International Journal of Scientific Research in Physics and Applied Sciences
Vol.11, Issue.3, pp.29-32, June 2023
E-ISSN: 2348-3423
Available online at: www.isroset.org

Research Paper

Magnetic, Electrical and Structural Measurments of $Bi_2Sr_2Ca_2(Cu_{1-x}Fe_x)_nO_{10+\delta}$ (x=0.01 and n=3)

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Received: 10/Mar/2023; **Accepted**: 24/Apr/2023; **Published**: 30/Jun/2023

Abstract— In this research work, we are presenting a study of the magnetic, electrical, and morphological properties of the $Bi_2Sr_2Ca_2(Cu_{1-x}Fe_x)_3O_{10+\delta}$ bulk superconductor. The hysteresis curve of the sample displays the magnetization of the applied magnetic field at ±15k (Oe), which exhibits paramagnetic behavior in the sample and reports a squareness ratio of 0.2. It is suggesting the presence of a single magnetic domain in the sample. We measured the electrical resistance by Four Prove method from room temperature to liquid nitrogen temperature range, which shows the metal and semiconducting transition, since the curve is linearly decreasing order nearly 200K temperature. After that, the resistance again slowly increases and shows semiconducting behavior. We studied morphology of the sample by FE-SEM, and collected structural data. These morphological representations show platelet type layered structures at the micron range in the sample. These results are quite similar to Bi-2223 ceramic superconductor.

Keywords— Superconductors, bismuth compounds, electrical and magnetic study, morphology, hysteresis curve, FE-SEM.

1. Introduction

Technology continues to develop at an astonishing rate every day, and many people cannot comprehend this. The age of new technology also increases the scientific research. It is becoming more competitive and interesting, as more researchers wanted to expand and invent different ideas. As a tool to aid effective technology, we can say that the three most expanding fields are telecommunication, computing and transport. Nowadays, all technological improvements in these fields illustrate the quick way to success. Superconducting materials play a very important and interesting role in the expansion of the said technology and fields. In 1988, H. Maeda et al. investigated superconductivity in the Bi-Sr-Ca-Cu-O superconductors [1]. Researchers observed three superconducting phases, in terms of its chemical compositions, Bi-2201, Bi-2212 and Bi-2223, in the Bi–Sr–Ca–Cu–O (BSCCO) system. These superconductors have 110K critical temperature, which develops more interest in their construction [2-4]. The Bi-2223 type superconductors show ceramic properties at room temperature and show high resistance, but at low temperature these show superconducting behavior [5-9].

2. Experimental Details

Some researchers have reported that the particle size reduction in the material plays a key role in the change of physical properties [10-12]. Therefore, we focused on this phenomenon of particle size reduction, and investigated the changes in the physical properties of the Bi-2223 ceramic sample. We used a ball mill to grind the stoichiometric compound and adopt the progressive milling process. Single-phase Bi-2223 was prepared by the traditional solid-state reaction method as reported by the researchers [13-14].Successively, it was ball milled for different times up to 6 hours to get the powder of very tiny particles. A systematic investigation of the structural, micro structural, electrical and magnetic properties of ball milled ceramic powder $Bi_2Sr_2Ca_2(Cu_{1-x}Fe_x)_3O_{10+\delta}$. was performed. The samples were also characterized by several techniques, like field emission scanning electron microscopy (FE-SEM). The electrical and magnetic properties were also studied by four prove technique and magnetic field dependence of the magnetic Hysteresis curve, respectively.

The X-Ray diffraction (XRD) study and Fourier Transform Infrared (FTIR) study has done for the sample $Bi_2Sr_2Ca_2(Cu_{1-x}Fe_x)_3O_{10+\delta}$ (x=0.01 and n=3). These studies show an initial growth of Bi-2223 superconducting phase in the sample and

FTIR confirms the bond formation of Bi-2223 phases as reported elsewhere [15-16]. In this paper, we are reporting on the study of magnetic, electrical and morphological properties of the sample. There is a lot of information that can be collected from these studies about the superconducting material and they are very beneficial for discovering different superconducting characteristics.

2.1 Morphological Measurement with (FESEM)

We have carried the Morphological measurement using Field Emission Scanning Electron Microscope (FE-SEM) at different scales. These are shown in figure-1. We captured all the pictures at room temperature; that demonstrate an even distribution of particles and several plate-like formations.

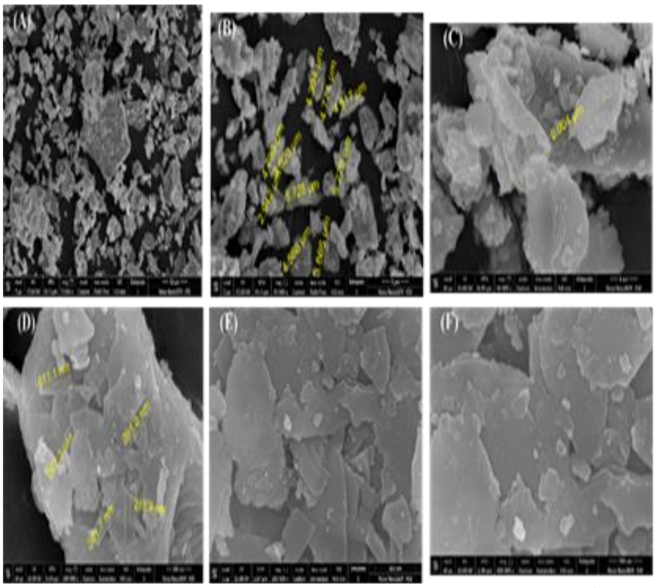

Figure 1. Surface morphological image (A), (B), (C), (D), (E), (F) of sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$.

2.2 Magnetic (VSM) and Electrical (Four Prove) Measurement

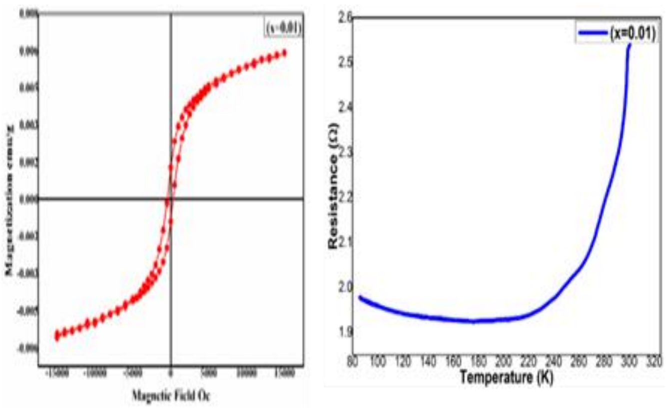

Figure 2. (a) Hysteresis loop at room temperature of the sample and (b) Resistance Versus Temperature curve of sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$

It has carried the Magnetic measurement on the sample using Vibrating Sample Magnetometer (VSM). A magnetic field up to ±15K (Oe) was applied on the sample at room temperature. Then the graphical data between applied magnetic field H(Oe) versus magnetization MS (emu/g) induced automatically. In the resulted a hysteresis loop is plotted at room temperature of sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$) as shown in figure-2(a).

It has carried the Electrical resistance measurement on the bulk sample using Four Prove method from room temperature to liquid nitrogen temperature. We used a silver pest to make four connections on the pellet sample as described by the researcher [17]. Then the graphical data between Resistance (R) Ω and Temperature (T) K induced automatically. The R verses T curve is drawn and shown in figure-2(b).

3. Results and Discussion

This section contains the Magnetic, Electrical and morphological analysis of the sample. The hysteresis curve at room temperature of sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$shown in figure-2 (a) is clearly depicted that the saturation magnetization (+MS) was observed as 0.000789 emu/g on saturation Magnetic field 14990 (+Hs) and remanence magnetization (MR) was observed as 0.000172 emu/g on applied Magnetic field -4(Hr). The coercivity (HC) of the sample varies between 505 (-Hc) and 400 (+Hc). Similarly, in opposite direction, saturation magnetization (-MS) was observed as 0.000742 emu/g on saturation Magnetic field 15006 (-Hs) and remanence magnetization (-MR) was observed as 0.000118 emu/g on applied Magnetic field -7 (-Hr). The ratio of saturation magnetization and remanence magnetization is known as the Squareness ratio (MR/MS). Thus, the calculated value of Squareness ratio (MR/MS) is found to be 0.2178 at room temperature and in the opposite direction, it comes out to be 0.1591. Therefore, the sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$(x = 0.01) shows the paramagnetic behavior [18]. The spin and unpaired electrons of the sample lead to a magnetic behavior in it, resulting in increased resistance. This is because the sample has a magnetic dipole moment and behaves like small magnets. Therefore, the sample is the form of magnetism and it is weakly attracted by an externally applied field. The internal and induced magnetic fields form when a magnetic field is applied. It is seen that the Squareness ratio is close to 0.2, showing that the sample is creating a single magnetic domain [19].

The sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$ did not show the superconductivity phenomenon at low temperature with iron concentration (0.01) as shown in figure-1(b). This sample shows resistance 2.5393Ω at room temperature. When we start the cooling process or decrease the temperature by liquid nitrogen on the sample, then the resistance decreases linearly. The continuous linear behavior of the sample exists at low temperature 176.53K with resistance 1.9236Ω, which shows the metallic transition of the sample. After this observation, it is noticed that the resistance of the sample increases linearly for the further low-temperature range. The linear behavior of the sample was continued at low temperature 85.89K with resistance 1.9780Ω, which shows the insulating and semiconducting transition of the sample. Probably, these results are obtained due to the low grains connectivity and disordered nano particles. This insulator or semiconductor behavior can occur due to the deficiency of oxygen or coupling in CuO_2 planes [20-21]. Therefore, there is no Tc and Tc onset temperatures were observed.

We studied the grain size and structure of the sample using field emission scanning electron microscope (FE-SEM). The FE-SEM images of sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$ were carried out at micro scale 10µm, 5µm, 1µm and at nano scale 500nm, 400nm and 200nm as shown in figure-1 (A), (B), (C), (D), (E) and (F) respectively. The high voltage of 15kV was applied on the sample surface which produced the magnification as 5000, 10000, 50000, 100000, 200000 and 300000 and shown the images (A), (B), (C), (D), (E) and (F) respectively. The image (A) at 10 µm represents randomly distributing of micro and nano particles. Images (B), (C) and (D) show the arrangement of particles with nano and micro labels as platelet-like layered structure of the sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$. Particularly for image (D) at one micron range, a number of plate-like structures in layers can be seen clearly, which indicates the initial phase of Bi-2223 superconductor.

4. Conclusion

The study of the sample $Bi_2Sr_2Ca_2(Cu_{0.99}Fe_{0.01})_3O_{10+\delta}$shows the initial growth of Bi-2223 ceramic superconductor. However, it could not get the superconducting transition, may be due to unpaired electrons. The improper heating for required hours of the sample may bea primary cause. Therefore, the unpaired electrons created the magnetic moment, and it made the sample paramagnetic, while a superconductor has diamagnetic property. So, this sample shows the metal semiconductor transition at low temperature.

Data Availability

The data are collected from Department of Physics, Himachal Pradesh University, Shimla by Dr. Arun Kumar providing VSM facilities and electrical resistance measurement facilities at liquid Nitrogen temperature by Prof. K. L. Yadav, Department of Physics, I. I. T. Roorkee, Uttarakhand. The MNIT Jaipur (Rajasthan) provided FE-SEM facility for the measurement of in our samples.

Conflict of Interest

Authors do not have any conflict of interest.

Funding Source

All the characterization and measurement are carried out by funding RGNF Fellowship U.G.C Delhi.

Authors' Contributions

The corresponding author Dr. Rohitash Kumar collected all the experimental data form mentioned laboratories and the data was discuss with Dr. Yadunath Singh. So, both the authors have contribution experimentally and theoretically.

Acknowledgements

We are very thankful to Dr. Arun Kumar, Department of Physics, Himachal Pradesh University, Shimla for providing VSM facilities and also enlighten us during the detailed discussions. We are also thankful to Prof. K. L. Yadav, Department of Physics, I. I. T. Roorkee, Uttarakhand for providing electrical resistance measurement facilities at liquid Nitrogen temperature. Authors are also thankful to MNIT, Jaipur (Rajasthan) for providing facility for the measurement of FESEM in our samples. The financial assistance to carry out this work provided by U.G.C., New Delhi, was gratefully acknowledged.

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