply decreases to zero with decreasing temperature. In the normal state, the thermoelectric power decreases with increasing temperature. The temperature of the maximum thermopower is ~117K and has a negative slope dS/dT=-0,015μV/K^2. Hole type of conductivity and negative temperature coefficient of thermoelectric power, indicates the participation of electrons in conduction at the same time. It is known that in bismuth superconductors in

Bi-O layers, electronic conductivity dominates, and in Cu-O, hole conductivity prevails [5, 12, 13].

Xin et al. [3] propose a two-zone model, where one zone is formed by Cu-O and the other by Bi-O planes. The Cu–O plane contributes to the conductivity of holes, while the conduction electrons in the Bi–O planes are of a semiconducting nature. According to [3], the thermopower is determined by the expression:

$$S = -g\pi^2 \left[\frac{d\ln\sigma^+(E)}{d\ln E}\right] T + \left[\frac{E_c}{e} + \frac{k}{e}\frac{d\ln\tau(E)}{d\ln E} T\right] e^{-E_a/kT} \quad (1)$$

Taking into account the linear and exponential parts, expression (2) can be represented as

$$S=AT+(B\lambda+CT)\exp(-\lambda/T) \quad (2)$$

where A, B and C are constants for a given material, T is the temperature, $\lambda=E_c/k_B$, $E_c=E_g/2$ -is the energy gap between the bottom of the conduction band and the middle of the band gap, k_B is the Boltzmann constant. As can be seen from expression (2), the value of the constant A determines the contribution of holes in the Cu-O planes.

The obtained value of λ was used to calculate the band gap of the semiconductor type Bi-O layers. The parameter λ, which is included in the exponent depends on the band gap between the Bi-O band and the conduction band. From the expression $\lambda=E_c/k_B$ and $E_c=E_g/2$, the band gap of the investigated sample is determined as E_g=0.059 eV. The values of the adjustable constants A, B, C were equal to A=0.068 μV/K^2, B=-0.13435 μV/K^2, C=-0,03746 μV/K^2, respectively.

CONCLUSION

The temperature dependence of the thermo power of $Bi_2Sr_2Ca_{0,4}Zn_{0,6}Cu_2O_y$ is analyzed within the framework of the Xin's two-band model. The calculation is carried out and the width of the forbidden zone of the semiconductor type Bi-O layers is determined E_g = 0.059 eV.

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Received: 17.11.2020