YBCO Superconductors and a Comparative Study on Scattering Strengths

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Abstract—**Achieving of zero resistance during the conduction in certain materials below a characteristic temperature was discovered by Heike Kamerlingh Onnes on April 8, 1911. A normal conductor shows some resistance even near absolute zero but in a superconductor, when the material is cooled below its critical temperature, the resistance drops abruptly to zero. With no power source, an electric current flowing in a loop of superconducting wire persists indefinitely. As the superconducting systems promise wide range of applications for the human welfare, particularly in the areas of communication, memory devices, medical scanners etc., therefore, measuring of their thermal conduction has been a great interest of the researchers. Due to its peculiar structure and configuration, YBCO has been most studied material. The present paper discusses about the YBCO i.e. $YBa_2Cu_3O_7$ Superconductors considering the experimental work carried out by Cohen et. al.**

Simulation technique is being applied in measuring the conductivity of YBCO superconductor in the temperature range from 10 K to 280 K and observations show a good agreement with the experimental results between 10 to 40K and 160-240K and poor in the range 40 – 160 K; whereas beyond 240K i.e. upto 280K has also been measured for which the experimental results are yet to be found.

Thus, the present mathematical model validates the estimation of the thermal conductivity of $YBa_2Cu_3O_7$ superconductors upto 240K and comparing with other results, impact of the scattering strengths can be noticed.

Keywords- *YBCO Superconductors, Scattering Strength, Simulation*

I. INTRODUCTION

Achieving of zero resistance during the conduction in mercury at cryogenic temperature was discovered by Heike Kamerlingh Onnes on April 8, 1911. A normal conductor shows some resistance even near absolute zero but in a superconductor, when the material is cooled below its critical temperature, the resistance drops abruptly to zero. With no power source, an electric current flowing in a loop of superconducting wire persists indefinitely[1]. The characteristics of superconductivity appear when the temperature T is lowered below a critical temperature Tc; which varies from material to material. During the next 75 years, the variation of only 10 to 20K transition temperature was observed. Above the boiling point of liquid nitrogen-77 K, the discovery of high temperature superconductors with transition temperature near 90K led the scientists to deeply research the YBCO material. Thus, Due to its peculiar structure and configuration, YBCO has become the most studied material. The presence of two layers of CuO2 and one Cu–O chains have been the key feature; which play an important role for superconductivity.

In conventional superconductors, electrons are held together in pairs by an attraction mediated by lattice phonons. The characteristics of superconductivity appear when the temperature T is lowered below a critical temperature Tc as shown in the Figure-1, which varies from material to material. There are mainly three properties of superconductors materials viz. the critical temperature (Tc) below which zero resistance is reached, the critical current density (Jc) which indicates the maximum current carried without losing the superconducting state, and, to tolerate the maximum magnetic field (Hc, the critical magnetic field). Due to these characteristics and reasons, its usage became a cost effective for its commercial applications.

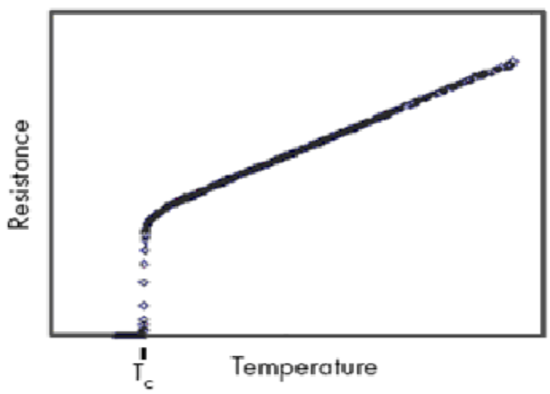

Figure 1. Critical Temperature Tc

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To leverage its benefits researchers have been carried their work in medical imaging systems, superconducting quantum interference devices (SQUIDS), infrared sensors, analog signal processing devices, microwave devices, power transmission, superconducting magnets in generators, energy storage devices, particle accelerators, levitated vehicle transportation, rotating machinery, and magnetic separators. The superconducting systems promise wide range of applications[2-3] for the human welfare, particularly in the areas of communication, memory devices, medical scanners etc. In the directions of superconducting fault current limiters, superconducting power transmission lines, new MRI-magnets and applications, increased performance/ low power consumption superconducting electronics some experiments have been successfully observed [4]. In the field of electricity or power grid, projects [5] have also been going on e.g. the Korean Power Transmission Line project and the SMES in the USA. This is to make them cost effective for the commercial usage. These innovative efforts are on the way by the research scientist and its accelerated growth [6] is envisaged to foresee the potential applications.

Therefore, measuring of their thermal conduction has been a great interest of the researchers [7-8]. The present papers also caries a numerical test for the estimation of thermal conductivity of $YBa_2Cu_3O_7$ Superconductors incorporating various scattering processes involve during the conduction. The results has been taken using computer-based simulation technique in the temperature range from 10 K to 160 K and show a good agreement with the experimental results up to the 160 K. This validates the present mathematical model for the estimation of the thermal conductivity of $YBa_2Cu_3O_7$ superconductors.

The following sections discuss over the conductivity measurement and analysis. Lastly a discussion with the conclusion hasve been made.

II. CONDUCTIVITY MEASUREMENT

A numerical test has been carried out here just to show that how thermal conductivity is computed via computer-based simulation technique. A mathematical model [9] has been considered for the present analysis. This model has also been used in a modified form[10-11]. The model is as follows:

$$K = A\, t^3 \int x^4 e^x / [(e^x -1) 2 . F(t, x)]\, dx \qquad ....(1)$$

Where F(t,x) is -

$$F(t,x)=[1+\alpha x^4t^4+\beta x^2t^2+ \gamma txg(x,y)+ \delta x^3t^4+ (\in_1 + \in_2 e^{-\Theta/aT})\, x^2t^5] \; ....(2)$$

The parameters A, α, β, γ, δ, $\in_1$ and $\in_2$ stand for boundary scattering, point defect scattering, sheet like fault, electron–phonon scattering, interference scattering (between point defect and 3-phonon processes), 3-phonon normal and U-scattering, respectively. Another term, t (= T/Tc) is the reduced energy, where Tc is the transition temperature of $YBa_2Cu_3O_7$ superconductors. The above mentioned Equation (2) differs from that of Ravindran et. al.[12] where they have neglected exponential dependence of U-processes contained along with the term $\in_2$. Second difference is that they have represented 3-phonon U-processes by the term $\in x^2t^4$ whereas presently it is taken as $(\in_1 + \in_2 e^{-\Theta/aT})\, x^2t^5$ respectively. The model is being simulated in the temperature range of 10 K to 280 K. Observation shows some good agreement with the experimental results. On the similar YBCO sample, previous work has considered the Umklapp scattering [13] and in the present work, the boundary, point defect, sheet like fault, electron-phonon, and interference scattering strengths have been changed. This comparison has been shown in the Table-1 as follows:

TABLE I. YBCO Scattering Strengths

Ref.	A	α	β	γ	δ	$\in_1$	$\in_2$
Bhatt & Gairola (2001)	**4.8**	**60**	**35**	**300**	**150**	**.02**	**.02**
Present	**6.0**	**15**	**50**	**50**	**200**	**.02**	**.02 .**

The difference between these Umklapp and normal has been discussed in the discussion section. Among the simulated responses, only closet to the experimental results have been figured out in the following Table-2.

TABLE II. YBCO Conductivity Values

Temp./K	**10**	**20**	**30**	**40**	**50**	**60**
Conduct. / w/mK	**2.1419**	**4.2895**	**5.4007**	**5.9082**	**6.1053**	**6.1388**
Temp./K	**70**	**80**	**90**	**100**	**110**	**120**
Conduct. / w/mK	**6.0784**	**5.9593**	**5.8019**	**5.6203**	**5.4250**	**5.2237**

Temp./K	130	140	150	160	170	180
Conduct. / w/mK	5.0221	4.8241	4.6323	4.4484	4.2731	4.1070
Temp./K	190	200	210	220	230	240
Conduct. / w/mK	3.9499	3.8018	3.6622	3.5308	3.4071	3.2906
Temp./K	250	260	270	280		
Conduct. / w/mK	3.1809	3.0774	2.9798	2.8877		

The Figure-2 shows the experimental results of three samples of YBCO. The present analysis has been carried over the sample C, which has been graphically shown as the upper most curves in the Figure-2 (curve marked with O symbol).

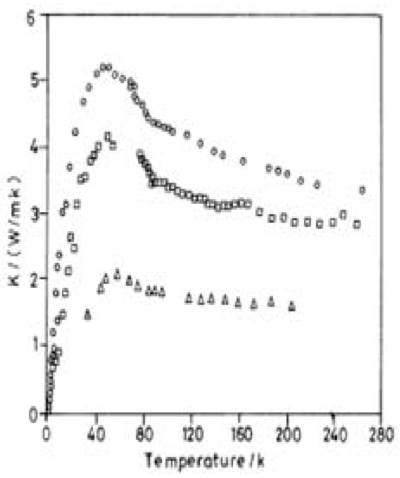

Figure 2. K vs T graph of YBCO samples: □, sample A; Δ, sample B; O, sample C (Cohn et al.[12]).

Corresponding to the values tabulated above in the Table-II has been plotted as shown in the Figure-3.

The present analysis as depicted in the Figure-3, shows good agreements with the experimental results between 10 to 40K and 160-240K and poor in the range 40 – 160 K; whereas beyond 240K i.e. up to 280K has also been measured but needs to be validated from the experimental results which is yet to be noticed.

Another fact can also be drawn from the Table-II, that deviation in the temperature region from 40 to 160 K can be attributed due to changes in the values of scattering strength other than the Umklapp processes as reported by Bhatt & Gairola[13].

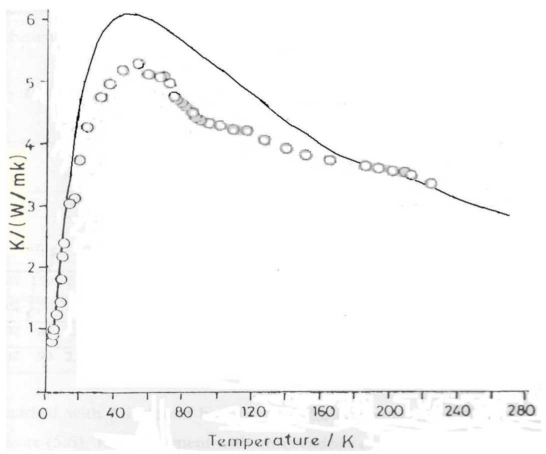

Figure 3. YBCO Conductivity Curve for Sample C

The above facts depicts the combined impact of scattering strengths keeping the Umklapp scattering strengths constant and is also being critically examined in the following section.

III. ANALYSIS

For different YBCO samples as shown in the Figure-2, the present work is carried to measure the conductivity of the sample-C. In contrary to the earlier work, the present analysis considers the change in the boundary scattering (A), point defect scattering (α), sheet like fault (β), electron-phonon scattering (γ), and interference scattering (δ) strengths as shown in the Table-1. Other scattering strengths are the same taken into account like the boundary scattering (A), point defect scattering (α), sheet like fault (β), electron-phonon scattering (γ), and interference scattering (δ) respectively.

Simulation technique is being applied in measuring the conductivity of YBCO superconductors the temperature range from 10 K to 280 K. This analysis differs from the work reported by Ravindran et.al.[12] and Cohen et.al[9]. Ravindran et.al.[12] have carried the work on the sample A and Cohen et.al[9] have included the 3-phonon processes by adding the term $\in x^2t^4$ for the sample C whereas in the present study this term is $\in x^2t^5$. In addition, the present study also includes the interference scattering by adding the term δx^3t^4. A good agreement with the experimental results have been found between the temperature range 10 to 40K and 160-240K and poor agreement in the range 40 – 160 K. Beyond 240K i.e. upto 280K, conductivity has also been measured but it needs to be validated from the experimental results which is yet to be found. As far as the impact of the boundary scattering is concerned, an enhancement in conductivity level in the temperature region upto 40K can be attributed[14] due to increase of its (boundary scattering) value. In another approach [15], by increasing the value of sheet-like fault(β) decrease in the conductivity level was examined.

IV. DISCUSSION

The applications of superconductors have been provided in various fields like distribution of electricity where 7% power save has been found[16] by replacing the copper cables with the HTS. About 50% reduction has also been reported [17,18] in the large industrial motors using HTS materials. Increasing demand in the world for the electricity is one of the biggest challenge particularly for the advanced countries like America where two times increase has been expected by 2030 [19]. Recently, emerging benefits with its challenges have been reported and few suggestions have also been compiled[20]. Therefore, aiming to these benefits and considering the challenges, some method should be devised so that in coming future this material could be made commercial viable in the walk of human life.

Since, many researchers are working to study this material for example, in estimating the conductivity and then examining the role of various kinds of scattering strengths could pave the way to mimic the properties with the help of simulation and modeling approach[21] without consuming much resources prior to the actual experimental work.

V. COCLUSION

Significant work has been progressing towards the applications of YBCO material and no doubt in near future use of HTS based applications will be more viable. As far as impact of various scattering strengths involved in the estimation of the conductivity is concerned, the proposed model is suitable to examine the role of each scattering strength with the help of simulated technique. In the present observation, it has been examined that by increasing the boundary scattering, conductivity level is increased whereas in contrary to this, decrease in the sheet-like fault scattering gives a raise in the conductivity. Therefore, several kinds of inferences can be noticed towards the behavior of these scattering strengths.

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