Rotating Cylindrical ITO Targets for Large Area Coating

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ABSTRACT

ITO (indium-tin oxide) is one of the best performing TCO's (transparent conductive oxides) in thin film industry. Applications range from flat panel displays (LCD, PDP, OLED), smart windows, touch panels, photovoltaic solar cells, electro luminescent "thin film" lamps to (transparent) EMI shielding and are often based on the use of the ITO layer as a transparent electrode.

DC magnetron sputter deposition from a ceramic planar ITO target is the most common method for the application of an ITO coating on glass or plastic substrates. However, planar magnetrons show several limitations. Rotating cylindrical ITO targets are expected to solve the limitations of these planar ceramic ITO targets to a great extent. The inherent advantages of rotating cylindrical target technology over planar cathodes include: a larger useful target inventory and an increased target material utilization (leading to a reduced machine down-time and lower cost-of-ownership); improved target cooling meaning that an increased power density is possible and hence a higher deposition rate can be achieved, and excellent process stability for reactive depositions, etc.

In this paper we present rotating cylindrical (ceramic) ITO sputtering targets for large area coating applications. The sputter related behavior and layer properties will be discussed and compared to commercially available planar ITO targets.

INTRODUCTION

The use of transparent conductive oxides is required in a wide variety of applications such as flat panel displays, smart windows, touch panels, photovoltaic solar cells, electro-luminescent "thin film" lamps, (transparent) EMI shielding, etc. TCO thin films combine a high visual transparency with a high electrical conductivity [1,2].

Because of the unique combination of excellent performance, both optically as well as electrically, tin-doped indium-oxide is the TCO par excellence for a wide variety of applications. Next to its good electrical and optical properties, this wide band gap n-type semiconductor (commonly called indium-tin-oxide or ITO) also shows a high hardness and a good chemical and thermal stability.

Among the available methods, reactive DC magnetron sputter deposition from a planar ceramic target is the most extensively used technique for the reliable and cost effective deposition of ITO coatings on glass and plastic substrates. The use of planar targets, however, typically consisting of one or more tiles bonded to a metallic backing plate, shows several limitations (such as limited target utilization due to the formation of an erosion groove, limited power density, and nodule formation). In industries where the typical target materials are readily available in rotatable version (such as the large area architectural and automotive glass coating industry), the rotatable magnetron was introduced and implemented successfully since the 1990s.

While the use of rotatable magnetrons nowadays is standard for large area architectural and automotive applications, it remains limited in the display industry for several reasons. Firstly, since the cost of rotatable magnetrons does not scale with substrate or target sizes, they have been a cost effective alternative for large architectural glass coaters (having substrates up to 3.2m x 6m). In the somewhat smaller display coaters, the introduction of rotatable magnetrons only becomes interesting for the more recent equipment generations. Secondly, the specific coater design (vertically) also complicates retrofitting of planar cathodes by rotatable cathodes. Replacing planar cathodes with end block rotatables may result in somewhat shorter target lengths and, as a consequence, a reduction in uniform coating width. The use of cantilevered magnetrons may offer the desired solution as long as the coater geometry allows the mounting of this type of rotating magnetrons. Thirdly, not all target materials specific for display applications have been commercially available in rotatable version. The most crucial material in this aspect is definitely ceramic ITO.

In this paper, rotating cylindrical (ceramic) ITO sputtering targets for large area coating applications are presented. The above mentioned advantages of rotating cylindrical magnetrons will be demonstrated and the sputter related behavior and layer properties will be discussed and compared to planar magnetrons.

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ROTATING CYLINDRICAL MAGNETRONS

The key features for the success of the rotating cylindrical magnetron are the drastically reduced arc sensitivity during reactive sputtering, the higher material consumption and higher target material inventory as compared to planar magnetrons, the possibility to use a higher power density and thus obtain a higher deposition rate and the enhanced anode functionality during AC sputtering.

The use of rotating cylindrical targets restricts the arcing zone to two ring shaped areas at the cathode tube ends. Very little arcing occurs in the racetrack area of a rotating cylindrical target since it is continuously cleaned by the plasma and only a thin zone at both extreme ends of the target tubes gets contaminated. An important feature is the fact that the arc sensitive zone for rotating cylindrical targets is independent of the target length.

For planar magnetrons, the presence of a racetrack limits the target consumption and increases the cost of ownership. Although a stationary plasma track is present during sputter deposition for a rotatable cylindrical target too, no racetrack groove corresponding to the magnet configuration (comparable to the one formed at a planar target) is formed in the rotating target and very high material utilization may be achieved.

Another interesting feature of rotating cylindrical targets is the fact that a single target offers a higher coating capacity as compared to a similar standard planar target. This higher coating capacity results from the higher target utilization (as discussed before) but also from the larger amount of available target material. Because of the circumferential presence of target material, a rotatable target can contain up to three times more material than a planar target (for equivalent layer thickness and target width/diameter).

Increasing the throughput of the coating equipment can be accomplished by the use of higher power densities (higher deposition rates). For planar targets this is however not always a possible solution because the target material may melt or crack under the thermal load. In contrast to planar targets, rotating cylindrical targets offer the possibility to use higher power densities. For these targets, the thermal load is uniformly distributed over the complete circumference of the target resulting in less local heating of the efficiently water cooled target tube.

Less important for the specific case of ITO is the fact that the use of a rotating cylindrical magnetron as an anode (in AC sputtering) does not suffer from the disadvantages of a “magnetic anode”. The total effective anode area is firstly much larger as compared to a similar planar magnetron and secondly, the field free area is much larger too. This implies that the effects created by the presence of the magnetic anode (decrease of deposition rate due to formation of an anode fall resulting in a decreased cathode voltage) are not an issue for dual magnetron sputtering with rotating cylindrical magnetrons.

The most important gain for the display industry is a distinct reduction in cost-of-ownership and bottom line, cost per coated substrate area. This is not only achieved by a drastically increased machine throughput and coating capacity (due to a combination of an increased target material inventory and power density) but also by an enhanced target utilization of very expensive materials.

EXPERIMENT

Planar targets (from different manufacturers) and rotatable ITO targets were compared. Tests were carried out in different roll coaters. Various power supplies were used during these tests. Since all tests were performed on polymer web, no substrate heating could be performed during sputter deposition.

The planar targets consisted of several tiles bonded to a backing plate. The rotatable targets, however, were made as one single piece (not assembled from different tiles or different cylindrical segments or rings bonded to a backing tube). In conventional ITO target production methods, the target material (built from individual tiles or cylindrical rings) is bonded to the backing plate or tube as a last step in the production process [3]. In contrast to this, for the rotatable ITO targets discussed in this paper, the ITO material is directly applied to the backing tube during the target production process. This implies an optimal and homogeneous bonding of the ITO to the backing tube and as a result, an optimized thermal conductivity. This enhanced thermal conductivity ensures a better cooling of the target material and, as a consequence, the possibility to use higher power densities.

Cylindrical single piece ITO targets have been developed by several production routes. Material purity was typically over 99.9%. Target material densities ranged from 6.6 up to 7.1 g/cm^3 (which is from 92.3% up to 99.3% of the theoretical density). For this study, target lengths varied from 350 mm to 1700 mm. Target lengths were, however, only limited due to the available coater space. The ITO layer thickness on the targets varied from 0.4 mm up to 4 mm. The limits for ITO target lengths and material layer thickness are similar as for the conventional rotatable targets: lengths up to 152” and layer thicknesses up to several mm should be attainable.

The targets were evaluated during the sputter process (process stability, arcing) as well as after the process (nodule formation). The deposited ITO films are first of all characterized inline by their key optical and electrical properties. Afterwards, the resistivity and/or optical light transmission are also evaluated before and after an annealing step and a chemical durability test. Finally adhesion was checked and grain size was evaluated by SEM.

Figure 1. Two rotatable ITO targets mounted in a production scale in-line sputtering chamber.

RESULTS

Process Stability and Target Evaluation

In general, the process stability of rotatable ITO targets is comparable to planar targets, having stable sputtering voltage over long periods of time and low arcing levels. It should, however, by noted that at higher power (higher than typically possible on planar targets) adequate tuning of the arc handling of the power supply is quite important to maintain stable processing. This can be obtained with the Bekaert arc suppressing unit.

In Figure 2 a typical resistance curve as function of oxygen flow is shown for a rotatable target. The central area is sufficiently wide to allow stable processing and further tuning of optical properties. It is noted that typically, higher O_2 flows are needed as compared to planar targets in similar sputter conditions.

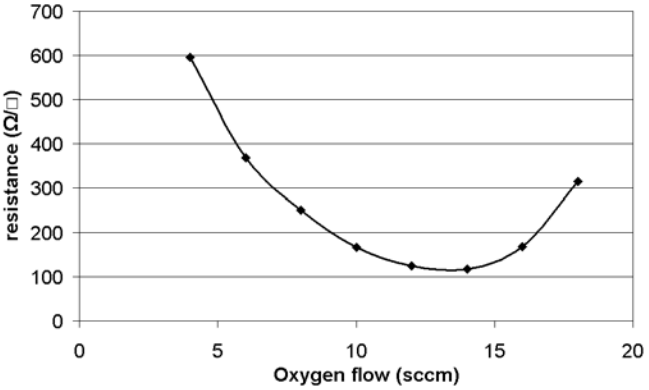

Figure 2. Typical resistance curve as a function of oxygen flow for a rotatable target.

The target surface has been examined to determine the rate of nodule formation. After the first tests, no nodules could be detected on the rotatable targets, implying an extended run time before cleaning becomes necessary.

Optical and Electrical Properties

Optical light transmission, absorption, refractive index and extinction coefficient have been evaluated. In Figure 3 the extinction coefficient and refractive index as a function of wavelength are compared for layers deposited from a rotatable target and a planar target. Layer thickness, power density and film speed were comparable. Both parameters show similar or slightly better results for rotatable targets.

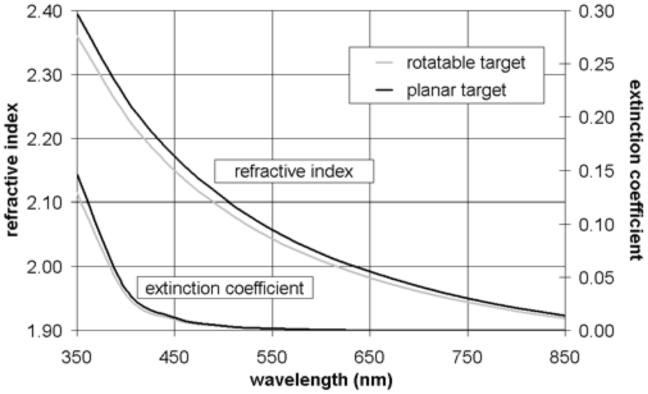

Figure 3. Comparison of optical properties of ITO layers deposited on standard PET film from a rotatable and a planar target in similar sputter conditions.

The refractive index and extinction coefficient for layers deposited from a rotatable target at a higher power than possible for a planar target are also comparable to the results obtained at lower power.

Table 1 gives a comparison of the total visual light transmission before and after annealing for ITO layers from a planar and a rotatable target. A higher transmission is obtained for the rotatable target in all cases.

Table 1. Total visual light transmission before and after annealing.

	Before	After
Planar target	86.6	86.9
Rotatable target	87	88.1

Resistivity was measured on samples from rotatable targets both at similar and at higher power densities as compared to the maximal possible power densities for the planar targets. On 175 and 75 μm thick, optical grade PET foil (deposition at 25°C) a resistivity below 500 μΩcm was found, which was comparable to the result obtained from planar targets.

The resistivity values were checked before and after an annealing step and a chemical durability test. The initial results as well as the changes after the annealing and chemical step were comparable for planar and rotatable targets.

Sputter Rate and Power Density

Sputter rates were evaluated for rotatable targets at similar and higher power densities than possible for planar targets. Results are given in Table 2. The deposition rate is similar for planar and rotatable targets at similar nominal power. However, since much higher (at least 3 times higher) power levels can be used for rotatable targets, the deposition rate was also increased by a factor of 3.

Table 2. Deposition rate as a function of power density (for target width/diameter of 140 mm).

Magnetron	Power (kW/m)	Deposition rate (nm m/min)
Planar	3.2	20
Rotatable	3.4	21
Planar	3.9	30
Rotatable	6.8	42
Rotatable	10.2	max 65
Rotatable	15.0	max 100

Adhesion and Grain Size

An adhesion test showed similar results for the planar and the rotatable targets. A SEM analysis was done comparing ITO layers from standard production from a planar target with the initial tests from a rotatable target (see Figure 4). Important to note is that no complete optimization of the process parameters was done yet for the rotatable target. Despite this, it is clear that the grain size is already quite comparable. After optimization of all process parameters for the rotatable target, it is expected that planar and rotatable targets will give similar results.

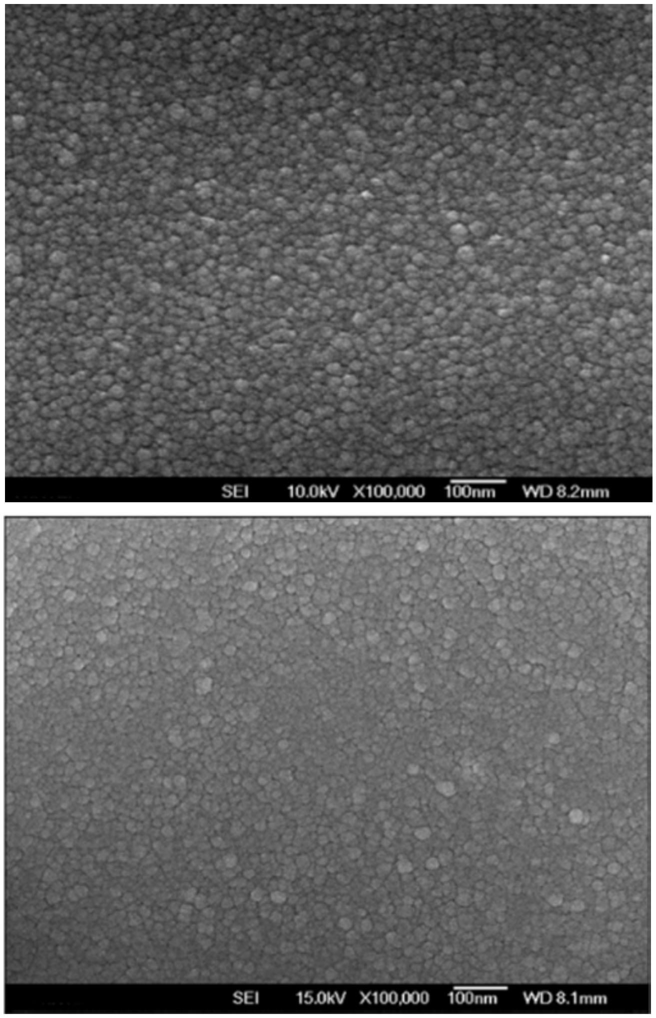

Figure 4. SEM pictures of ITO layers deposited from planar (above) and rotatable targets (below).

MAGNET ARRAY FOR ROTATABLE ITO

Production conditions for the sputter deposition of thin ITO films differ quite significantly from those for the typical thin films for large area architectural or automotive applications. One of the specific requirements for achieving low resistivity ITO layers is a low sputtering voltage [4]. These sputter process conditions can be obtained with an appropriate tuned magnetic confinement of charged particles (electrons and ions) and may help significantly in improving the properties of the growing ITO film.

Magnet arrays are available for producing adequate magnetic field configurations [5]. The basis for this magnet arrays is a hermetically sealed thin walled housing, allowing the use of very strong NeFeB magnets. The thin walled hermetically sealed housing prevents the magnets from degrading while still ensuring optimal cooling of the targets and magnets.

CONCLUSION

Cylindrical single piece ITO targets have been developed by several production routes. Large size prototype targets were tested in web coating production environments and compared to planar targets.

It can be concluded that the sputter behavior, the electrical properties, and the optical properties coincide with planar target sputtering results at equal power densities. The thermal and chemical stability, the adhesion and grain size also showed comparable results. Tests at higher power clearly show the possibility to use an at least 3 times higher power density for a rotatable target as for a planar target with comparable size, resulting in a 3 times higher deposition rate. Initial tests on layers deposited at higher power densities also show promising results.

Above all, the inherent benefit of rotatable targets with respect to target utilization (more than 85%) is a major advantage for very expensive ceramic materials such as ITO.

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