

PINNING ENERGY OF  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$  AND  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$ 

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The superconducting  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$  and  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$  which was obtained by solid-state synthesis method was investigated. The pinning energy was estimated according the magnetic field dependence of specific resistivity. It was observed that, the Zn substitution of Ca leads to increase of the pinning energy.

**Keywords:** pinning energy, superconducting material, specific resistivity, coherence length, magnetic field dependence

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## INTRODUCTION

For a wide practical application of superconducting materials, it is necessary high critical temperature and high conductive capacity. The critical current density is one of the critical parameters that limit the existence of superconductivity. The study of current transfer processes is also of interest from a physical point of view, since it allows one to obtain additional information on some parameters of the superconducting state. The magnitude of the critical current is highly dependent on the conditions and technology of manufacturing high-temperature superconductor [1-8].

In superconductors of the second kind, the pinning effect plays a large role. The values of the critical current density ( $j_c$ ) in second-type superconducting materials are directly dependent on the ability to move vortices and pinning centers. Pinning flow is always enhanced with increasing sample heterogeneity [8-13]. In the case of Bi-based HTSCs, it can be assumed that such centers may be phase boundaries, superstoichiometric concentrations of Ca and Cu, and others impurities [2,4,5,11].

In the present work we analyzed the pinning energy of  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$  and  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$  polycrystalline samples.

## EXPERIMENTAL RESULTS AND THEIR DISCUSSION

The investigated  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$  and  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$  was synthesized by solid-state synthesis method. Samples were prepared from stoichiometric amounts of high-purity  $\text{Bi}_2\text{O}_3$ ,  $\text{CaCO}_3$ ,  $\text{SrCO}_3$ ,  $\text{ZnO}$  and  $\text{CuO}$  powders. First, refractory components ( $\text{CaCO}_3$ ,  $\text{SrCO}_3$ , and  $\text{CuO}$ ) taken in a desired proportion were sintered at 1173-1243K for 20-50 h and then  $\text{Bi}_2\text{O}_3$  and  $\text{ZnO}$  were added. The solid state reaction of the mixed and pressed powders was performed at 1100-1135K in air for 50h applying intermediate grindings. Cooling was carried out with a rate of  $1.5^\circ\text{C}/\text{min}$ .

The phase purity of the obtained samples was investigated by X-ray analyses. The XRD analysis was performed using a Bruker -D8 advance diffractometer at room temperature. The X-ray diffractogram of  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ ,  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$  are shown in fig.1. According the x-ray data  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$  and  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$  can be called single phase. One can see from fig.1, the additional peaks are observed for the Zn-doped compound. From the XRD data, various structural characteristics such as, lattice parameter:  $a=5,396$ ;  $b=5,395$ ;  $c=30,643$ ,  $V=892.06 \text{ \AA}^3$ , system-orthorhombic, space group Pnnn for  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$  and  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$  were deduced.

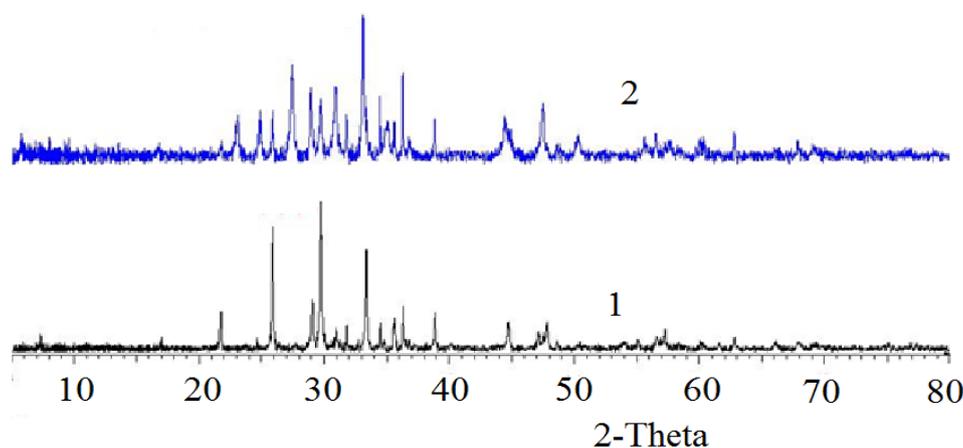


Fig. 1. The X-ray diffractogram of  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ ,  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$ .

To calculate the pinning energy, we used the temperature dependences of the resistivity at various values of the magnetic field [14].

Figure 1 shows the dependence of the activation energy  $U_p$  on the external magnetic field for the investigated samples.

At present, the nature of pinning centers in HTSCs has not been finally established, but it is clear that the relatively weak pinning of vortexes in these materials is due to the low energy  $U_p$  of the fluxoid bond at the pinning center due to the small coherence length  $\xi$ . It is known that pinning is most effective in a separate vortex line [8,9,11]. Pinning flow is always enhanced with increasing sample heterogeneity. In this case, the replacement of the element of calcium by zinc leads to the formation of defects in the crystal structure. The result is an increase in pinning energy.

To evaluate  $U_0$ , you can use the expression [10,11]

$$U_0 = \beta B_c^2 \xi \phi_0 / B \quad (1)$$

where  $B_c$  is a thermodynamic critical field,  $\phi_0$  - flow quantum ( $\phi_0 = 2.07 \cdot 10^{-15} \text{Tl.m}^2$ ),  $\beta = 1$  is the number coefficient. As can be seen from (1), a decrease in  $\xi$  leads to a drop in  $U_0$ .

As can be seen, to determine the pinning energy, it is necessary to know the upper critical magnetic fields and the coherence length. The upper critical magnetic fields and the coherence length values were experimentally determined from the dependence of the resistance on the magnetic field [5,14]. In the low-temperature region of the resistive transition to the superconducting state, the pinning energy of Abrikosov vortexes  $U_p$  is significantly higher than the thermal energy ( $U_p \gg kT$ ). In this region, the resistance is determined by thermally activated motion

of the magnetic flux and is expressed by the well-known Arrhenius law [6-8].

$$\rho = \rho_0 \cdot \exp\left(-U_0/k_B T\right) \quad (2)$$

The pinning energy  $U_p$  was calculated for fixed magnetic fields from the slope of the linear sections of the dependences  $\ln(\rho/\rho_0) = f(1/T)$ . The obtained values of  $U_p$  for investigated samples are presented in fig.1.

As can be seen from fig.1, the pinning energy decreases with increasing magnetic field in investigated samples. Note that the rate of decrease in the activation energy  $U_p(B)$  also slows down. Apparently, this dependence  $U_p(B)$  is caused by the saturation of the activation energy in strong fields and at low temperatures, where the effects of magnetic flux movement become less significant. As can be seen,  $U_0$  for the sample  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$  (with the addition of Zn element) is higher than in the  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ . In our opinion, this is due to the different nature of the pinning centers in these materials: point defects, the presence of other phases. Structural defects that occur in complex HTSC materials serve as an effective pinning center for magnetic flux lines [12]. The presence of impurities and phases in HTSCs leads to a local decrease in the Gibbs free energy of vortex lines. If these defects can lead to a change in the superconducting order parameter, then the flux lines will pinning efficiently. The degree of variation of the superconducting order parameter is approximately equal to the radius of the normal part of the vortexes, or the coherence length. Therefore, in order to understand the effect of pinning flow lines, it is very important to know the coherence length with respect to the sizes of defects. These intrinsic superconducting properties can be determined from measurements of the temperature dependence of the second critical magnetic field.

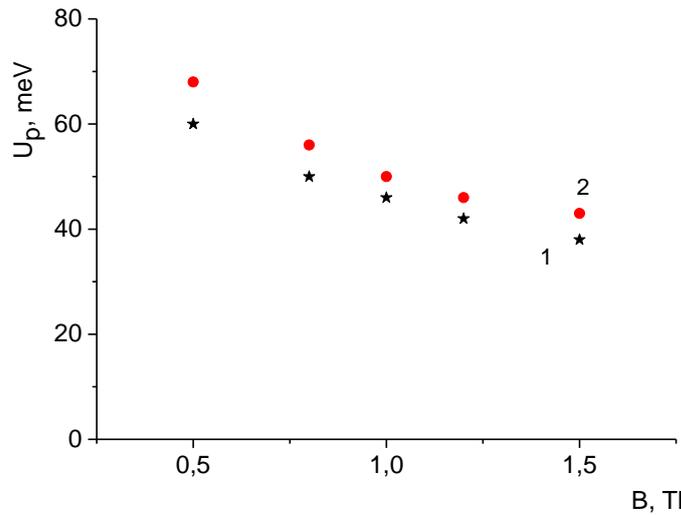


Fig. 2. The magnetic field dependence of pinning energy of  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$  (1) and  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$ (2)

The replacement of Ca with Zn leads to the formation of defects in the crystal structure of the sample. Moreover the resistance of the samples may increase either by increasing the number of defects or by decreasing the density of charge carriers. It is possible that in this case both mechanisms take place. The defects in the crystal structure as a result of the introduction of the element Zn, lead to additional pinning centers. And this in turn increases the pinning energy of the whole in the sample.

Note that when replacing calcium with zinc, the lattice parameter decreases. This is due to the fact that zinc has a smaller ionic radius than calcium (1.04 Å and 0.83 Å, respectively). In this case the crystal structure deforms, similar to that arising under external pressure, as a result of which the lattice parameter decreases.

## CONCLUSION

The replacement of Ca with Zn leads to the formation of defects in the crystal structure of the superconducting  $\text{Bi}_2\text{Sr}_2\text{Ca}_{0.8}\text{Zn}_{0.2}\text{Cu}_2\text{O}_x$ . The pinning energy was estimated according the magnetic field dependence of specific resistivity. It was observed that, the Zn substitution of Ca leads to increase of pinning energy.

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