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Effect of heat treatment on optical, electrical and thermal properties of ZnO/Cu/ZnO thin films for energy-saving application

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ABSTRACT

In this work, the effect of annealing on the ZnO/Cu/ZnO films prepared by an RF/DC magnetron sputtering system was studied. Structural, optical, and thermal properties of both the as-prepared samples and their annealing data were systematically investigated. Our evaluation shows that these layers can be used as suitable coatings in energy storage applications. The ZnO/Cu/ZnO sample after annealing at 400 °C has the lowest resistivity (14.04Ω/sq), highest FOM ($6.37 \times 10^{-4}\ \Omega^{-1}$), and lowest emissivity (0.16). It can also be chosen as the best coating on building windows to save energy because of its high transmittance at 550 nm (68%) and low U-value (1.63 W/Cm^2.K).

1. Introduction

Transparent conducting oxides are both conductive and transparent. These two features make them suitable for use in various industrial applications including liquid crystal displays, solar cells, organic light-emitting diodes (OLEDs), photovoltaic devices, and smart windows [1–6]. Low emission (low-E) transparent conductive electrodes are especially used in optical filters, heat mirrors, and low emission glass in buildings [7,8].

Indium tin oxide (ITO) is one of the transparent conductive electrodes that is widely used in the industry due to its high conductivity and transparency. Due to rising demand and high prices, however, researchers are seeking alternative materials. To date, many studies have shown that metal oxide/metal/metal oxide electrodes have better optical and electrical properties than ITO single layer electrodes. Moreover, as a result of the presence of metals in the middle layer, they have low-E and heat resistance properties, considering their high reflection in the IR region [9].

ZnO metal oxides have good transparency in the visible area, but due to the high electrical resistance to ITO, a thin layer of metal is used between the two layers of ZnO to maintain the transparency of the structure. Studies have shown that the strength of three-layer films is greatly reduced because of the existence of metal in the intermediate layer and the transfer of electrons between the metal oxide and the metal, but its transparency is not greatly reduced. In addition, the metal layer greatly reduces the IR reflectivity of these films to transparent single-layer conductive oxides (ITO or ZnO …), which leads to a variety of applications in industry, especially in the field of energy-saving. Building windows are a major factor of energy loss in summer and winter. Consequently, the fabrication of energy-efficient coatings for windows, by which heat transfer is remarkably reduced, is of great significance. The desired material should have high transparency and low heat absorption. To check the quality of the material for energy storage of building windows, U and G values are used.

The U value determines the insulating capacity of the glass and indicates the rate of heat transfer through the glass. Therefore, a lower U value indicates better thermal insulating glass. The solar heat gain factor (SHGC) is the amount of heat from direct sunlight that passes through the glass. The lower the SHGC is, the lower the heat transfer (from direct sunlight) will be; such samples would be identical for places where sunlight radiates directly [10].

Much research has been done on ZnO/Ag/ZnO as a transparent conductive electrode because of its low Ag resistance. The resistance of Cu metal is comparative to that of Ag, but studies have shown that ZnO/Cu/ZnO structures have acceptable conductivity and transparency and are similar to the structure of ZnO/Ag/ZnO. Moreover, Cu is much cheaper than Ag.

The current study examined and compared the optical, electrical, and thermal properties of transparent conductive ZnO/Cu/ZnO electrodes before and after annealing. XRD, FESEM, AFM, and RBS analyses were performed to evaluate the thickness and concentration of the elements in the samples, and the optical properties of samples were

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