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Fluctuation conductivity of hafnium doped $YBa_2Cu_3O_{7-\delta}$ ceramic

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The conductivity of Hf doped $YBa_2Cu_3O_{7-\delta}$ ceramics was studied in the thesis. It was shown that the introduction of Hf additive leads to the increase of the amount of scattering effective centers of normal carriers. Excessive conductivity of the studied samples near T_c is satisfactorily described by a theoretical model of Aslamazov-Larkin. At the same time Hf additive leads to a significant increase in the absolute value of $\xi_c(0)$ and the shift of 3D-2D crossover point with regard to the temperature.
Keywords: $YBa_2Cu_3O_{7-\delta}$ ceramics, doping, fluctuation conductivity, the coherence length, 3D-2D crossover.

В работе исследована проводимость керамик $YBa_2Cu_3O_{7-\delta}$ допированных Hf. Показано, что внесение примеси Hf приводит к возрастанию числа эффективных центров рассеяния нормальных носителей. Избыточная проводимости исследованных образцов вблизи T_c удовлетворительно описывается теоретической моделью Асламазова-Ларкина. При этом добавка Hf приводит к значительному возрастанию абсолютного значения величины $\xi_c(0)$ и смещению по температуре точки 3D-2D кроссовера.
Ключові слова: кераміки $YBa_2Cu_3O_{7-\delta}$, допування, флуктуаційна провідність, довжина когерентності, 3D-2D кросовер.

У роботі досліджена провідність керамік $YBa_2Cu_3O_{7-\delta}$ допованих Hf. Показано, що внесення домішки Hf призводить до зростання числа ефективних центрів розсіювання нормальних носіїв. Надлишкова провідність досліджених зразків поблизу T_c задовільно описується теоретичною моделлю Асламазова-Ларкіна. При цьому добавка Hf призводить до значного зростання абсолютного значення величини $\xi_c(0)$ і зміщення по температурі точки 3D-2D кросовера.
Ключевые слова: керамики $YBa_2Cu_3O_{7-\delta}$, допирование, флуктуационная проводимость, длина когерентности, 3D-2D кроссовер.

A characteristic feature of HTSC, compounds of the 1-2-3 system, is relative simplicity of full or partial substitution of components by their isoelectronic analogues [1]. As it was established in a number of studies [2] such substitution often facilitates slowing of the aging processes in the compounds of such a type and improving of the stability of their technological characteristics. Most clearly it is demonstrated in the case of ceramic samples, which are also currently the most functional in terms of their practical application [3].

At the same time this kind of substitution often leads to the significant evolution of specific physical phenomena observed in the HTSC - materials with regard to the normal (non-superconducting) condition. The latter refers to the pseudogap (PG) and fluctuation (FC) abnormalities, transitions of the metal-insulator type, incoherent electric transport, anisotropy of some physical characteristics, and etc. [4]. According to the modern concepts [4] these unusual phenomena may serve as a key to understanding of the microscopic nature of the high-temperature superconductors, which remains unknown despite the 29-year history of intense experimental and theoretical research.

Taking into consideration the abovementioned the influence of Hf impurities on the fluctuation conductivity in HTSC – YBaCuO ceramics at the near critical temperatures – was investigated in the study.

Samples of $YBa_2Cu_3O_{7-\delta}$ ceramics were synthesized by interaction of Y_2O_3, $BaCO_3$, and CuO (all OS grades) compounds taken in the respective molar ratios in the temperature range 750-900° C. The obtained powder was pressed under pressure of 4 ton/cm^2 into the disks of 20x4 mm size and sintered at the temperature of 950-970°C within 5 hours followed by cooling to the room temperature with intermediate dwell of 2-3 hours at the temperatures of 890 and 530°C. The obtained tablets represented superconducting ceramics with rhombic symmetry of lattice and T_c~90 K. For obtaining samples with addition of hafnium the starting material was added with a various quantity of weight % of Hf_2O_3. Modes of production and saturation with oxygen were the same as for the undoped ceramics.

X-ray studies of the structure and phase composition of the samples of $YBa_2Cu_3O_{7-\delta}$ ceramic depending on

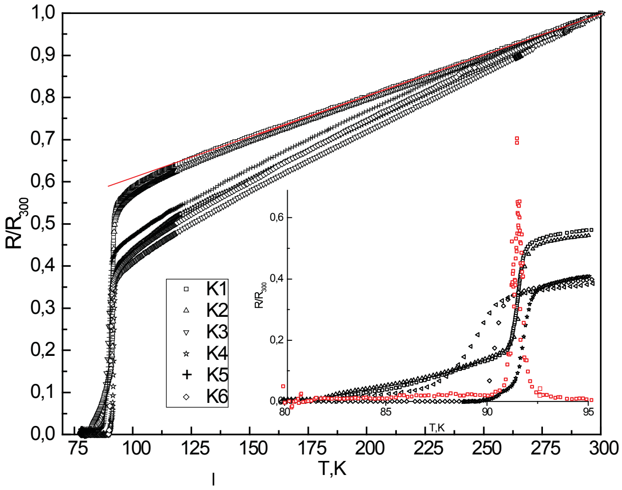

Fig. 1. Dependence of reduced electrical resistance $R/R_{300}(T)$ of ceramic samples with the addition of K1 hafnium. The inset shows the transition to the superconducting state in the coordinates of $R/R_{300}(T)$ and $d(R/R_{300}(T))/dT$ - T in the area of superconducting transition of one sample. Numbering of the curves in the inset corresponds to the numbering in the Fig.

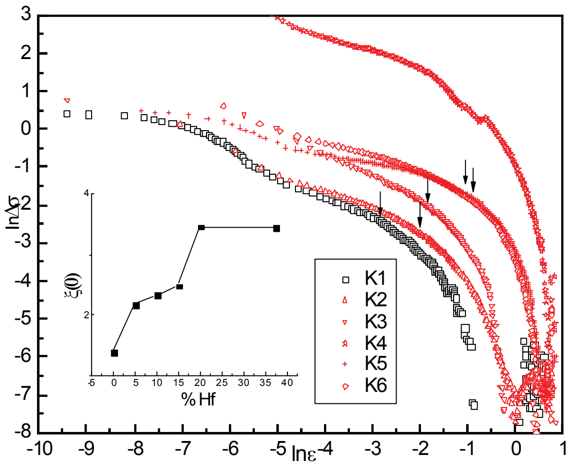

Fig. 2. Temperature dependences of the excess conductivity for K1 - K6 samples in lnΔσ-lnε. Designation of the curves corresponds to the designations in the Fig.1. Straight lines show an approximation to the inclination angle $tg\alpha_1 \approx -0.5$ (3D - mode) and $tg\alpha_2 \approx -1.0$ (2D - mode). Arrows show the point of 2D-3D crossover. The inset shows the dependences of coherence length $\xi_c(0)$ on the percentage of hafnium in the samples.

the hafnium additions were carried out on the DRON-3 X-ray diffractometer in Cu-Kα-radiation. Profiles of X-ray diffraction peaks were built by manual scanning with intervals of angles of 2θ=0,1° in the background and with intervals of 2θ=0,02° at maximum. Analysis of the obtained diffractograms showed that the initial sample had an orthorhombic structure of perovskite type with the following lattice parameters: a=3.8348Å, b=3.8895Å, c=11.6790Å, which corresponds to the literature data. With increasing content of Hf_2O_3 hafnium oxide additives the intensity of X-ray diffraction peaks corresponding to the initial structure is reduced and diffraction peaks corresponding to the orthorhombic structure perovskite of type appear on diffractograms X-ray but with higher parameters of lattice.

For resistive studies the pieces of rectangular shape were sawed from the "tablets". Contacts were applied by rubbing of ceramic India into the surface followed by soldering of copper conductors to these sites. The electrical resistivity was measured by standard 4 contact procedure with direct current up to 10 mA. The sample temperature was determined by platinum thermal resistor.

Temperature dependences of the stated electrical resistance of $R/R_{300}(T)$ samples are shown in Figure 1. Resistive transitions into the superconducting state of the same samples are shown in the inset. It appears that the dependences are quasimetallic. The parameters of the studies samples are shown in the table. According to the literature data the high values of T_c=92.1 K critical temperature correspond to the oxygen content δ≤0.1 [5].

As we can see from the Figure 1 $R/R_{300}(T)$ deviation from linear dependence take place with the decrease of temperature below a certain characteristic value of T* which shows the appearance of a certain excess conductivity, which according to the theoretical concepts [6] near T_c is conditioned by processes of fluctuation pairing of the carriers. Their contribution to the conductivity at $T>T_c$ for two (2D) and three-dimensional (3D) cases is determined by the following power dependence (6):

$$\Delta\sigma_{2D} = \frac{e^2}{16\hbar d}\varepsilon^{-1}, \tag{1}$$

$$\Delta\sigma_{3D} = \frac{e^2}{32\hbar\xi_c(0)}\varepsilon^{-1/2}, \tag{2}$$

where $\varepsilon=(T-T_c)/T_c$, e - electron charge, $\xi_c(0)$ - is coherence length along the c axis at T→0 and d - is a characteristic size of a two-dimensional layer. In our case T_c was determined at the maximum point in the dependences of $d(R/R_{300})/dT$ in the area of superconducting transition (Fig. 1 Inset).

The temperature dependence of the excess conductivity is usually determined by the equation:

$$\Delta\sigma = \sigma - \sigma_0, \tag{3}$$

where $\sigma_0=\rho_0^{-1}=(A+BT)^{-1}$ is the conductivity determined by interpolation of the linear section of ρ(T) to the zero value of the temperature and $\sigma=\rho^{-1}$ is an experimentally determined value of conductivity in the normal condition.

Fig. 2 shows the temperature dependences of Δσ(T) in ln Δσ– lnε coordinates. It can be seen that near T_c these curves are approximated satisfactorily by straight lines with a slope of tg α1~0.5 corresponding to the exponent parameter of —1/2 in the equation (2), which obviously

Table

Samples	% Hf	T_c, K	T*, K	Δ^*_{ab}, meV	Ln(ε_0)	ε_0	$\xi_c(0)$, Å
K1	0	91,47	154	0,1006	-2,87	0,0567	1,39297
K2	5	91,62	160	0,06776	-1,98	0,13807	2,17372
K3	10	89,5	165	0,0675	-1,84	0,15882	2,33134
K4	15	91,65	250	0,05647	-1,714	0,18014	2,48294
K5	20	90,17	240	0,0306	-1,05	0,34994	3,4606
K6	37,5	90,38	237	0,03897	-1,06	0,34646	3,44334

evidences about 3D character of the fluctuation conductivity in this temperature interval. Upon further temperature increase the rate of $\Delta\sigma$ decrease substantially increases (tg $\alpha 2 \sim 1$) which in its turn can be interpreted as an indication for change of fluctuation conductivity dimensionality. As it follows from Eqs. (1) and (2) at the point of 2D-3D crossover:

$$\xi_c(0)\varepsilon_0^{-1/2} = d/2 . \quad (4)$$

In this case having determined ε_0 value and using literature data on the dependence of the interplane distance on δ [7] ($d \approx 11.7$ Å) it may be possible to calculate the values of $\xi c(0)$. The concentration dependences of the coherence length $\xi_c(0)$ are shown in the inset to the Figure 2.

The made calculations showed that with introduction of Hf additives a change in the value of coherence length from $\xi_c(0)$=1,39Å in YBaCuO to $\xi_c(0)$=3.44Å in Hf doped samples takes place by 37.5% and 3D-2D crossover point significantly shifts with regard to the temperature (see Table and Fig. 2).

In conclusion, we briefly resume the main results obtained in this paper. Excessive conductivity $\Delta\sigma(T)$ of Hf-doped YBaCuO samples in the case nearing T_c is satisfactorily described in the framework of a theoretical model of Aslamazov-Larkin. Doping of YBaCuO single crystals by hafnium leads to a more than twofold increase in the absolute value of $\xi_c(0)$ and significant shift of 3D-2D crossover point with regard to the temperature.

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