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Current density-voltage characteristics in thin film Cu/CuO/Cu sandwich structure

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Abstract

The preparation of thin film Cu/CuO/Cu sandwich structure by vacuum deposition is described. Cu and CuO were evaporated by conventional heating resistance methods under the pressure of 10^{-6} Torr. The current-voltage characteristic of the Cu/CuO/Cu sandwich structure was investigated in order to understand the electrical transportation mechanism of CuO. The current density-voltage characteristics show the presence of two linear sections, separated by a "jump" in the values of the current density. A triangle-shaped hysteresis was measured at various temperatures in the range of 300-500K and for various thickness of CuO in the range of 10-30 nm. It was observed that the triangle-shaped hysteresis was dependent on temperature and thickness of thin film CuO. The triangle-shaped hysteresis in the current-voltage characteristic was explained by means of CuO traps.

Key words: current density-voltage characteristics; thin film, sandwich structure.

Curvas características densidad de corriente-voltaje en estructuras Cu/CuO/Cu de películas delgadas

Resumen

Se describe la preparación por deposición al vacío de estructuras tipo sandwich Cu/CuO/Cu de películas delgadas. El Cu y el CuO fueron evaporados, utilizando el método convencional de calentamiento resistivo, a una presión de 10^{-6} Torr. La curva característica corriente-voltaje de la estructura Cu/CuO/Cu fue investigada con el objetivo de entender el mecanismo de transporte eléctrico del CuO. Las curvas características densidad de corriente-voltaje muestran la presencia de dos secciones lineales separadas por un salto en los valores de la densidad de corriente. Una histéresis de forma triangular fue medida a varias temperaturas en el rango de 300 a 500 K, para espesores de CuO en el rango de 10 a 30 nm. Se observo que la histéresis de forma triangular depende de la temperatura y del espesor del CuO. La presencia de la histéresis en las curvas características corriente-voltaje fue explicada por medio de las trampas en el CuO.

Palabras clave: curva característica densidad de corriente-voltaje; película delgada; estructura sandwich.

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Introduction

The copper oxide system has undergone many investigations in part due to it ease of productions, for example, by the thermal oxidation of copper. It has been reported that many of the growth methods for cuprous oxide result in a combined growth of copper oxide Cu_2O and copper oxide CuO (1, 2). The electrical conductivity mechanisms in metal-insulator-metal sandwich structure assume that the insulating material is pure. Recent investigations have shown that the fabrication technique can introduce additional energy levels in the insulator, identified as tramps levels. These levels modify the natural state of the insulator (3-5).

Along with thermal oxidation many other methods have been used for the growth of the oxide, such as electrochemical deposition (6), laser ablation (7) and radio frequency sputtering (8). We grow our films by thermal evaporation of the Cu and CuO onto glass substrates.

In this article, we aim to investigate the electrical conductivity of the Cu/CuO/Cu thin film sandwich structure in order to understand the electrical transportation mechanism of the CuO. This study was realized from the current-voltage characteristic of the thin film Cu/CuO/Cu sandwich structure over the temperature range of 300-500K and for thicknesses of CuO in the range of 10-30 nm.

Experimental

The thin film Cu/CuO/Cu structures were deposited on cleaned microscope slides, held at fixed room temperature by thermal evaporation at a residual pressure of 1.10^{-6} Torr.

Samples were prepared by evaporating an appropriate amount of Cu in wire form and CuO in granular form, both materials with a 99.9999% of purity. The deposition rate was held around 5 nm/s for the CuO films. A quartz crystal monitor (Balzer model: QSG301) controlled the deposition rate and thickness.

The pattern of the structures was formed by evaporating the film materials through a mask that was made form 1 mm thick molybdenum and was in direct contact with the substrate to give good film edge definition. Samples had a planar geometry, with a MIM structure of $(1,5 \times 5)\ mm^2$.

The current-voltage characteristic of the Cu/CuO/Cu sandwich structure were measured, by means a heating system, at various temperatures over the range of 300-500 K and for CuO thickness between 10-30 nm.

Results and Discussion

The current-voltage characteristics for the thin film sandwich structures for CuO thickness of 12 nm, 26 nm and 31 nm, is shown in figure 1.

It was observed that the current-voltage characteristics were independent of the voltage polarity and that the current increased as the voltage increased. A triangle-shaped hysteresis in the current-voltage characteristic was observed (figure 2).

It was seen (figure 2), that at certain voltage V_{st} (the so-called saturation voltage) the current approached saturation. At a certain voltage V_{sp} (so-called step voltage) the current rapidly increased. As the voltage increased, it was observed that path (I) was followed. As the voltage decreased, the path (II) was followed. In other terms, the current did not follow the previous path as the voltage decreased except for the saturation region. In this region the current-voltage characteristics at voltage V_{sp} was the continuity of the current-voltage characteristics at voltage V_{st}. The voltage increasing and decreasing tests were carried out on the different thin film structures many times. The

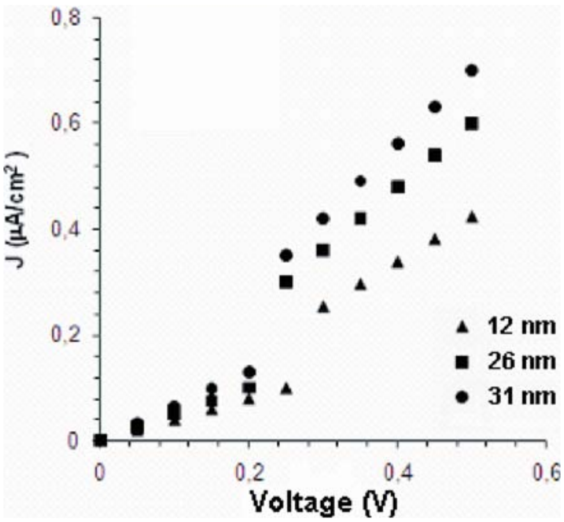

Figure 1. The current density-voltage characteristic of the thin film Cu/CuO/Cu sandwich structure for CuO thickness.

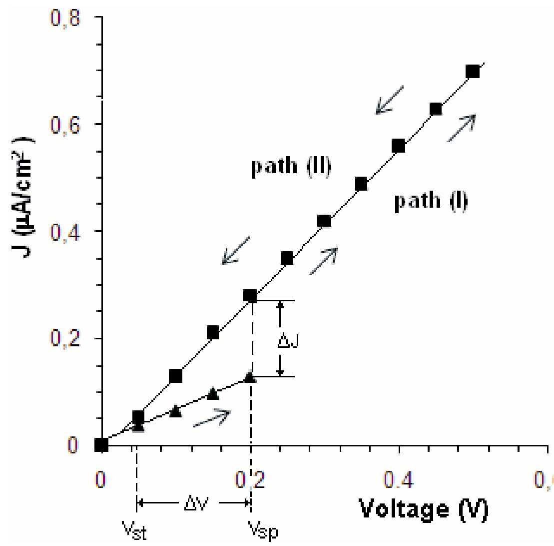

Figure 2. The current density-voltage characteristic of the thin film Cu/CuO/Cu sandwich structure for CuO thickness of 12 nm at 300 K.

same behaviour was observed. It was also confirmed that the samples were reproducible. Temperature-current measurements (figure 3) realized in the temperature range 300-500 K at the temperatures of 300, 340, 400 and 500 K show the following results: (i) ΔJ was nearly independent of temperature, (ii) $\Delta V = V_{st} - V_{sp}$ decreased as the temperature increased, (iii) the triangle area of hysteresis A= (ΔJ × ΔV)/2 (2) decreased as the temperature increased (figure 4).

The activation energy of the thin film sandwich structures was found using Eq. [1]

$$J = AT^2 e^{-\frac{E_b'}{kT}} \qquad [1]$$

where *A* is the Richardson constant, *T* the temperature, *k* Boltzmann constant, corresponds to the potential barrier for a voltage different from zero.

The figure 5, show the plot of Ln (J/AT^2) versus 1/T, for a voltage of 0.5 V. A straight line was obtained and the activation energy

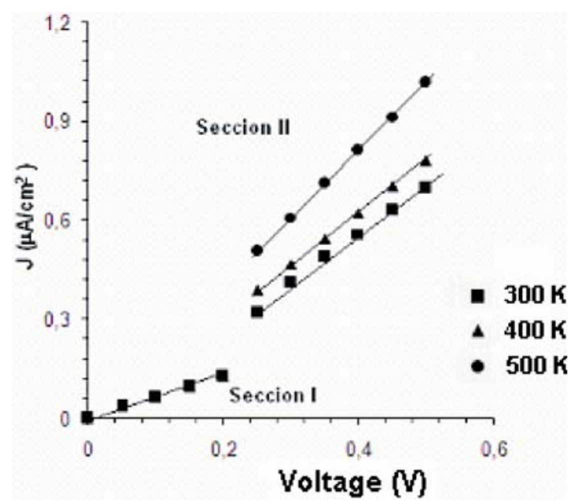

Figure 3. The current density-voltage characteristic of the thin film Cu/CuO/Cu sandwich structure for CuO thickness of 12 nm.

was determined as 0.037 eV from the slope of this straight line.

The current voltage characteristic of the thin film Cu/CuO/Cu sandwich structure shown in figure 2 could be explained by

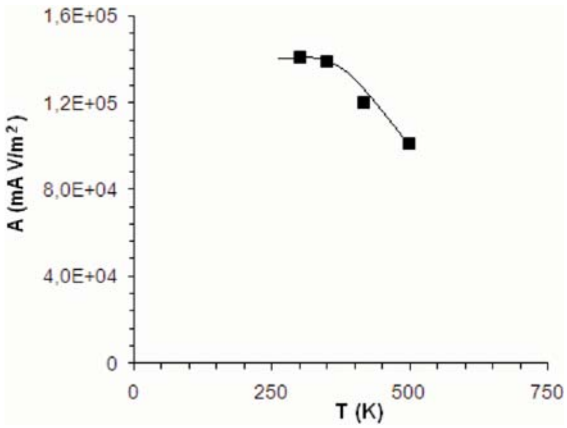

Figure 4. The triangle-shaped hysteresis area versus temperature in the range of 300-500 K.

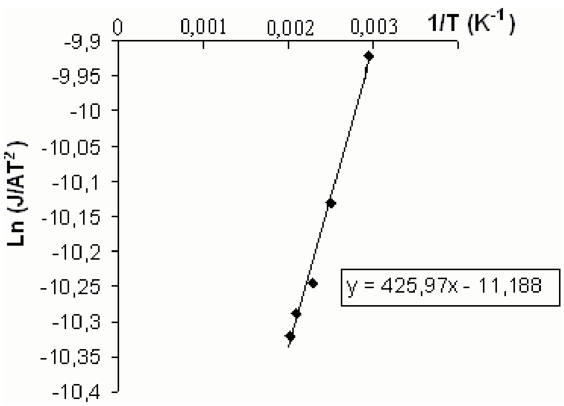

Figure 5. The current density of CuO versus 1/T values in the temperature range of 300-500 K.

means the double injection and trap-limited current space-charge saturation theory (9). According to this theory, the carriers injected by emission are used to fill traps. In the filling period of traps the current stays at a constant value even though the voltage is increased. When the traps are filled at saturation, the Fermi level is shifted into the neighbouring conduction band and additional carriers pass producing an increment in the current. Since all traps are full, the current decrement follows the way of the path (II), as the voltage at the terminals of the MIM structure decreases. When the voltage reached a value lower than V_{st}, carrier injection by emission at the contacts diminishes and the Fermi level shifts its previous position and the traps are evacuated (10). The voltage between V_{st} and V_{sp} controls the injection range.

Conclusions

Thin film Cu/CuO/Cu sandwich structures by vacuum deposition have been prepared. A triangle-shaped hysteresis was observed in the current-voltage characteristics, which were measured at various temperatures in the range of 300-500 K. It was observed that the triangle-shaped hysteresis was dependent on temperature. The hysteresis was explained by means of carrier injection and filling of traps by emission.

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