INVESTIGATION ON SURFACE, ELECTRICAL AND OPTICAL PROPERTIES OF ITO-AG-ITO COATED GLASS

Necdet Aslan[1], Tuba Şen[1], Turgay Çoruhlu[1], Kenan Şentürk[2], Sinan Keskin[3], Sedat Şeker[4], Andrey Dobrovolskiy[5]

[1]Yeditepe University, Physics Department, Istanbul, Turkey;
[2]Beykent University, Energy Systems Engineering Department, Istanbul, Turkey;
[3]Marmara University, Environmental Engineering Department, Istanbul, Turkey;
[4]Gebze Institute of Technology, Materials Science & Engineering Department, Istanbul, Turkey;
[5]Institute of Physics, Kyiv, Ukraine

The aim of this work was to study the optical and electrical properties of thick ITO-Ag-ITO multilayer coating onto glass. ITO-Ag-ITO coatings with thickness of ITO layers 110 nm, 185 nm and intermediate Ag layer thickness 40 nm were prepared by magnetron sputtering. The optical, electrical and atomic properties of the coating were examined by scanning electron microscope, atomic force microscope, X-ray diffraction analysis and ultraviolet-visible spectroscopy.

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INTRODUCTION

Indium tin oxide (ITO) films, which are transparent and conductive, have attracted a growing interest in many industrial devices, such as solar cells, liquid crystal displays, and organic light emitting diodes due to their low resistance and high optical transparency in the visible region of spectrum. However, their resistivity is rather high in some cases for improved practical applications, particularly, at their use as a transparent electrode of a color filter in the case of an improved display panels.

One of the ways of resistivity reduction of transparent conductive electrodes is the use of thin metal films in combination with ITO [1-3]. However, optical and electrical features of such multilayer films essentially depend on their structure. Used metal films should have a continuous structure and high transmittance. Otherwise, presence of island structures in the film body can lead to both resistivity increase and transmittance decrease. One of the most suitable metals is Ag due to its high conductivity, and good transmittance of thin Ag films in visible spectrum range.

The aim of this work was to study the optical and electrical properties of thick ITO-Ag-ITO multiplayer coating. ITO-Ag-ITO coatings with thickness of ITO layers 110, 185 nm and intermediate Ag layer thickness 40 nm have been prepared by magnetron sputtering.

1. EXPERIMENTAL PART

1.1. MATERIALS AND METHODS

Glass microscope slides (RE-WA Lehmann-Schmidt, 55x25 mm) that were amorphous, transparent to visible and near-infrared light were used in our experiments. To prepare a clean adhesion surface, the glass slides were washed by water and then treated by water-ethanol solution (20%, Greenfield Ethanol Inc.) for 10 min. After that the glass slides were cleaned by ultrasonic cleaner (MTI Corp., USA) for 20 minutes and finally left to dry for 10 min before sticking it to the substrate holder. The coating materials (targets for magnetron sputtering) used in this study were Ag, and ITO (all of 99.99% purity, 50.8 mm diameter, 4 mm thickness).

1.2. CHARACTERIZATION AND MEASUREMENT METHODS

The film thicknesses on glass coatings were measured (by Dektak Profilometer, Germany); cross sections of the films were examined in the SEM images.

In order to examine the optical properties of the ITO-Ag-ITO coating, a 50 W halogen lamp (producing a continuous light intensity between 300…900 nm) and the BAKI spectrometer (BEAM Ar-Ge Optic, Laser Technologies Ltd, Turkey) were used.

The AFM measurements were carried out by the AFM machine (Park systems, USA).

The X ray diffraction (XRD) measurements were established by Rigaku D-Max/2200 PC model system. The measurements were carried out at 40 kV and 40 mA with 2 degrees scanning/minutes.

At studies of the features of obtained films, energy dispersive X ray (EDX) analysis and scanning electron microscopy (SEM) (Tescan, Mira/LMU Schottky) were also used.

The conductivity tests on the coated glass surface were done by four probe method (4 channel digitizing oscilloscope from TEKTRONIX TDS 510A).

2. RESULTS AND DISCUSSION

One of the problems arising at the way of creating high-quality uniform coatings is ITO cluster formation during the coating. Due to that, at creation of multiplayer ITO-Ag-ITO coating by magnetron sputtering method especially great attention was paid to operation mode choice, particularly, the coating time. It was determined that the average cross section diameters of these clusters increased from 200 to 400 nm after 5 and 25 min of coating (Fig. 1). The film thickness was found to change from150 nm (for 5 min) to 350 nm (for 25 min). It was found that the coating thickness increased linearly with the coating time. This cluster formation can be reduced after annealing in a temperature range of 200…300°C. It should be also noted that the EDX analysis of these clusters and flat regions between clusters showed identical results, so that the atoms in flat regions and those in clusters are the same.

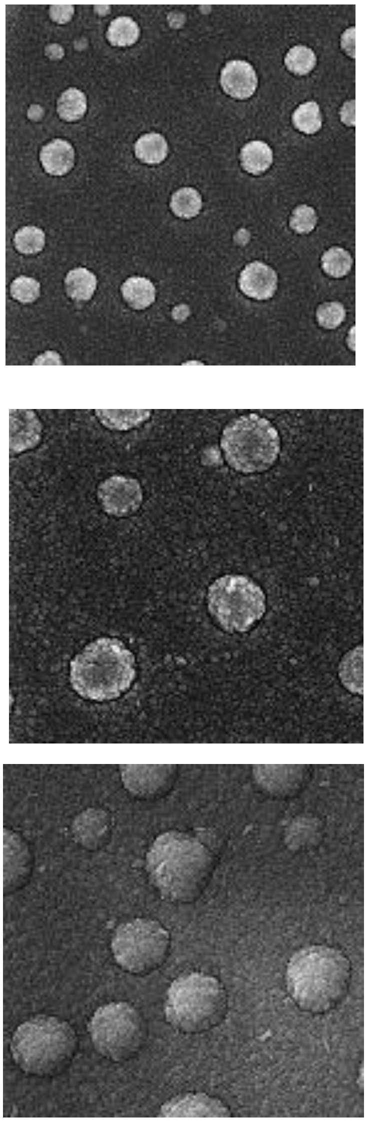
a
b
c

Fig. 1. The SEM pictures (x20K magnification) ITO coating onto glass for different exposition times: 5 min (a); 15 min (b); 25 min (c)

Layers of 1st ITO, Ag and top ITO were deposited stepwise for both surface morphology control and convenience of performing optical measurements (Fig. 2). The film thickness of the first ITO layer (21 min. coating) was measured to be 110 nm and the Ag and final ITO layer thicknesses were measured to be 40 nm and 185 nm, respectively. Fig. 3 shows the SEM images of these coatings taken at the points a-c, as shown in Fig. 2.

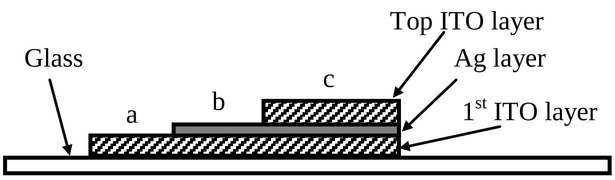

Fig. 2. The multilayer coating of ITO-Ag-ITO onto microscope slide glass

As one can see from this Figure, initial ITO coating produces clusters, Ag coating smoothes the surface, but the clusters at final ITO coating become larger. Similar clustering formation has been also previously observed [4].

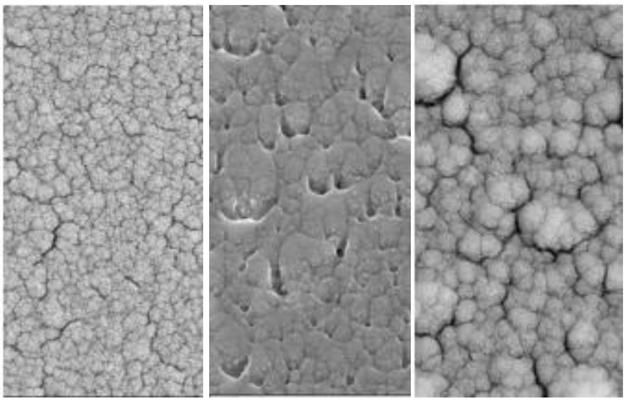
a b c

Fig. 3. The SEM pictures (x75K magnification) ITO-Ag-ITO coating on microscope slide: First ITO coating (a); Ag coating onto first ITO (b); top ITO coating onto Ag (c)

At creation of such multilayer coating, the structure of single layers was also controlled. Fig. 4 shows the single ITO coating side view SEM picture of 75K magnification. One can see from the figure that deposited ITO layer has regular columnar structure.

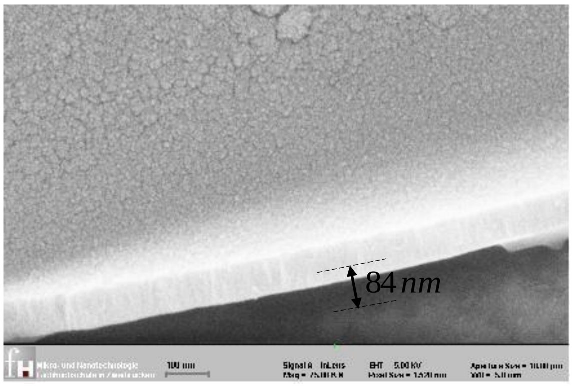

Fig. 4. The SEM pictures (x75K magnification) of cross section of glass- ITO film coated for 12 minutes

Morphological feature of this ITO thin film was also monitored using atomic force microscopy (AFM) (Fig. 5). One can see from the Figure that the surface of deposited layer is smooth enough – its roughness does not exceed several tens of nanometers.

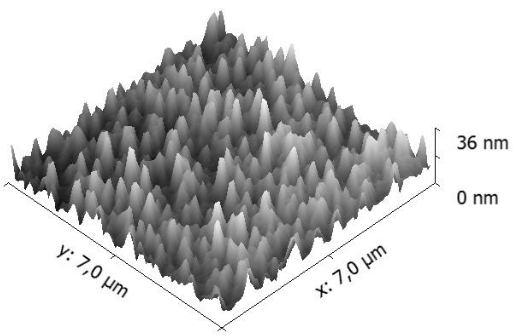

Fig. 5. The AFM image of single 84 nm thickness *layer of ITO coating*

Results of researching the transmission of created multilayer ITO-Ag-ITO coating in 400 to 900 nm range are presented in Fig. 6. Deposition of the first ITO layer with 110 nm thickness practically has no influence on transmission spectrum of the film, whereas adding 40 nm thick Ag layer leads to transmission decrease in visible range by almost 30% (transmission minimum is located at about 650 nm wavelength). Adding top 185 nm thick ITO layer does not change the transmission value in 400…650 nm range, but decreases it at longer wavelengths. Such behavior of transmission spectrum differs from data presented in [3], where transmission spectrum is bell-shaped (with the transmission maximum at ≈ 600 nm) at Ag layer thickness variation from 10 to 20 nm.

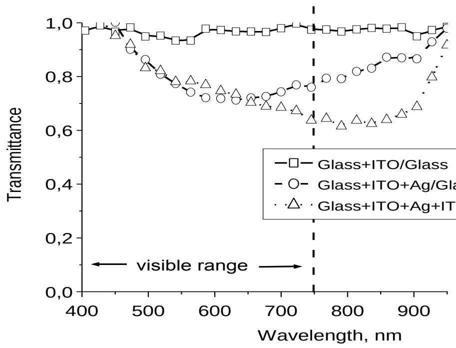

Fig. 6. The transmittance spectra for-ITO-Ag-ITO multiplayer consisting of 110 nm thick ITO, 40 nm Ag and 185 nm ITO

Clarification of a reason of such discrepancy is planned in subsequent researches.

The resistances of ITO monolayer and ITO-Ag-ITO multilayer structures deposited on the glass slide by magnetron sputtering was measured by 4-probe method, and it was found that the resistance of ITO-Ag-ITO (measured from top) reduces to only 1 Ω from initial ITO resistance of nearly 70 Ω . The low resistance is due to the immersion of Ag layer between the ITO layers. It should be noted that, owing to light transmittance reduction with the increase of Ag coating thickness, it is important to carefully adjust Ag thickness, if ITO layers are to be used for optical purposes.

CONCLUSIONS

The optical, electrical and atomic properties of multilayer ITO-Ag-ITO coating were examined by SEM, AFM and XRD analysis. It was measured that the average cross section diameters of these clusters increased from 200 to 400 nm after 5 and 25 min of coating. The film thickness of the first ITO layer (21 min coating) in ITO-Ag-ITO coating was measured to be 110 nm and the Ag and final ITO layer thicknesses were measured to be 40 nm and 185 nm respectively. It was found that the sheet resistance of ITO-Ag-ITO (measured from top) reduces to only 1 Ω from initial ITO resistance of nearly 70 Ω ohms. The low sheet resistance is due to the immersion of Ag layer between the ITO layers.

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ИССЛЕДОВАНИЕ ПОВЕРХОСТНЫХ, ЭЛЕКТРИЧЕСКИХ И ОПТИЧЕСКИХ ХАРАКТЕРИСТИК ITO-Ag-ITO-ПОКРЫТИЙ НА СТЕКЛЕ

Necdet Aslan, Tuba Şen, Turgay Çoruhlu, Kenan Şentürk, Sinan Keskin, Sedat Şeker, Andrey Dobrovolskiy

Целью работы было изучение оптических и электрических характеристик толстых ITO-Ag-ITO многослойных покрытий на стекле. ITO-Ag-ITO-покрытия с толщиной ITO-слоев 110, 185 нм и промежуточным слоем Ag толщиной 40 нм были изготовлены с помощью магнетронного напыления. Оптические, электрические и атомные характеристики были исследованы с помощью сканирующего электронного микроскопа, атомного силового микроскопа, рентгеновского дифракционного анализа и оптической спектроскопии.

ДОСЛІДЖЕННЯ ПОВЕРХНЕВИХ, ЕЛЕКТРИЧНИХ ТА ОПТИЧНИХ ХАРАКТЕРИСТИК ITO- Ag -ITO-ПОКРИТТІВ НА СКЛІ

Necdet Aslan, Tuba Şen, Turgay Çoruhlu, Kenan Şentürk, Sinan Keskin, Sedat Şeker, Andrey Dobrovolskiy

Метою роботи було вивчення оптичних та електричних характеристик товстих ITO-Ag-ITO багатошарових покриттів на склі. ITO-Ag-ITO-покриття з товщиною ITO-шарів 110 і 185 нм та проміжним шаром Ag товщиною 40 нм було виготовлено за допомогою магнетронного напилення. Оптичні, електричні та атомні характеристики такого покриття були досліджені із застосуванням скануючого електронного мікроскопа, атомного силового мікроскопа, рентгенівського дифракційного аналізу та оптичної спектроскопії.