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AN EVALUATION OF THE TEMPERATURE DEPENDENCE MAGNETORESISTANCE OF $Bi_2Sr_2CaCu_2O_8$ SUPERCONDUCTOR ALONG A-B PLANE AND C PLANE

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ABSTRACT

In this paper, we have evaluated the temperature dependence magnetoresistance of $Bi_2Sr_2CaCu_2O_8$ monocrystal in the a-b plane and along the c-direction for magnetic fields 0T, 0.5T and 7T. We have given the magnetic field dependence of critical current densities obtained from magnetisation and transport measurements for Pb-depend BiSrCaCuO/Ag superconducting tape at 20K. We have given the ratio of magnetisation to transport critical current densities at 20K, 35K and 50K. The result indicates that the ratio J_c M/J_c T decreases very fast for T=50K and very slowly for T 20K. Similarly J_c decreases very slowly for magnetisation and very fast for transport at fixed temperatures. Our temperature dependent magnetoresistance in the a-b plane of $Bi_2Sr_2CaCu_2O_8$ monocrystal for 0T indicates a sharp decrease after 90K, for 0.5T a sharp decrease is observed at 60K and for 7T the decrease is noticed from 30K. This shows that the magnetoresistance of the cuprate in the normal state is not very much affected by the application of small or moderate magnetic fields. A study of $YBa_2Cu_3O_{7-\delta}$ showed very little change in the transverse and longitudinal magnetoresistance for field upto 10T and temperature upto 150K. For higher fields at 150K, the longitudinal magneto resistance was found to increase and is transverse counterpart was found to decrease as the applied field was raised to 43T.

Keywords: *Four Probe Method, Hall effect, magnetisation, magnetoresistivity, polycrystalline, quantum wires, superconductivity, superconductor, yattrium compound.*

1. INTRODUCTION

The effects of applied magnetic fields on the flow of transport currents in the a-b plane and c plane have been studied. Biggs et al. [1] have studied the temperature dependence of the critical current J_c determined by the magnetisation method for a magnetic field applied parallel to the Cu-O planes. The results indicate that J_{ab} ($10^4 A/cm^2$) decreases with the temperature T (K) increases. Schmitt et al [2] have studied the magnetic field dependence of the transport current of a $Bi_2Sr_2CaCu_2O_8$ epitaxial film determined at 4.2K and 60K for magnetic fields applied parallel to the Cu-O planes i.e. $\underline{B} \perp c$ and perpendicular to Cu-O planes. The results indicate that the critical current is smaller when the field is applied along c, perpendicular to the plane of the film, than when it is applied in the plane. One observes that the drop-off in J_c with increasing field is especially pronounced at 60K and more less so at 402K. Ekin et al. [3] and Lon et al [4] have made a more comprehensive study of the magnetic field dependence of transport current in grains aligned $YBa_2Cu_3O_{7-\delta}$. The grains were platelets 5 micron in diameter with the c axis perpendicular to the plane forming blocks approximately 1mm x 1 mm in cross-section and 15mm long. This results show that applying the field along the c direction ($B \perp ab$) counts a greater decrease in the current than applying the field in the plane ($B \parallel ab$). The current decreased much less with increasing field at 4K than it did at 76K. In all of these measurements, the applied field and current flow were perpendicular. Force-free values of J_c were determined by rotating the applied field along J_c, which increased the critical current. The dependence of the critical current on the angle which the applied field makes with the c direction suggests that J_c depends on $\rho_{ab}\delta_{in}^2(H)$. M.P. Marley et al. [5] found that the applied field degraded the magnetisation currents to a greater extent than did the transport currents. In this paper, we have studied the resistivity of a wire in the pressure of magnetic field, which ordinarily is applied transverse to the current direction. This resistivity, called the magnetoresistivity (ρ_m) is the same as the zero-field resistivity & for some metals, though it has a different value for others.

2. MATHEMATICAL FORMULATION USED IN THE EVALUATION

Consider the current flow situation in the absence of a magnetic field. The following current produces the potential difference $(V_2 - V_1)$ between the ends of the wire. The resistance 'R' as given by Ohm's law is

$$R = (V_2 - V_1)/I \qquad (1)$$

In this way it can be written in terms of the current during $J = I/ad$ where 'a' is the thickness and 'd' is the width. The longitudinal electrical field $E_y = (V_2 - V_1) / L$ to give for the resistivity.

$$\rho = E_y / J \qquad (2)$$

Which is equivalent to

$$\rho_0 = E / J \qquad (3)$$

where ρ_0 is dc electrical resistivity. When a transverse magnetic field is applied, a transverse Hall effect field $\vec{E} = \vec{V} \times \vec{B}_{app}$ is induced than separate the charge on either side of the wire. A resistance measurement provides the magnetoresistivity ρ_{xy} .

$$\rho_{xy}=E_y/ J \quad (4)$$

This is more precisely called the transverse magneto resistivity. The longitudinal magneto electric is defined for a magnetic field aligned along the directions of current flow. For ordinary conductors the applied field does not affect the longitudinal current flow, so that the resistance of the wire is field independent and ρ_m = 1. However, at very high magnetic fields the trajectories of the electrons deflected by the field can be open, i.e. extending from one Brillouin zone into the next or they can choose on themselves in k-space, making the situation complicated. The magnetoresistivity often tends to increase with increasing magnetic fields strength, but in some cases it saturates, i.e., approaches a field independent value at the highest fields. The resistivity of $YBa_2Cu_3O_{7-\delta}$ is around two orders of magnitude greater along the c-axis than parallel to ab plane than ρ_c/ρ_{ab} = 100 and for $Bi_{2+x}Sr_{2-y}CuO_{6-\delta}$ ($\rho_c/\rho_{ab} = 10^5$). [10] The temperature dependence of these resistivity measured exhibits a plane near T_c. When the data is fitted to the expression [11]

$$\rho_{ab} = \frac{A_{ab}}{T} + B_{ab}T \quad (5)$$

$$\rho_c = \frac{A_c}{T} + B_cT \quad (6)$$

by putting $\rho_{ab}T$ and ρ_cT from data of Hagen et al. [12] v/s T^2. The angular dependence of the resistivity is found to obey the expression. [13]

$$\rho(H) = \rho_{ab}\delta_{in}^2(H) + \rho_c\delta_{in}^2(H) \quad (7)$$

where (H) is the percentage of the current dimension relative to the c-axis. Typical measured resistivity of polycrystalline samples are much closer to the in-plane values. The anisotropy ratio ρ_c/ρ_{ab} = 100 is so large that the current encounters less resistance when it follows a longer path in the planes when it takes the shorter path perpendicular to the planes. So it tends to flow mainly along the crystalline planes. Each individual current zigzags from one crystal lattice to the next, so that its total path is longer than it would be if all of the crystallites were aligned with this plane parallel to the direction of the current. The increase in the resistivity of a poly crystalline sample beyond ρ_{ab} can be a measure of how much the average path length increases. One measures the resistivity of a sample by Four Probe Method. For a high temperature superconductor, one requires two samples for the resistivity determination, one with the c-axis along the current flow direction and one with the c-axis perpendicular to this direction. Transverse and longitudinal resistance determines R_t and R_l respectively can both be made on a sample cut in the shape of a rectangular solid with a = b with the shorter c-axis along the current division. These resistances R_t and R_l can be used to calculate the resistivity ρ_{ab} in the a, b plane and resistivity ρ_c perpendicular to the plane i.e. along c-axis. The expression that relates the resistances depend on the parameter x.

$$x = c / a(\rho_c / \rho_{ab})^{1/2} \quad (8)$$

For the limiting case x << 1 the measured resistance and given by[14]

$$R_t = \frac{a}{bc}\rho_{ab}\left[1 - \frac{4 ln2}{\pi x}\right], \text{ where } x << 1 \quad (9a)$$

$$R_l = \frac{c}{ab}\rho_c\left[\frac{16 exp(1-\pi/x)}{\pi x}\right], \text{ where } x << 1 \quad (9b)$$

and for opposite limit x >> 1, one has

$$R_t = \frac{a}{bc}\rho_{ab}\left[\frac{16 exp(-\pi/x)}{\pi}\right], \text{ where } x >> 1 \quad (10a)$$

$$R_l = \frac{c}{ab}\rho_c\left[1 - \frac{4 ln2}{\pi x}\right], \text{ where } x >> 1 \quad (10b)$$

Both the resistance with the exponential factor and the common term containing the factor $\frac{4 ln2}{\pi}$ are small. When a current flows along a film of thickness d through a region of surface with dimensions a x a, it encounters the resistance R_s which is given by

$$R_s = \frac{\rho a}{a d} = \rho/d \quad (11)$$

The resistance ρ/d is called the sheet-resistance and is independent of the length of side a. It is analogous to the surface resistance $R_s = \rho/\delta$ of a metallic surface interacting with an incident-high frequency electromagnetic wave, when δ is the thin depth of the material at the frequency of the wave. There is a quantum of resistance $h/4e^2$ with the value $h/4e^2 = 6.45 k\Omega$ when the range is 21 per pair. It has been founded experimentally [15] that bismuth and lead films deposited on germanium substrates greater than 0.673 nm and 0.328 nm respectively. Thinner films exhibit resistivity increases down to the lower measured temperatures. Copper-oxide planes in high-temperature superconductor can be considered as the conducting layers with thickness 'c' for $YBa_2Cu_3O_{7-\delta}$ corresponding to a sheet resistance ρ_{ab} /½c. Using this layer approximation the Ioffe-Regel parameter $k_F l$ can be estimated

$$k_F l = \frac{\text{conductance per square}}{\text{conductance quantum}} / \frac{h/4e^2}{2\rho_{ab}/1/2c} \quad (12)$$

when the conductance is the reciprocal of the resistance. Two reported the 1 values for $YBa_2Cu_3O_{7-\delta}$ calculated by this method gives $h = 4.6 \times 10^{-7}$ cm^{-1}. It is of interval that metallic contracts of atomic six exhibit conduction jump [16] at interval multiples of $21^2/h$ and the Hall effect resistance in one-dimensional objects so called quantum wires [17], is quantized to $h/2Ne^2$ where N =1, 2, 3……….

3. RESULTS AND DISCUSSION

In this paper, we have evaluated the temperature dependence of magnetoresistance of $Bi_2Sr_2CaCu_2O_8$ monocrystal in the a-b plane and along the c-directional for magnetic fields 0, 0.5 and 7T. The results are shown in Table – 1 to Table – 4. In table 1, we have given the magnetic field dependence of critical-current densities obtained from magnetisation and transport measurements for Pb-depend BiSrCaCuO/Ag superconducting tap at 20K.

Table – 1

Magnetic field dependence of critical current densities obtained from magnetisation and transport measurements of Pb-doped BiSrCaCuO/Ag super conducting tape at 20K.

Magnetic Field B(T)	Critical Current density J_c (A/cm^2)	
	Magnetisation	Transport
1	5.4×10^4	8.6×10^4
2	6.8×10^3	8.6×10^4
3	4.0×10^3	7.5×10^4
4	2.0×10^3	6.8×10^4
5	8.7×10^2	6.0×10^4
6	6.5×10^2	5.2×10^4
7	5.0×10^2	4.7×10^4
8	4.1×10^2	4.2×10^4
9	3.8×10^2	4.2×10^4
10	3.8×10^2	3.5×10^4
11	2.0×10^2	2.6×10^4

In table 2, we have given the ratio of magnetisation to transport critical current densities at 20K, 35K and 50k.

Table - 2

Evaluation of ratio of magnetisation to transfer critical current densities J_cM/J_cT at 20K, 35K and 50K for Pb-doped BiSrCaCuO/Ag superconducting tape as a function of magnetic field.

Magnetic Field B(T)	J_cM /J_cT		
	T=50K	T=35K	T=20K
1	1.25	1.35	1.45
2	1.20	1.30	1.40
3	0.98	1.22	1.32
4	0.75	1.17	1.22
5	0.62	1.05	1.15
6	0.57	0.93	1.08
7	0.50	0.90	1.02
8	0.30	0.87	0.98
9	0.20	0.80	0.93
10	0.10	0.72	0.90

The result indicates that the ratio J_cM/J_cT decreases very fast for T=50K and very slowly for T = 20K. Similarly J_c decreases very slowly for magnetisation and very fast for transport at fixed temperatures.

Our temperature dependent magnetoresistance in the a-b plane of $Bi_2Sr_2CaCu_2O_8$ monocrystal for 0T indicates a sharp decrease after 90K, for 0.5T a sharp decrease is observed at 60K and for 7T the decrease is noticed from 30K. This shows that the magneto resistance of the cuprate superconductor in the normal state is not very much affected by the application of small or moderate magnetic fields.

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Table - 03

An evaluation of temperature dependence of magnetoresistance in the a-b plane of $Bi_2Sr_2CaCu_2O_8$ monocrystal for magnetic field 0T, 0.5T and 7.0 T.

Temperature (K)	ρ_{ab} ($\mu\Omega$-cm)		
	H=0T	H=0.5T	H=7T
20	0.0	0.0	0.0
30	0.0	0.0	10.8
40	0.0	0.0	30.9
50	0.0	0.0	50.2
60	0.0	20.2	100.6
70	0.0	50.8	150.8
80	0.0	120.9	180.2
90	0.6	150.6	220.6
100	2.0	180.8	250.5
110	3.0	200.7	290.6
120	4.0	230.2	310.6
130	5.0	250.6	340.2
140	6.0	270.8	360.8
150	8.0	290.9	400.2

A study of $YBa_2Cu_3O_{7-\delta}$ showed very little change in the transverse and longitudinal magnetoresistance for field upto 10T and temperature upto 150K. For higher fields at 150K, the longitudinal magnetoresistance was found to increase and in transverse counterpart was founded to decrease rapidly as the applied field was raised to 43T.

In the superconducting state the pressure of an applied magnetic field shifts the transition temperature downward and broadening the transition temperature. This has been shown below in table 4.

Table - 4

An evaluation of temperature dependence of magnetoresistance along c-direction of a $Bi_2Sr_2CaCu_2O_8$ monocrystal for magnetic fields of 0, 0.5 and 7T (H∥c)

Temperature (K)	ρ_c ($\mu\Omega$-cm)		
	H=0T	H=0.5T	H=7T
20	0.0	0.0	0.0
30	0.0	0.0	0.0
40	0.0	0.0	0.08
50	0.0	0.0	0.20
60	0.0	0.05	0.50
70	0.0	0.10	1.20
80	0.0	0.15	1.30
90	1.0	0.20	1.50
100	1.12	0.80	1.65
110	1.15	1.0	1.72
120	1.20	1.15	1.88
130	1.25	1.20	1.98
140	1.28	1.30	2.00
150	1.30	1.50	2.05

Hence the magnetoresistivity in c dimension ρ_c is found to be zero as 80K for magnetic field of 0T (i.e. in the absence of magnetic field) and ρ_c is zero at 50K at 0.5T and zero at 30K for 7T. Some downward shift is also to be expected. Similar results have been reported [18-23] for $(La_{1-\delta}Sr_\delta)_2CuO_4$, $Nd_{1.85}Se_{0.15}CuO_4$, $YBa_2Cu_3O_{7-\delta}$ and $Ti_2Ba_2CaCu_2O_8$.

The ratio of ρ_{ab} and ρ_c i.e. ρ_c/ρ_{ab} = 150 for $YBa_2Cu_3O_{7-\delta}$ and ρ_c/ρ_{ab} = 5600 for $Bi_2Sr_2CaCu_2O_8$.This demonstrate that the bismuth compound is much more anisotropic. This also constitutes one of the principal differences between the two superconductors.[24] The n-type superconductor $Nd_{1.85}Ce_{0.15}CuO_4$, $YBa_2Cu_3O_{7-\delta}$ has

ρ_c / ρ_{ab}= 310 which is closer to the values for the yattrium compound. [25] The shift and broadening of the in-plane resistivity (ρ_{ab}) plots are greater for applied fields along the c-axis than for applied fields in the a-b plane.

4. CONCLUSION

Magnetoresistance studies give the fact that the resistivity of superconductor are different in different crystallographic axes. It is larger in a-b plane and smaller in c plane.

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