Processing Parameters and Property of AZO Thin Film Prepared by Magnetron Sputtering

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Abstract. As we all know, transparent and conductive Al:ZnO (AZO) films are being considered for manufacturing transparent electrodes in flat panel displays, solar cells and organic light emitting diodes due to their high electro optical quality, high material availability and low material cost for large area applications. In this experiment, AZO thin films were prepared on glass substrate by Magnetron Sputtering method with a 2wt % Al–doped ceramic target. The processing parameters on electrical properties of AZO thin film were investigated. When processing pressure is 0.8 Pa, the sputtering power is 225 W, the temperature of substrate is 225 °C, the AZO thin films have a lowest resistivity of $9.81 \times 10^{-4}$ Ω.cm and visible light transmittance of more than 85%.

1. Introduction

As we all know, transparent and conductive Al:ZnO (AZO) films are being considered for manufacturing transparent electrodes in flat panel displays, solar cells and organic light emitting diodes due to their high electro optical quality, high material availability and low material cost for large area applications. There are several deposition techniques to grow AZO films such as chemical vapor deposition (CVD) [3], spray pyrolysis [4], pulsed laser deposition [5], magnetron sputtering [6] and sol–gel [7]. Among the processes used to prepare AZO coatings, magnetron sputtering is considered to be a suitable technique due to its inherent characteristics such as high deposition rate, good Controllability and scalability to large areas.

In this experiment, AZO thin films were prepared on glass substrate by Magnetron Sputtering method with a 2wt % Al–doped ceramic target. The processing parameters on electrical properties of AZO thin film were investigated.

2. Experimental details

The AZO films were deposited onto glass substrates in a homemade radio-frequency magnetron sputtering system. A 2wt % Al–doped ceramic target was used. Glass substrates were ultrasonically and chemically cleaned in acetone, alcohol and deionized water, and dried. Then, the substrates were mounted on a 50 mm diameter holder. The target-substrate distance was 40 mm. The chamber was evacuated to a base pressure of $<1 \times 10^{-4}$ Torr by a turbomolecular pump. The RF sputtering power was 125-225 W and the sputtering time was 20 min. Before deposition, the target was presputtered for 10 min prior to the film deposition. During the deposition, the substrate holder continuously rotated to enhance film uniformity.

The morphology, electrical and optical properties of AZO films were examined and characterized. The influence of sputter power, working pressure on the electrical and optical properties of the deposited film was investigated in detail. The surface roughness was measured by an atomic force microscope (AFM). Optical transmittance of the films was measured by using a UV-VIS-NIR...
spectrophotometer. The resistivity of AZO thin films were determined by a Hall Effect measurement and the sheet resistance measured by a four-point probe measurement.

3. Results and discussion

The two criteria of TCO (Transparent Conductive Oxide) thin films are highly transparent in the visible wavelength range where the solar cell is operating to minimize the photon absorption and high conductivity to reduce the resistive losses. The electrical properties of AZO films are essential to adjust the sputtering parameters for its change obviously, so in this experiment sheet resistance and the resistivity were investigated in detail.

There is an equation between the sheet resistance and the resistivity:

\[ R_s = \frac{\rho}{t} \]

where \( \rho \) = resistivity and \( t \) = thickness of films. \( R_s \) = sheet resistance

Figure 1 shows the sheet resistance and resistivity with different O2 flow rate at room temperature under conditions of the sputtering power of 225w, process pressure of 0.8Pa and thinkness of 4780-4800nm. With an increase in O2 flow rate from 0 to 20 sccm, the resistivity goes from \( 3.88 \times 10^{-2} \) \( \Omega \).cm to \( 4.28 \times 10^{-1} \) \( \Omega \).cm and the sheet resistance from 81 \( \Omega \) to 895 \( \Omega \). The conduction mechanism of TCO investigated by many researchers can be classified into two large groups: one was the occurrence of intrinsic carrier by oxygen vacancy, and the other was the introduction of extrinsic carrier by impurity doping. The occurrence of the carrier caused by the development of resistivity was greatly affected by impurity doping than oxygen vacancy when the film was deposited by the doped target. The behaviour was consistent with the other authors in previous works [8].

![Figure 1](image1.png)

Figure 1 Sheet resistance and resistivity with different O2 flow rate at room temperature

Several researches on AZO thin films indicate that increasing the substrate temperature in the 200-250°C range enhanced the crystallite size and electrical conductivity, but the resistivity increased when the substrate temperature was above that range[9-11]. Figure 2 shows the sheet resistance and resistivity of AZO thin films with different substrate temperature under conditions of the sputtering power of 225w, process pressure of 0.8Pa, thinkness of 725-732nm and the Ar flow rate of 100 sccm. The lowest resistivity is \( 9.81 \times 10^{-4} \) \( \Omega \).cm and the lowest sheet resistance is 14\( \Omega \) at 250°C.

![Figure 2](image2.png)
Figure 2. Sheet resistance and resistivity with different substrate temperature

Figure 3 shows the sheet resistance and resistivity at different deposition pressure for AZO films under conditions of the sputtering power of 225W, temperature of 250°C, thickness of 700-780nm and the Ar flow rate of 100 sccm. From the figure, the sheet resistance and resistivity of the film deposited at process pressure of 0.8Pa were lowest.

Figure 3. Sheet resistance and resistivity with different process pressure at 250°C

Figure 4 shows the sheet resistance and resistivity at different sputtering power for AZO films under conditions of the process pressure of 0.8Pa, temperature of 250°C, thickness of 500-730nm and the Ar flow rate of 100 sccm. From the figure, the sheet resistance and resistivity of the film decrease quickly with an increase of sputtering power. Take the stability of sputtering power into consideration, the sputtering power was choose as 225 W.
Figure 4. Sheet resistance and resistivity with different sputtering power at 250°C

Figure 5. The transmission of AZO thin film deposited at 225W RF power and 0.8 Pa working pressure

The transmittance of the AZO thin film is another critical factor for TCO applications. Figure 5 shows the transmission of AZO thin film deposited at 225W RF power and 0.8 Pa working pressure. From Figure 5, the AZO thin film are highly transparent in the visible region of the electromagnetic spectrum. The average transmittance in the visible range (305 – 800 nm) was greater than 85%, even 90% excluding the transmittance of glass background. The AFM image of the AZO thin film deposited at 225W RF power and 0.8 Pa working pressure is shown in Figure 6. From the AFM image, the average grains are 28.93 nm in size.
Figure 6. The AFM image of AZO thin film deposited at 225W RF power and 0.8 Pa working pressure.

4. Conclusions

AZO thin films were prepared on glass substrate by Magnetron Sputtering method with a 2wt% Al-doped ceramic target. The processing parameters on electrical properties of AZO thin film were investigated. When processing pressure is 0.8Pa, the sputtering power is 225W, the temperature of substrate is 225℃, the AZO thin films have a lowest resistivity of $9.81 \times 10^{-4}$ Ω cm and visible light transmittance of more than 85%. The results obtained are very important to the selection of the technical conditions.

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