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Data Acquisition System for Resistance Measurement of High-temperature Superconductors

Ahmad Kamal Yahya, R. Abd-Shukor[1] and Faizah Md. Salleh

School of Applied Sciences
Institut Teknologi Mara
40450 Shah Alam, Selangor Darul Ehsan, Malaysia

[1]Department of Physics
Universiti Kebangsaan Malaysia
43600 Bangi, Selangor Darul Ehsan, Malaysia

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ABSTRAK

Kertas kerja ini membincangkan reka bentuk sistem perolehan data yang menggunakan mikrokomputer 80486 sebagai pengawal dan dihubungkan melalui kad PC-Lab 848B kepada multimeter berdigit dan pengawal suhu menggunakan laluan IEEE 488. Sistem ini berupaya mencatat, menyimpan dan memplot graf bagi bacaan-bacaan suhu melawan rintangan. Pengukuran rintangan bagi fasa $YBa_2Cu_3O_{7-\delta}$ dilaporkan dan dibandingkan dengan keputusan yang terdahulu. Pengukuran bagi $(Y_{0.5}Eu_{0.5})Ba_2Cu_3O_{7-\delta}$ menunjukkan peningkatan nilai $T_{c\ mula}$ dan $T_{c\ sifar}$ dan ini diterangkan sebagai akibat dari perubahan tekanan dalaman di dalam satah CuO yang berlaku apabila Eu^{3+} yang lebih besar menggantikan sebahagian daripada Y^{3+}. Sistem perolehan ini mudah digunakan dan sangat sensitif untuk mengesan perubahan suhu genting yang kecil. Suhu boleh diukur dengan kepersisan 0.1 K dan ketepatan ± 1 K yang merupakan had pengesan suhu perintang platinum yang digunakan. Nilai imbangan sifar-mutlak adalah kurang daripada 0.1 K.

ABSTRACT

This paper discusses the design of a data acquisition system based on the 80486 microcomputer serving as a controller connected via a PC-Lab 848B card to digital multimeters and a temperature controller using IEEE 488 standard bus. The system is able to log, store and plot temperature versus resistance readings. Resistance measurement on $YBa_2Cu_3O_{7-\delta}$ phase is reported and compared with previous results. Measurements on $(Y_{0.5}Eu_{0.5})Ba_2Cu_3O_{7-\delta}$ showed an increase in $T_{c\ onset}$ and $T_{c\ zero}$; this was explained in terms of change in the internal pressure in the CuO planes due to partial substitution of larger Eu^{3+} in place of Y^{3+}. This data acquisition system is simple to use and very sensitive in detecting small variations in transition temperatures. The temperature can be measured with a precision of 0.1 K and accuracy of ± 1 K, which is the limit of the platinum resistor temperature sensor. The absolute-zero offset value is less than 0.1 K.

Keywords: resistance, automated data acquisition, $YBa_2Cu_3O_{7-\delta}$ superconductor

INTRODUCTION

The electrical resistivity of many metals and alloys drops suddenly to zero when the specimen is cooled to a sufficiently low temperature, often a temperature in the liquid helium range. At the transition temperature, T_c the specimen undergoes a phase transition from a state of normal resistivity to a superconducting state. In the superconducting state, the dc resistivity is zero and thus current can flow in a superconductor without any loss.

The copper oxide-based superconductor was first discovered in the LaBaCuO system (Bednorz and Müller 1986). A significant leap occurred with the discovery of the ceramic superconductor $YBa_2Cu_3O_{7-\delta}$ ("123") with a transition temperature higher than 90 K (Wu *et al.* 1987). The discovery led to a switch in cryogen to liquid nitrogen, which is relatively cheaper than liquid helium. The discovery of "123" has triggered the race for other high-temperature superconductors (HTSC) and has led to the discovery of the bismuth (Maeda 1988), thallium (Sheng and Hermann 1988), mercury (Putilin *et al.* 1993) and calcium-doped mercury (Schilling *et al.* 1993) systems of high temperature superconductor. The calcium-doped mercury (Hg-Ba-Ca-Cu-O) superconductor currently has the highest transition temperature of 134 K.

One of the important parameters of a superconductor is the transition temperature. This paper describes a simple, accurate method (accuracy of $\pm$ 1 K) of determining the transition temperature of HTSC ceramics using the four point-probe resistance measurement. The 80486 microcomputer was used as a controller, connected via a PC-Lab 848B card to two digital multimeters and a temperature controller using the IEEE 488 standard bus. The hardware interfacing and software development for raw data capture, storage and data conversion are discussed. Resistance measurement on $YBa_2Cu_3O_{7-\delta}$ is reported and compared with results of other researchers. In addition, measurements of $(Y_{0.5}Eu_{0.5})Ba_2Cu_3O_{7-\delta}$ have also been made and the results discussed.

MATERIALS AND METHODS

Sample Preparation

The $YBa_2Cu_3O_{7-\delta}$ and $(Y_{0.5}Eu_{0.5})Ba_2Cu_3O_{7-\delta}$ samples were prepared by the standard solid state reaction method using mixed powder of Y_2O_3, Eu_2O_3, $BaCO_3$ and CuO with a purity of 99.99%. The starting materials were carefully mixed and ground in a mortar. The powders were calcined in air at 950°C for 48 h with several intermittent grindings, and furnace cooled. The powders were then reground and pressed into 13-mm diameter, 4-mm thick pellets under a pressure of 5 tons using a hand-held hydraulic press. These pellets were sintered in air for another 24 h at 950°C followed by a slow furnace cooling at a controlled rate of 40°C/hour to room temperature. A detailed preparation method has been described elsewhere (Abd-Shukor 1993). The Siemens D 5000 X-ray diffractometer was used to confirm the resultant phase of the samples.

Instrumentation

Resistance measurement was done using the four-point probe technique. The distance between the current leads was 10 mm, while the distance between voltage leads was 5 mm. The electrical contacts to the specimen were achieved by using silver conductive paint.

A stable dc current source LakeShore Model 120 CS was used to supply a current of 50 mA through the specimen. Higher currents were not used due to the existence of a critical current value above which superconductivity disappears. Typical critical current density for polycrystalline samples is $10^1 - 10^3$ A/cm^2 at 77 K and zero field (Murakami 1992). The voltage across the specimen was measured by Keithley model 197 (5 1/2 digit) Digital Multimeter (DMM) with built-in IEEE-488 Interface. A typical value of voltage across the specimen at room temperature with constant current set to 50 mA was approximately 300 μV.

The cryogenic system used was a Janis VPF-100 liquid nitrogen pourfill cryostat with the necessary vacuum pump attached. The sample was placed in vacuum and held relatively close to a platinum resistor temperature sensor. A heater located at the cryostat cold head was used to control the sample temperature.

The instruments mentioned above were interfaced to a 80486 microcomputer via PC-Lab 848B card to the digital multimeters using the IEEE 488 standard bus. The 80486 microcomputer acts as a controller for both DMM and temperature controller. Each device was given a different address and sent specific talk or listen commands through the bus. The connection layout of the data acquisition system is shown in *Fig. 1*.

Programming was done on Turbo Pascal to allow the controller to communicate through the IEEE-488 bus. The PC-Lab 848B Interface card was a convenient choice as it has ready-made software drivers packaged in read-only-memory onboard. This makes the software programming convenient and flexible. Through the software, the system is able to log, store and plot temperature and resistance readings (*Fig. 2*). Each set of readings was recorded only when either a significant change in temperature or a change in voltage reading of 1 μV in the sample was detected. The resolution of the temperature measurement is better than 0.1 K. The software also automatically indicates the value of the transition temperature $T_{c\ zero}$ after each thermal scan. $T_{c\ onset}$ was obtained by manually moving a vertical search line on the onset location. The

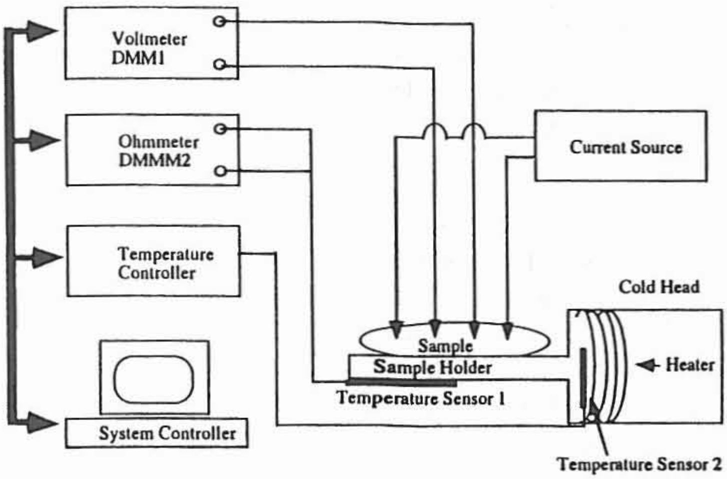

Fig. 1. Schematic layout of the data acquisition system

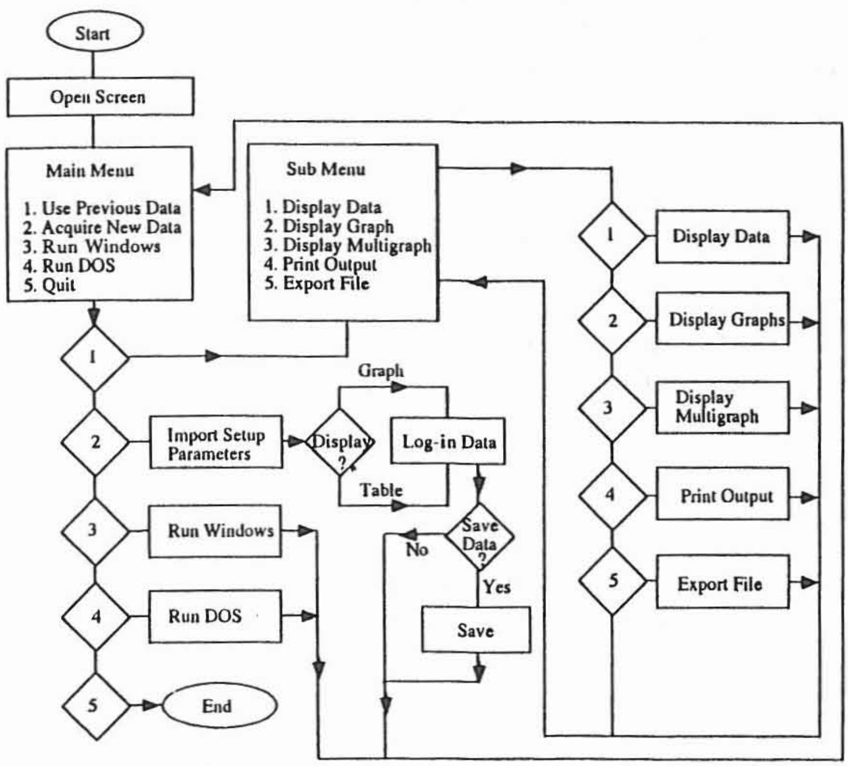

Fig. 2. Flowchart of the data acquisition program

temperature coordinate of the search line reported by the software gives the value of $T_{c\ onset}$.

RESULTS AND DISCUSSION

The X-ray diffraction pattern confirms the formation of the "123" perovskite-like structure of the space group P4/mmm with the general formula $YBa_2Cu_3O_{7-\delta}$. The normalized resistance versus temperature curve shows a metallic normal-state behaviour with $T_{c\ onset}$ of 96 K and $T_{c\ zero}$ of 91 K (*Fig. 3*). We found the measurements of $YBa_2Cu_3O_{7-\delta}$ comparable to earlier reports (see, e.g., Kirkup 1988). A similar X-ray diffraction pattern was also obtained for the $(Y_{0.5}Eu_{0.5})Ba_2Cu_3O_{7-\delta}$ sample. The $T_{c\ onset}$ and $T_{c\ zero}$ values of 98 K and 93 K, respectively, are slightly higher than the "123" sample (*Fig. 3*). This may be due to the changes in the lattice parameter as a result of substitution of the larger Eu^{3+} (0.95 Å) in place of Y^{3+} (0.89 Å). This substitution could have changed the internal pressure in the crystal structure and affect the dynamics of the charge carriers in the material. This result is consistent with results reported by previous workers (Guillaume 1994; Ata-Allah 1994) where T_c was found to scale linearly with the ionic radius of rare earth elements used to fully substitute Y^{3+} in the "123" structure.

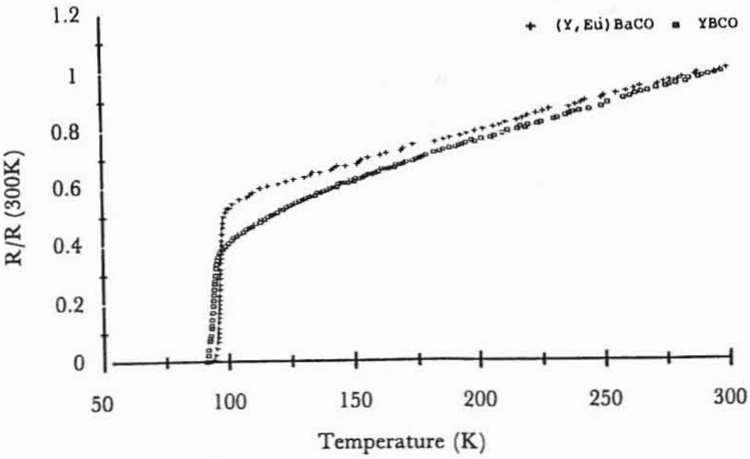

Fig. 3. Normalized resistance of $YBa_2Cu_3O_{7-\delta}$ and $(Y_{0.5}Eu_{0.5})Ba_2Cu_3O_{7-\delta}$ as a function temperature

Tests on the data acquisition system above prove it to be a reliable system for resistance measurements at temperatures above 77 K. Minute variations in the microstructure of the material which can lead to changes in the T_c profile (± 1 K), such as in the case of the $(Y_{0.5}Eu_{0.5})Ba_2Cu_3O_{7-\delta}$, can be readily detected with our system. The full flexibility offered when using a microcomputer and the appropriate IEEE-488 interface card has been the major factor in the development. The system can also be improved by using a programmable current source with built-in IEEE-488 interface. This allows the system to automatically reverse current direction or vary current magnitude during a thermal scan for more accurate resistance and T_c measurements. Further, the sensitivity of the system may be upgraded by using a nanovoltmeter in place of the 5 1/2 digit digital multimeter for voltage readings. The accuracy of the temperature measurements can be improved by using more accurate temperature sensors such as a silicon diode. Construction of a system to measure multiple samples in a single thermal scan is in progress.

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