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Determination of Characteristic Relaxation Times and Their Significance in A Copper Oxide Thin Film

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ABSTRACT

The copper oxide thin film was characterized using both the theoretical and experimental approach at different oxidation temperatures between 150oC to 450oC. Two experimental methodologies were combined with theoretical model to investigate the effect of time relaxations on the samples. The time relaxation of the current predicted the suitability of the sample to be used to fabricate either solar cell or semiconductor. The time relaxation of the voltage showed the degree of disorderliness created within the sample during fabrication.

Keywords

Disordered structures; amorphous and glassy solids, Specific materials: fabrication, treatment, testing, and analysis.

1. INTRODUCTION

The prospects of the copper oxide thin film have been investigated in different perspective as seen in numerous research papers. For example, the copper oxides have been investigated as a p-type and n-type semiconducting thin film in the past [1-4]. The optical behaviour of individual copper oxide family was found to vary due to its preparation methods and conditions [1,2]. The energy gap levels present in copper oxides signifies that it's a good solar converter and may be used in the fabrication of solar cells [1,5]. The applications of the copper thin film have been a long time idea in high thermal superconductivity. For example, various hypothesis the high temperature superconductivity in the last three decades centers on the copper oxide layer [6,7] and its prospects in fabricating superconductors-expected to operate at room temperature. Also, the secret in the fabrication of photochemical cells is another proof of the importance of copper oxide [3,8]. Another application of the copper oxide family has been reported in variable reflectance coatings for radiant energy control in architectural and aerospace applications [2]. Recently, it was reported that the copper oxide thin film can be used as gas sensor [10].

Despite the numerous application of the copper oxide family, the copper oxide thin film has shown its familiar difficulty in that it usually possesses a high resistivity which makes it not suitable for the fabrication of solar cell. These problems have

been reported to be solved by revisiting the preparation methods [11] and the creation of defects within its structure [10]. The strain and stress relaxation during copper oxide preparation was also reported as one of the difficulty encountered in lowering the resistivity of the material because it affects the oxide morphology development [12]. This problem was solved by modifying the oxidation temperature [12]. Determination of the relaxation times of the copper oxide thin film very important to understand its applicability to other technological tools e.g spin-based quantum information storage amongst others. Beyond experimental reach to determine certain parameters (spin nematic order due to long relaxation time) within the copper oxide thin film. In this paper, theoretical and experimental approach was applied to discover other unknown difficulties in the copper oxide thin film.

2. THEORY

The Valdes[13] gave the theoretical relation of the experimental work of Rhoderick [14] and Broom et al.,[15] to be

$$\rho = 2\pi s \frac{V}{I} \quad (1)$$

Due to the spin orbit interaction expected experimentally, there is an assumption that the energy of the conduction band was equal to the energy possessed by the supercurrent. Therefore, we adopted the solutions of the energy levels calculated by Emeter[16] in order to generate series of theoretical equations (2&3).

$$I = V^{-1} \left(m \cdot \omega_1 M_y \left(\frac{t}{T_1} \right)^\beta + \frac{1}{t} \right) \quad (2)$$

Where V is given as

$$V = \left(\frac{\rho}{2\pi s} \left(\frac{1}{t} - m\omega_1 M_y \left(\frac{t}{T_1} \right)^\beta \right) \right) \quad (3)$$

Where ρ =resistivity, s = space, V = voltage, I =current, ω_1 =frequency, M_y =magnetization, t =time, T_1 =characteristics relaxation, β = -1

Another reason for the emergence of equations (2&3) was because the Spin coherency in the process can be measured on applying a microwave magnetic field in the presence of a static magnetic field. This is accounted for by the presence of M_y in the equation. The spin neumatic state was also accounted for by using the $\frac{1}{T_1}$ to determine the quantum phases of the copper oxide thin film.

3. METHODOLOGY

Copper thin film deposition was carried out using EDWARDS AUTO306 thermal evaporator equipped with FL400 vacuum system and SQC-310C deposition controller. A 7059 corning glass slide was used as the substrate which was thoroughly cleaned before the deposition of the thin film to prevent impurity. The substrate glass was dip into a dilute chemical detergent, then rinsed with water and placed inside boiling diluted peroxide (H2O2) solution for nearly 15min, under ultrasonic agitation. Lastly, the substrate was immersed into methanol and then-dried by blowing the substrate with pressured nitrogen gas. The pure substrate is placed inside EDWARDS AUTO306 thermal evaporator is operated at a substrate temperature of 100oC and a pressure of 1.6x10-5 Torr, so as to create a vacuum environment. The thickness of the film was controlled using the crystal monitor. The film thickness was 200 nm (2 kÅ) depositing at 7.35 (Å/s) rate. The VEECO DEKTAK 150 profilometer was used in the measurement of the film thickness. Fortunately, the calculation of the energy bandgap is done with the thickness of the material. The oxidation process of the Copper thin film was carried out in open air at varied temperatures of 150 oC, 250 oC, 350 oC and 450 oC using a horizontal diffusion furnace.

The different samples are oxidized individually. First, sample A was placed into the heating chamber of the furnace which was set at 150 oC, at a ramp rate of 10 oC/min, and heated for two hours (dwell time) as programmed by the operator. The furnace is then allowed to cool down to room temperature and same process is repeated for other three samples B, C, D at 250 oC, 350 oC and 450 oC respectively. The preliminary micro-structural analysis of the four samples

showed the image of the copper film (sample A) at 150oC as smooth coating film with dense uniform distribution on the substrate. Other copper-oxide films (sample B,C & D) at 250 oC, 350 oC and 450 oC films were swollen and breaking off the substrate. The experimental methodology of Rhoderick[14] and Broom et al., [15] was remodeled to enable the actual extraction of data during the electrical characterization. A QUADPRO-301-6 four point probe meter is used to carry out the electrical characterization measurements. A four way probe operational process upon which QUADPRO-301-6 works includes the two outer probes measure the current I (source measure units SMU 1 & 2) and two inner probes sense the voltage V (SMU 3 and ground unit GNDU as shown in fig.[a] below). This method is a non-destructive way of determining the resistivity of the samples and eliminates measurement errors due to the probe resistance. One source measure units (SMU1) and the GNDU (ground unit) are used to source current between the outer two probes. Two other SMUs (SMU2 and SMU3) are used to measure the voltage drop between the two inner probes. Where the space's' is given as 200Ao.

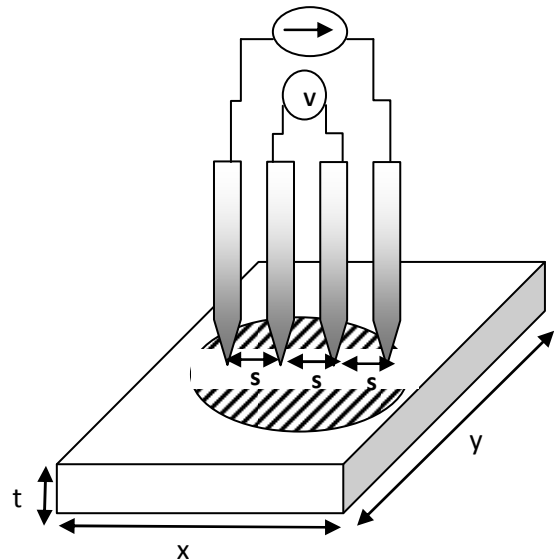


Fig. a. SMU 3 and ground unit GNDU

4. RESULTS AND DISCUSSION

The experimental results of the copper oxide samples generated at different temperatures are listed in the Table[1] below.

Table 1: SHEET RESISTANCE, RESISTIVITY AND COMPOSITION OF FILMS IN DIFFERENT SAMPLE

| Sample | Oxidation temperature (°C) | Sheet resistance (ohms) | Resistivity (Ω-cm) | %weight of Cu | %weight of O |
|-----------------|----------------------------|-------------------------|-----------------------|---------------|--------------|
| Cu_as-deposited | - | 1.2922x10 ⁻¹ | 4.1x10 ⁻⁶ | | |
| Cu_150°C | 150 | 6.1064x10 ⁻² | 1.92x10 ⁻⁶ | 46.06 | 53.95 |

| | | | | | |
|--------------|-----|------------------------|--------------|-------|-------|
| Cu_25 0°C | 250 | 2.1555x10 ⁷ | 1076.75 8 | 40.90 | 59.21 |
| Cu_35 0°C | 350 | 2.5498x10 ⁶ | 127.511 4 | 38.75 | 61.25 |
| Cu_45 0°C | 450 | 4.1028x10 ⁶ | 205.16 | 38.48 | 61.52 |

The resistivity was highest on the sample prepared at 250°C and lowest on the sample prepared at 150°C. The percentage mass gained (ΔM_c) by the oxygen content was discovered to be within the range $7 \approx \Delta M_c \approx 18$. Experimentally, resistivity increases with thickness and thicker films are less effective in the fabrication of solar cells. This faulted the solution of Zhou et al [12]. The relaxation time between the two striking samples were further simulated as shown in figure [1] shown below

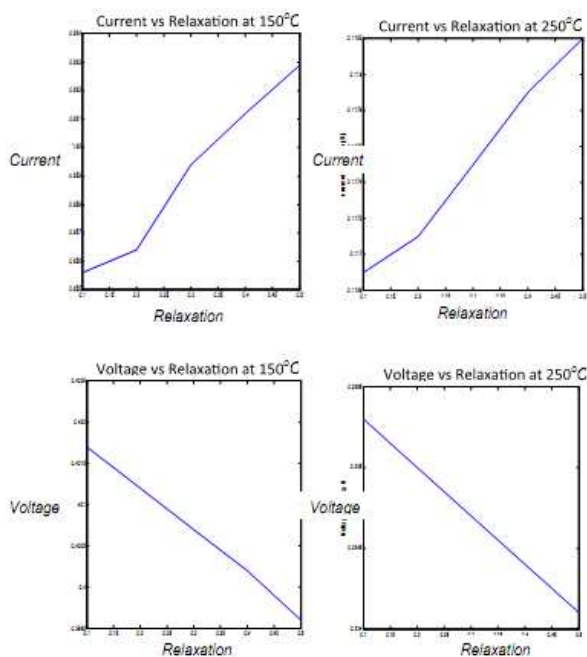


Fig. 1. current-relaxation times at 150°C(top left) and current-relaxation times at 250°C(top right).

Comparative analysis of figure [1] shows that the copper oxide thin film can be regarded as a non-ohmic device. The current –relaxation time for the two samples slightly dissimilar in shape which obviously means that the electrical path for the supercurrent differs. This may likely be as a result of some form of disorder registered during the preparation. In other words, the solution given by Ogwu et al.,(10) may be true to an extent. The voltage-relaxation time is perfectly linear for the 250°C sample and bending for 150°C sample which simply means that the work done in bringing the charge between the two terminals (potential difference) are hindered by lower oxide morphology development in the 150°C sample. In other words, lower oxide morphology development at low temperatures favours the fabrication of solar cells. The low electric field generated by the 250°C sample shows that it is a better semiconducting thin-film device than the 150°C copper oxide film sample. The copper oxide film 350°C and 450°C sample normally possess a high resistivity which shows that they can either be used as semiconductors and gas sensing but not as solar

cell. The current-relaxation time expressions in Figure [2] shows few significant features.

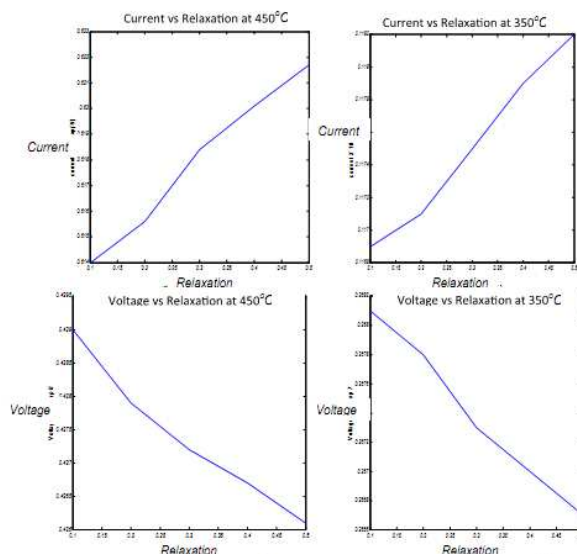


Fig. 2. current-relaxation times at 450°C(top left) and current-relaxation times at 350°C(top right). voltage-relaxation times at 450°C(down left) and voltage-relaxation times at 350°C(down right)

The formation at higher temperatures decreases the percentage mass of the copper in the samples. The relaxation time for the current shows vanishing small field intensities. It also shows the relaxation time dependence on disordered sample structure. As shown in the relaxation time for voltage (figure [2])which was earlier defined as showing the disorderliness in the sample structure, it therefore logical to infer that at higher temperatures the disorder within the sample increases.

5. CONCLUSION

The relaxation time for the current and voltage has been proven to determine the degree of disorderliness in the sample. At low temperature preparation method favours the fabrication of solar cells while the high temperature preparation method favours the fabrication of semiconductors. At certain conditions i.e. at high temperature, modifying the oxidation temperature does not reduce the resistivity. The copper oxide is a non ohmic device, therefore its relaxation times differs depending on their vanishing electric field intensities.

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