Vertical In-Line Rotary Magnetron Sputtering System for Large Area AZO Coatings

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***Abstract*—Aluminum doped Zinc Oxide (AZO) is finding applications in various aspects of sensing, and in displays and solar cells. The paper describes the features of a vertical in-line rotary magnetron based sputtering system that has been developed for deposition of AZO coatings on large area glass substrates.**

Keywords—Transparent Conducting Oxide (TCO), Aluminum doped Zinc Oxide (AZO), Magnetron sputtering, Rotary Magnetron, Large-area Coatings.

I. Introduction

Aluminum doped Zinc Oxide (AZO) is being investigated for applications in numerous areas such as transparent conductive oxides for solar cells, displays, and touch sensors, and for application in the areas of gas sensing, humidity sensing, smell sensing, nano-mechanical sensing, piezoelectrics, optical sensors, and SAW sensors [1 – 8]. Magnetron sputtering is one of the approaches that are widely used for the fabrication of AZO films due to the ability to produce films with good electrical, optical and structural properties, with process scalability to large areas. In this work, a vertical in-line rotary magnetron sputtering system has been developed for carrying out large area depositions of AZO coatings on glass substrates of sizes up to 1.1 m x 1.4 m. There are a number of manufacturers who offer systems for AZO Coatings such as Von Ardenne GmbH, Leybold Optics GmbH, Centrotherm Group, Applied Materials Inc., Bay Zu Precision Company Limited, etc. [9] Some of the key differentiating factors of this system are: this is a vertical system thus reducing the system footprint, the system ensures a carrierless transport of the glass thus simplifying the manufacturing cycle, and the cost of ownership of the system is expected to be one of the lowest amongst the options available.

II. Experimental Details

For the development of AZO based TCO coatings, a vertical in-line rotary magnetron sputtering system has been designed and manufactured in-house. The system employs a rotary magnetron with a hollow cylindrical target for the deposition of the AZO films. The use of a rotary magnetron results in a higher target utilization (> 80 %), and the effective target cooling enables the use of higher power densities. The higher power densities result in higher deposition rates that lead to favorable properties in the resulting film because of the higher packing densities.

For the transportation of glass inside the vacuum chamber, the system employs a chain mechanism affixed with graphite pads on which the glass substrate rests, and a belt arrangement that provides support for the glass substrate at the top, both of which are compatible with high deposition temperatures. The chambers of the system are tilted by ~ 10 ° w.r.t the vertical which ensures that the glass is supported by the transport mechanism without the need for any holding frame. The pumping system includes dry pumps and turbo molecular pumps, and the base vacuum is of the order of 10^{-6} mbar.

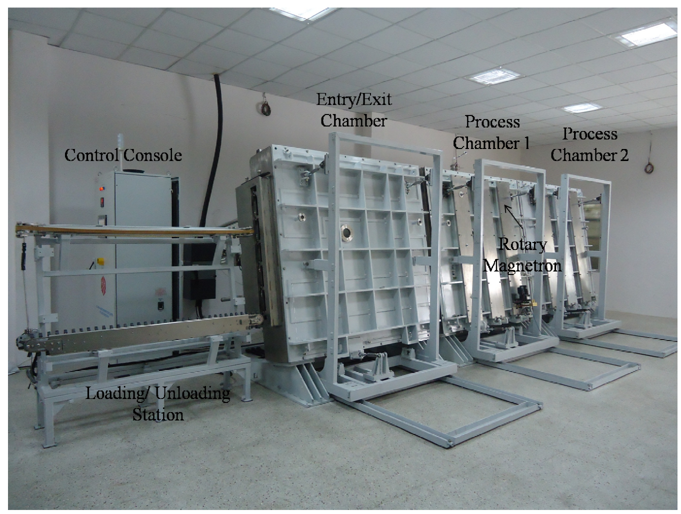

Figure 1. Rotary Magnetron Sputtering system developed by HHV for large area AZO coatings.

Figure 1 shows the picture of the rotary magnetron sputtering system developed for the large area TCO coatings. The system consists of a loading/unloading station, an entry/exit chamber, and two process chambers. The size of each chamber is approximately 2.1 m x 2.3 m x 0.4 m. All the chambers are equipped with heaters to maintain the required substrate temperature during deposition. Figure 2 shows the inside view of the system wherein the rotary magnetron is mounted on to the chamber door.

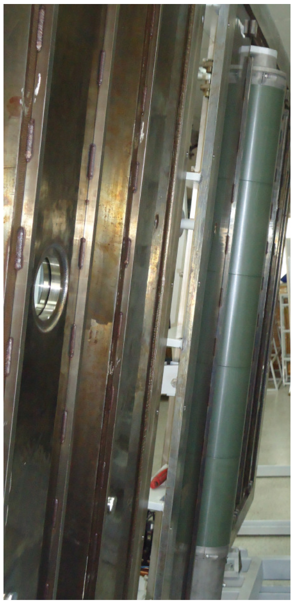

Figure 2. The inside view of the system showing the rotary magnetron mounted on to the chamber door.

The glasses to be coated are loaded onto the loading station. Since the system is being run in the R&D mode, the first chamber is used as load-lock for both entry as well as exit of the glass. This chamber has slit valves on either side for isolating it from atmosphere as well as from the process chambers. For initiating the sequence for coating, the load-lock chamber is vented and the glass substrate is moved into this chamber. Once the glass has moved in, this chamber is pumped to base vacuum, and simultaneously the pre-heating of glass also takes place for bringing it to the required deposition temperature. Once the chamber has reached base vacuum, it is combined with the process chambers which are maintained at base vacuum. Following this, Argon gas is introduced to bring the chambers to the desired pressure and the magnetron is turned on. The rotary magnetron has been mounted in the central chamber (process chamber 1) and the distance between the target and substrate is about 70 mm. The glass is then swept to-and-fro across the magnetron the required number of times for getting the desired thickness. Once the coating is complete, the substrate is brought to the load-lock chamber which is vented and the coated glass is moved out. The system has a modular design in which more process chambers can be added if required, and also, in each of the process chambers there are three ports provided for adding more magnetrons if required to decrease the cycle time.

The substrates used were float glass sheets of 3 mm thickness. Sputtering was carried out from a hollow cylindrical ceramic target (AZO, 2 wt %) using a 10 kW DC power supply (Creating Nano-Technologies, Taiwan). The substrate temperature during the depositions was maintained using PID controllers. A constant Argon gas flow was maintained through MFCs (Bronkhorst, Netherlands).The thickness of the deposited films were determined using a Stylus Profiler (Dektak 6M, Veeco Instruments). The optical properties of the AZO films were characterized using a UV-Vis-NIR double beam Spectrometer (Perkin Elmer, Lambda 750). The resistivity of the films was measured using a four probe sheet resistivity meter (NAGY SD-510). The hall measurements were done in van der Pauw configuration in a measurement system with permanent magnets with a magnetic field of 0.57 Tesla (Ecopia HMS 5300).

III. RESULTS AND DISCUSSIONS

The optimum properties of the AZO films in terms of transmission and electrical properties were obtained for depositions done at a substrate temperature of 300 °C, a chamber pressure of ~ 2 x 10^{-3} Torr, and a magnetron power of 7.5 kW. The optical transmission spectrum for the AZO film is plotted in figure 3. The values plotted are glass compensated values, i.e. transmission for the AZO film only. The average transmission in the visible region (380 – 780 nm) is 89 % for a film of thickness 700 nm.

The sheet resistance is 5.7 Ω/□ corresponding to a resistivity of 4 x 10^{-4} Ω.cm. The carrier concentration, and mobility, as measured from hall measurement are 5.53 x 10^{20}/cc, and 28.3 cm^2/V.s, respectively. The transmission and resistivity values obtained make the films suitable for application as front contact in thin film solar cells.

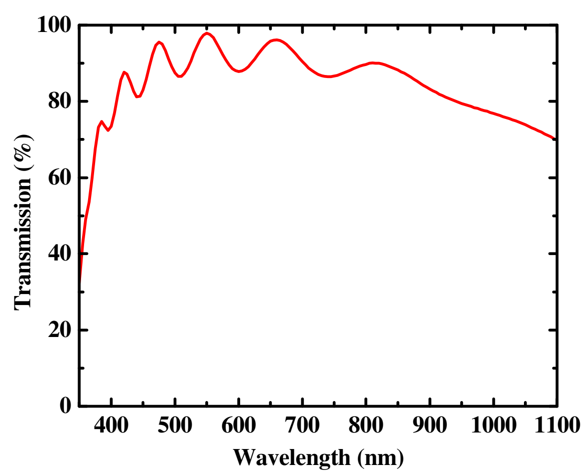

Figure 3. Transmission spectrum (glass compensated) for the optimized AZO coating.

Two of the most commonly used techniques for large area deposition of AZO coatings for solar cell applications are LPCVD and Sputtering. In case of LPCVD, the resistivity values are in the range of ~ 1 x 10^{-3} Ω.cm [10], and in the case of sputtering, resistivity values of ~ 3 – 8 x 10^{-4} Ω.cm have been reported [11 – 14]. In our equipment configuration, resistivity values of 4 x10^{-4} Ω.cm has been obtained by adding a suitable mask in front of the magnetron.

Tin doped Indium Oxide (ITO), which is predominantly used for TCO applications is being commercially produced on large area substrates with resistivity values ranging around 1.5 – 2 x 10^{-4} Ω.cm. The resistivity that is being obtained on AZO is slightly higher than the values obtained for ITO, but due to the lower cost potential of AZO, it is expected to be more economic for various TCO applications.

IV. CONCLUSIONS

In conclusion, a rotary magnetron sputtering system has been designed and manufactured for coating AZO films on large area glass substrates. The deposition conditions have been optimized for obtaining AZO films with an average transmission in the visible region of ~ 89 %, and a resistivity of ~ 4 x 10^{-4} Ω.cm which are suitable for a wide range of TCO applications.

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