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Fast, accurate and robust determination method for critical temperature of superconductors

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Abstract

Technological developments are inflection points in our life. One of such technologies driving developments is superconductor technologies. This technology is candidate to revolutionize many aspects of our life due to its attractive properties. One of the most important properties is Zero-DC electrical resistivity. In superconductor applications, zero electrical resistivity (infinite electrical conductivity) is utilized. The most significant figure of merit for superconductors is critical temperature, Tc. Below the critical temperature, material exhibits superconductive behaviour; at temperatures upper than Tc, material behaves as non-superconductive. Scientists are in race to discover materials having Tc as high as possible in order to utilize it in room-temperature level and reduce the cooling power consumption as much as possible. This work proposes a method to determine Tc of superconductors wisely and strongly. In this work, other determination methods are compared. Beside of Tc determination, a new figure of merit for superconductors is introduced. Scientists in race are encouraged to search materials having not only high or even ultra high critical temperature but also high stability and high quality factor. Also, introduced term will determine performance of future superconductor applications.

Keywords: superconductor, critical temperature, high t_c, high, q-factor.

1. Introduction

Who can imagine that a Dutch scientist spark a phenomenon which will revolutionize the whole technology including computation, transportation, medical imaging and energy transmission? Superconducting microprocessors, magnetic levitation trains, superconductive energy transfer lines, all of them will revolutionize the life that we live. As the applications of superconductors increase, the avalanches in our life are expected to increase.

Superconductivity, despite being the subject of intense physics, chemistry, and materials science research for more than a century, remains among one of the most puzzling scientific topics [1]. It has rather important characteristics those can fascinate anybody: Zero DC Resistivity, Meissner and Josephson Effects. In many applications of superconductors, zero DC resistivity has magical effect on them. But how is it possible to reach zero DC Resistivity in room temperature levels?

The most important figure of merit for superconductors is critical temperature, T_c. Below the critical temperature, resistivity of material vanishes and used as conductor having super-low resistance. In Onnes's experiment, he has utilized mercury as superconductor and it has T_c = 4.2 K [2]. Mercury is not good for room temperature level usage. From Onnes to now, scientists have tried to find superconductors those can be used in room temperature, those are called as high-T_c superconductors. As the critical temperature increases, temperature margin becomes larger and cooling power consumption becomes lower. As researches extend, myth of "Room Temperature Superconductor" becomes real day-by-day. The record value for superconductor is 250 K at high pressures on the order of GPa [3]. In today's technology, although GPa order pressure is not an easy application, if GPa order pressure effect is somehow introduced to materials, it is not that much far to replace superconductor material with normal conductors in room temperatures.

Scientists all over the world force themselves to find as high Tc as possible to make it possible in applications. This effort at the beginning was rather weak. In years between 1911 to 1965, rate of change of maximum critical temperature was 0.3 K/year [4]. However, as the hydrogen-rich materials are

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discovered as high Tc superconductor, this rate of change has been broken up and get close to only 50° C away from room temperature [3]. If this increase is considered, days for super applications are not that much far from today. Also, If the power of silicon in semiconductor revolution is considered analogously, it is not required to become a monk to predict hydrides as room temperature super conductors because God gifts whole humanity with such technologies that almost every human can reach to that technology just like sand from beach or carbon from charcoal mine rather than rare earth materials [5-9].

Efforts of scientists to reach T_c values as high as possible form a shape that superconductor collections are created. SuperCon is currently the biggest and most comprehensive database of superconductors in the world [10]. It is not required to pay to use it, also it is open to public. Scientists utilize some sophisticated techniques like AI or ML to discover new high-T_C valued compounds by using compounds of database having more than 33,000 entries more than 5,000 ones having regarding graph also more than 7,000 ones having regarding publication [11-15].

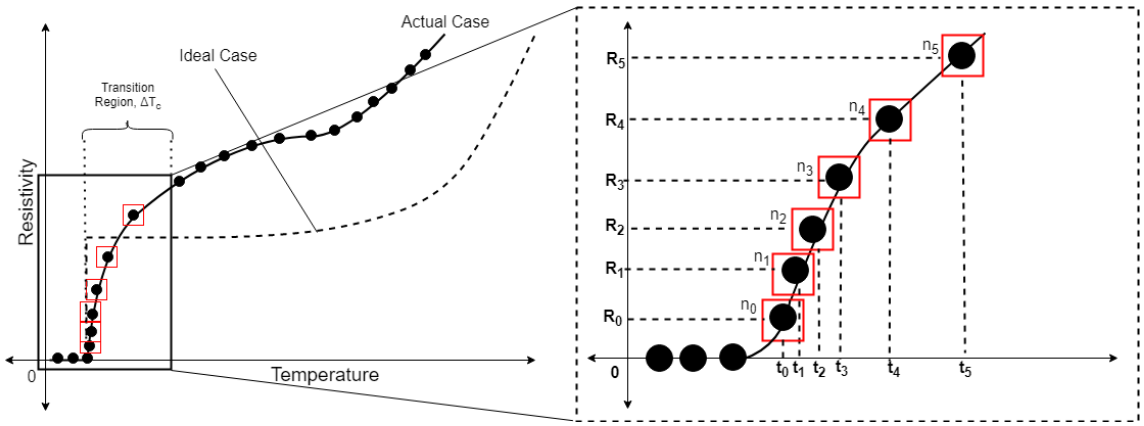


Figure 1. Fig. 1. Resistivity over temperature characteristic of superconductors

There are many test methods to measure T_c of superconductive materials. If the state of the material is considered, resistance method is rather applicable to bulky materials rather than powder, thick film and heterogenous materials. The methods other than resistance method, are sensitive to measurements, needs more information and complex to analyze. They are appropriate for heterogenous materials, powder materials and materials whose resistance is difficult to measure. On the other hand, resistance method is rather simple, reliable and also applicable to most of the metallic superconductors in industry.

2. Method

The critical temperature of a superconductor is defined as the temperature below which a superconductor material shows super conductive properties like Zero DC Resistance, Meissner Effect or Josephson Effect. Beyond the critical temperature, material exhibits it's normal properties like normal conduction or insulations depending on the material's structure. As it can be seen from Fig. 1. that ideally when a superconductor cools down, firstly it's resistivity reduces as expected. But after a point it's resistivity remains same and it drops at the temperature named as critical temperature, to zero-valued resistivity. However, experimentally firstly just like ideal case it's resistivity drops. After a point, transition region is seen and after transition region resistivity hits to zero value. The critical issue is to find critical point in transition region. Proposed method is to examine n-critical data points in transition region based on the slope that point has.

Slope of any point is given below:

$$S_n = \frac{dR_n}{dt_n} = \frac{R_{n+1} - R_n}{t_{n+1} - t_n} \quad (1)$$

Based on the computed slopes of critical data points, critical temperature is determined as the critical data point having maximum slope. This method is rather insightful because this resistance characteristic can be fit to combination of a concave and a convex behaviours. Inflection point between concave and convex behaviours is the point where slope of the point is maximum i.e. second derivative of the point is zero.

If transition region is considered, a new figure of merit can be derived by using transition region and critical temperature.

The narrower transition region width and the higher critical temperature, the higher quality superconductor. Quality factor of superconductor can be defined as below:

$$Q\ Factor = \frac{T_c}{\Delta T_c} \quad (2)$$

Table 1. T_c Determination method variables.

Variable	Definition
$\mathbf{n_0}$ **to** $\mathbf{n_{n-1}}$	Critical Data Point
$\mathbf{R_0}$ **to** $\mathbf{R_{n-1}}$	Resistivity of Regarding data point
$\mathbf{t_0}$ **to** $\mathbf{t_{n-1}}$	Temperature of regarding data point
$\mathbf{dR_0}$ **to** $\mathbf{dR_{n-1}}$	Resistivity difference between successive two data point
$\mathbf{dt_0}$ **to** $\mathbf{dt_{n-1}}$	Temperature difference between successive two data point

3. Results and discussion

This measurement method can be applied for metallic and oxide composite superconductors. Critical temperatures of YBCO crystalline in [17] and [18] can be measured by using proposed method. Method in [16] cannot be applied to [17] because upper-temperature resistance values are not available enough then determination of transition region is not avaliable. Also, though upper-Tc values are fitted in a line in [16] and validated in [18], it is still risky to fit a line to resistivity characteristic. Discontinuous behaviour in [19] is a good example to not to fit a line for such characteristic, it requires to stick the experimental data completely. Comparing the zero-level temperature approach is same with the one in [16]. Although some papers said that zero-valued resistance is not observed for some metallic compound, it is not an erroneous behaviour to fit the superconductive region as zero-valued resistance.

4.Conclusion

Technological breakdowns make revolution in our lives in many aspects. Superconductor technologies are one of such technologies which opens the door to new revolutions. What makes superconductors such amazing is nothing but it's zero-DC resistivity property. Although it has other fascinating features like Meissner effect and Josephson junction, Zero DC Resistivity feature is attractive in superconductor applications. The most important figure of merit for superconductors related to DC Resistivity is Critical Temperature, Tc. In this work, it is introduced some important ways to determine critical temperature value. New Tc value determination method is proposed. Not only importance of Tc value is given but also importance of transition width and a new figure of merit is introduced. Other Tc determination methods in literature are compared with proposed method and weak sides of other methods are given. All in all, this proposed method will enlight the journey of scientists efforting to find high-Tc even ultra high-Tc superconductors and mind the gap of critical temperature determination method in literature thanks to strong mathematical backgorund.

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