ANNOTATION

on the dissertation of the scientific degree of PhD in specialty 6D074000 – Nanomaterials and nanotechnologies

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INFLUENCE OF NANOPOWDER ADDITIVES $Co_{0.5}Zn_{0.5}Fe_2O_4$ AND $Ni_{0.5}Zn_{0.5}Fe_2O_4$ ON THE CHARACTERISTICS OF HIGH-TEMPERATURE SUPERCONDUCTORS

Introduction

General description of work. The dissertation is devoted to the study of the influence of nanopowder additives on the main characteristics of high-temperature superconductors, such as critical temperature and current density. The problem is solved by adding nanoscale $Co_{0.5}Zn_{0.5}Fe_2O_4$ (CZFO) and $Ni_{0.5}Zn_{0.5}Fe_2O_4$ (NZFO) powders to bismuth-containing BPSCCO and yttrium-barium YBCOhigh temperature superconductor (HTSC) materials in order to create effective pinning centers.

This paper consists of 3 chapters. The first chapter presents the current state of the problem, a literature review of the results of scientific works on achieving effective pinning centers using other types of additives, as well as through external exposure.

The second chapter is devoted to description of the methods of experiments and equipment that were used to achieve the goals of the thesis.

The third chapter presents: measurement results, comparison with the results of other studies and discussion of the analysis of the results obtained by different research methods, experimental results of the study of the effect of various nanoscale additives on the main characteristics of HTSC materials.

Relevance. Despite the lack of a recognized theory to explain the mechanism of superconductivity, HTSC materials are currently widely used in many sectors of the technological industry, such as electronics, energy, accelerator technology for transport, etc. Among these materials, one can distinguish ceramic HTSC materials based on complex cuprates, such as bismuth-containing and yttrium-barium materials used in the manufacture of current-carrying high-power cables. Due to the strong dependence of the main characteristics such as the critical temperature and current density on the external magnetic field, there is no possibility of a wider use of the above HTSC materials. To weaken the strong dependence on the external magnetic field, in recent years, the method of increasing the strength of pinning centers has begun to be widely used. Pinning centers are necessary to increase the depth of penetration of the magnetic field into the material, which makes it possible to increase the current density. The pinning centers themselves are created from varieties of defects on crystal lattices. The following main types of production or formation of defects at the atomic level are:

- the addition of impurities;
- external influences (radiation);

- creating a planar or ordered structure of defects.

The absence of a theory of the mechanism of superconductivity is compensated by the proposals of many models that allow one to interpret the obtained results, as well as to plan experiments aimed at determining the mutual relationship between structural parameters and superconducting properties. In this work, we apply a model called the “reservoir of charges — the plane”, where the achievement of high critical temperature parameters is associated with the optimal concentration of charge carriers formed by cuprate planes — CuO2.

The cuprate HTSC materials are characterized by a sharp anisotropy of critical currents due to the layered structure of their crystals. It is convenient to use nanosized powders to create defects at the atomic level, which serves as pinning centers. In the search for effective impurities that will make it possible to achieve a high density of pinning centers, the main purpose is to increase the current density. Adding nanosized powders allows to achieve higher efficiency compared to other methods. In the process of selecting the types of nanoadditives, their amount, concentration and nanosize, the main task is to find a compromise between an increase in the critical current density and a decrease in the critical temperature. In the case of the use of nanosized additives, there is a certain lower and upper threshold for the choice of concentration, where an effective increase in the current density and critical temperature occurs. In this work, the types of nanosized powders are determined based on previously obtained results. Therefore, in this work, nanosized powders (5–50 nm) with a complex composition, such as $Co_{0.5}Zn_{0.5}F_2O_4$ and $Ni_{0.5}Zn_{0.5}Fe_2O_4$, are selected. These nanoscale materials are obtained from various magnetic materials. It should be noted that magnetism and superconductivity are interesting topics to study, in view of the fact that they are mutually exclusive. Magnetic nanomaterial can increase the critical current density of superconductors due to the interaction between the network of magnetic fluxes and the magnetic texture. The addition of antiferromagnetic Co-Fe_2O_3, ferromagnetic Fe_3O, and diamagnetic ZnO to BPSCCO enhanced the critical current density. Complex magnetic oxides are potential materials for the center of fixation of magnetic fields by penetrating deep into the material. They have a wide range of properties due to the strong interaction of structural, electronic, magnetic, and even ionic degrees of freedom. In earlier studies in $Cu_{0.5}Tl_{0.5}Ba_2Ca_2Cu_3O_9$, added with 0.08% $Co_{0.5}Zn_{0.5}F_2O_4$ (CZFO), an improvement in the transition temperature by 3.35% and an increase in the hole concentration were shown. The effect of nanopowder additives CZFO and NZFO on the main characteristics of BPSCCO and YBCO materials has not been studied previously. In this regard, in this work, CZFO and NZFO were selected, which is like superparamagnet in nanoscale sizes, and it is also ferromagnetic in the manufacture with a sample.

It was assumed that the critical current density increases when magnetic particles with a characteristic size d are larger than the coherence length, but less than the penetration depth, λ. In this work, nanoparticles with an average size of d = 5-50 nm were added to BPSCCO and YBCO.

Thepurpose of this workis to study the effect of nanoscale powders of fillers CZFO and NZFO in HTSC materials BPSCCO and YBCO on the creation of pinning centers that increase the current density and do not reduce the critical temperature

To achieve this purpose in the thesis, the following objectives were obtained:

- study of the effect of the concentration of nanosized powders $Co_{0.5}Zn_{0.5}Fe_2O_4$ (CZFO) and $Ni_{0.5}Zn_{0.5}Fe_2O_4$ (NZFO) on the critical temperature and critical current density of materials $(Bi_{1.6}Pb_{0.4})Sr_2Ca_2Cu_3O_{10}$и$YBa_2Cu_3O_7$;
- comparison of the properties of samples of bismuth-containing and yttrium-containing HTSC materials containing nanodispersed fillers CZFO and NZFO obtained by solid-phase synthesis and co-deposition;
- determination of the effect of the concentration of nanosized powders and sintering time on changes in the values of the critical temperature and current density;
- comparison of the effectiveness of nanopowder pinning centers in HTSC materials obtained by solid-phase synthesis and co-deposition;

The main provisions to be defended:

1. Pinning centers created by addition of nanosized $Co_{0.5}Zn_{0.5}F_2O_4$powders to the HTSC material $(Bi_{1.6}Pb_{0.4})$ $Sr_2Ca_2Cu_3O_{10}$ in an amount of 0.01-0.1% of the total mass allows increasing the critical current density on 12%, and also contributes to retention of a critical temperature of at least at 100 K, while not increasing the sintering time (up to 125 hours).
2. Pinning centers created by addition of nanosized powders, such as $Ni_{0.5}Zn_{0.5}Fe_2O_4$, to the HTSC material $YBa_2Cu_3O_7$ in an amount of 0.02-0.1% of the total mass allows increasing the critical current density in three times and also allows the critical temperature to be kept at a minimum temperature of 90 K, without increasing the sintering time (at least 50 hours).
3. The application of the method of co-deposition is a more efficient wayto achieve uniformity of HTSC material than the application of the solid-phase synthesis method. And allows to increase twice share of Bi-2223 in comparison to Bi-2212 obtained by the method of solid phase synthesis.

The novelty of the work:

1. The critical characteristics of HTSC material $(Bi_{1.6}Pb_{0.4})_2Sr_2Ca_2Cu_3O_{10}$ with the addition of 0.01-0.5% of the total mass of nanoscale powders such as $Co_{0.5}Zn_{0.5}Fe_2O_4$ and$Ni_{0.5}Zn_{0.5}Fe_2O_4$ were first studied.
2. The critical characteristics of the HTSC material $YBa_2Cu_3O_7$ with the addition of 0.01-0.5% of the total mass of nanosized powders, such as $Co_{0.5}Zn_{0.5}Fe_2O_4$ and $Ni_{0.5}Zn_{0.5}Fe_2O_4$, were studied for the first time.
3. The influence of the concentrations of nanodispersed powders $Co_{0.5}Zn_{0.5}Fe_2O_4$ and$Ni_{0.5}Zn_{0.5}Fe_2O_4$ on the enhancement of characteristics of HTSC materials BPSCCOandYBCO was determined.
4. It was found that the use of the co-deposition method for the preparation of HTSC materials BPSCCO and YBCO with nanoadditives$Co_{0.5}Zn_{0.5}Fe_2O_4$ and$Ni_{0.5}Zn_{0.5}Fe_2O_4$increases twice the proportion of Bi-2223 in comparison to Bi-2212, what is more efficient than using solid-state synthesis.

The theoretical significance of the obtained results lies in the fact that the model concept of delaying (fixing) the creep of magnetic vortex flows over the surface of superconductors, using the artificial introduction of magnetic nanoscale powders, is additionally confirmed. These results allow us to correctly understand the effectiveness of the uniform distribution of nanosized magnetic powders as pinning centers, and can also be used in the further development of pinning centers in HTSC materials.

The practical significance of the obtained results lies in the fact that these nanoscale powders CZFO and NZFO contribute to the creation of effective pinning centers. The results are promising for application in the development of high current density superconducting materials.

Approbation of the work: The results of the dissertation were reported and discussed at the following international scientific and technical conferences:

- American Institute of Physics, Conference Proceedings (USA, 2016);
- Orenburg, Russian Federation, international research agency. New science: Current status and development ways, International scientific periodical following the results of the International scientific-practical conference, December 30, 2016;
- Almaty, K.I.Satpayev Kazakh National Research Technical University, Proceedings of the international Satpayev readings: “The role and place of young scientists in the implementation of the new economic policy of Kazakhstan”, Volume II, 2016;
- Almaty, Al-Farabi Kazakh National University, III international scientific conference of students and young scientists "FarabiAlemi", 2016. Kazakh National University Al-Farabi.

The experimental results were obtained using high-precision modern research methods and devices provided by the foreign supervisor in the laboratory for the study of high-temperature superconductors of the Institute of Applied Physics of the Malaysian National University (Kuala Lumpur, Malaysia), where a study of the properties of high-temperature superconductors BSCCO and YBCO was organized. Also, measurements of the characteristics of the obtained HTSC materials in the laboratories of the NJSC K.I. SatpayevKazNRTU and Al-FarabiKazNU.

The personal contribution of the author lies in the formulation and conduct of experiments, the synthesis and interpretation of the results, writing articles and reports. The purposes and objectives, experiment planning, discussion of the results and the main provisions for protection were discussed with scientific consultants.

Publications. In accordance with the topic of the dissertation, 9 articles were published, of which 4 were published in publications recommended by the Committee for Control in Education and Science of the Republic of Kazakhstan, 1 was included in the Thomson Reuters database in an international scientific journal, 4 were in materials of international scientific conferences, one of which is a foreign conference (included in the Thomson Reuters database) and 1 - thesis.

To achieve the set purpose in the thesis, the following objectives were got:

1. A review of the scientific literature in accordance with the theme of this dissertation.

2. HTSC materials of bismuth-containing and yttrium-containing HTSC materials were obtained by solid-phase synthesis and co-precipitation, comparing the properties of samples obtained by solid-phase synthesis and co-precipitation, in the form of tablets and ribbons.

3. Experimental studies of the critical characteristics of HTSC materials $(Bi_{1.6}Pb_{0.4})Sr_2Ca_2Cu_3O_{10}andYBa_2Cu_3O_7$, such as critical temperature T_c, critical current density J_c with the addition of nanoscale powders $Co_{0.5}Zn_{0.5}Fe_2O_4$ (CZFO) and $Ni_{0.5}Zn_{0.5}Fe_2O_4$ (NZFO)have been carried out;

4. The dependences of the magnetic susceptibility of HTSC materials on temperature are determined.

5. The dependences of the critical temperature and current density on the concentration of nanosized powders (x = 0.00, 0.01, 0.05, 0.1, 0.2, 0.3, 0.4)% are determined.

6. The dependences of the critical temperature and current density on the sintering time of the samples are determined.

7. The effectiveness of nanosizedpowder pinning centers was assessed by comparing the results of other methods for producing pinning centers, for example, such as the radiation method.

8 A comparative analysis of the X-ray diffraction pattern of samples obtained by the solid-state synthesis method and the method of co-deposition with nanoparticles of $Co_{0.5}Zn_{0.5}Fe_2O_4$ and$Ni_{0.5}Zn_{0.5}Fe_2O_4$was carried out.