Performance Comparison of Silver Sleeved Rotary Targets with Planar Targets

George M. Wityak - Academy Corporation, Albuquerque, NM
Anja Blondeel, Wilmert De Bosscher - Bekaert Advanced Coatings, Deinze, Belgium

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ABSTRACT

Thin silver films are used as a functional layer in many stacks for heat reflective applications. At the present time, large area coating stacks are produced by magnetron sputter deposition and often from rotating cylindrical targets. The inherent advantages of rotating cylindrical target technology over planar cathodes are already well known. However, silver is still one of the few metal targets not readily available in rotating cylindrical version. The reasons for this are related to cost, mechanical strength, and handling.
In this paper, a new approach for realizing Ag rotary targets is being proposed in which cylindrical sleeves are mounted and attached on a backing tube. Several cylindrical designs are compared and benchmarked against planar targets. Process and product related parameters such as process stability, sputter rate, uniformity and film quality are evaluated. The influence of the plasma heat load and the resulting thermally induced mechanical stresses on the Ag target performance, mechanical as well as on a process level, is discussed. Targets were evaluated during various stages of their lifetime in order to determine if performance was stable and could be reliably predicted.

INTRODUCTION

Silver has been used for some time as the principal infrared reflecting film in optical coatings. The outstanding inherent electrical and thermal conductive properties of silver guarantee that silver targets will sputter readily and are stable in most typical operating environments. Silver has been primarily manufactured and sputtered in planar form, principally due to the fact that silver manufacturing is conducted in far smaller quantities than copper, aluminum or titanium. The equipment typically employed for producing silver is much less significant in scope and volume than that used for other commercial materials.

EXPERIMENT PROCEDURES

Comparison of Designs

In keeping with the goals of this experiment, a number of different target designs were evaluated to examine the advantages and limitations of each design predicated upon what potential users of the technology would encounter in implementing silver rotary targets in their production systems.
Four designs were evaluated. They included:

- Indium bonded sleeves
- Mechanically mounted sleeves [3], [4]
- Mechanically mounted sleeves augmented with thermal conductive paste
- Monolithic tube

The first three designs were mounted upon a standard production stainless steel backing tube, the last design was made entirely of silver, not incorporating any backing tube for support.

The overall outside diameter of target in each case was 155 mm (6.1”) OD. The target length was 878 mm (~ 35”).

Commercial Attributes and Limitations

Rotary target systems have the ability to sputter at a higher rate than planar targets due to the possibility to use a higher power density. Rotary target performance is more consistent because the erosion is more uniform, the trenching seen throughout the length of planar targets is limited on a rotary target to the ends. Utilization is also higher for rotary targets, typically above 80%, while planar targets average around 30% yield. In the area of logistics and handling, use of mechanically mounted sleeves would allow the end user to remove and replace the target sleeves within their facility as part of normal target maintenance. This gives the customer more accurate silver weights, requires fewer backing tubes, and lowers the costs of shipping.
Bonded sleeves do not offer the management advantages nor can they be readily rebuilt within a customer facility. They do offer the opportunity for surface profiles and use of dissimilar materials when appropriate to the final application.

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A monolithic tube offers high rate deposition, ease of measuring target yield and target weight, but does have potential restrictions in its mechanical ability to span long lengths without deflecting and does not lower shipping costs of handling long lengths.

Controls & Measurements

Thermal gain in the target was the property of greatest concern to the experimenters. Intuitively, a sleeve design will have more issues related to thermal dissipation than solid, monolithic parts. Heat transfer through a gap or through a bonding media will also differ in rate. Therefore it was of great importance to measure thermal gain in the target as a function of incremental increases in applied sputtering power. After evaluating and rejecting external optically based thermal measurement techniques, it was found that a contact thermocouple was the most effective way of measuring thermal gain. A system was designed that incorporates a spring loaded lever arm to bring the thermocouple into firm contact with the target. The contact load was sufficient to create a wear groove in each of the tubes tested. Figure 1 illustrates scored surface.

Figure 1. Thermocouple Contact Point

Each target was installed in the system and sputtered at incrementally increasing power. Based upon process modeling and industry feedback, a power load goal of 5 kW (on the 35” targets) was set. This would provide a commercially viable sputter rate to increase the line speed of the coater. In order to determine the maximum performance envelope, each target was run at increasing power levels to identify possible failure mechanisms at elevated power loads.

Arc Measurement

Arc behavior was measured by an in-house developed system. [1] In practice, silver targets are not prone to arcing due to their high conductivity and they are normally sputtered in metallic mode. Counting the arcs for the different designs would highlight issues with electrical conductivity or plasma instability.

COATING SYSTEM CONFIGURATION

Coating System

A single chamber system (Figure 2) with glass transport system was employed for the testing. The target tubes were installed singularly and each series of test replicated. The targets were operated in DC mode.

Figure 2. Small Test Coating Chamber

Chamber Gas and Pressure

Argon was employed for all tests with a flow rate 140 sccm. The chamber pressure for all of the tests was between 2.0 – 2.3 x 10^{-3} mbar.

Water Flow Rate and Temperature

The flow rate was measured for each test along with the inlet and outlet temperatures. Large changes in water temperature would imply good thermal transfer. Comparing the differences at each power level offers insight into heat transmission through the sleeves to the backing tube to the water.

Magnet Array

The magnet array type for all tests was the Bekaert AMBV2.1. This adjustable magnet array is the typical design used for large area glass coating applications offering a parallel (tangential) field strength around 500 G on target surface and a target utilization of above 80 % in both DC and AC mode [2]. The included angle between the racetrack sections is between 30 and 35 degrees.

PROCESS & PRODUCT RELATED PARAMETERS

Process Stability

Each target was individually installed and evaluated using the same deposition conditions. The following parameters were set as a starting point for all aspects of the experiment.

Table 1. Process Parameters

Parameter	Measurement
Substrate to Source Distance	80 mm
Substrate Line Speed	1 meter per minute
Number of Passes	10
Thickness Measurements	34, spaced 25 mm apart

The sputter window in this coater was similar to a typical large area glass coating environment.

Sputter Rate

Sputter rate was determined by measuring the thickness of the coating on each substrate via Dektak IIa and calculating sputter rate based upon the line speed of the substrate and the number of passes.

Deposition Profile – Coating Uniformity

Measurement of thickness was conducted using 34 separate substrates to measure coating uniformity across the width

Conductive Media

For the two designs that incorporated a conductive media to promote electrical and thermal conduction between the target sleeves and the backing tube, the following materials were used:

Bonded tube – Pure indium – M.P. 156.6°C, thermal conductivity (at 85°C) .78 W/m∘K [5]
Mechanical with thermal paste - Dow Corning DC340 – maximum operating temperature – 200°C, thermal conductivity .42 W/m∘K

RESULTS AND DISCUSSIONS

Table 2. Specific Sputter Rates – nm m/min

Power Level (kW)	Bonded	Mechanical mount	Mechanical w/thermal paste	Monolithic
1	27	27	29	27
2.5	70	-	70	70
3.8	-	-	108	-
5	135	-	140	140
7.5	198	-	202	200
10	-	-	268	254

Table 3. Heat Load – Target Surface Temperature - °C

Power Level (kW)	Bonded	Mechanical mount	Mechanical w/thermal paste	Monolithic
1	33.3	260 and increasing	32-34.5	32
2.5	44	-	42-44.3	38.8
3.8	-	-	46.5-52.2	-
5	59.5	-	61 – 65.9	51
7.5	90	-	-	63
10	> 200 and increasing	-	111.5	89

Table 4. Max. Change in Water Temperature - °C -

Power Level (kW)	Bonded	Mechanical mount	Mechanical w/thermal paste	Monolithic
1	.4	.5	1	1.5
2.5	1.5	-	2.5	1.8
3.8	-	-	2.5	-
5	2.4	-	3.0	3
7.5	6.4	-	-	4.5
10	6.3	-	5.7	4.7

Coating Uniformity

Each design tested showed similar edge to edge coating properties. The substrates were cycled through 10 passes beneath the target. Figure 3 is a representative example of the uniformity of thickness across the width. The shape of the curve corresponds with the length of the magnetic array. The drop-off at both ends is due to the finiteness of the target. No distinct differences in uniformity were noted.

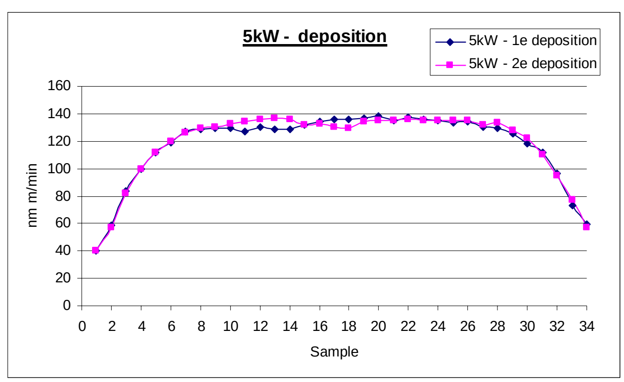

Figure 3. Edge To Edge Coating Uniformity (Typical)

Limitations of Each Design

In this test regime, the results indicate that the mechanically sleeved target was not an appropriate design, the increase in target temperature was immediate and dramatic. The same target when used in conjunction with a conductive paste, worked much better, but at elevated power loads, the paste became more fluid and would weep out of the sleeve-to-sleeve gaps causing arc events. Reducing the paste volume due to leakage also diminishes the heat transfer ability of the target. Over time, this would manifest in increasing target temperatures and reduced effective target life. The bonded target exhibited good performance up to 7.5 kW. However, when the target was first run to 10kW, a portion of the indium bond failed. Performance after that was erratic above 5 kW. As would be expected, the monolithic tube provided the best overall result. The monolithic target provided the good performance at all power levels.

Mechanical Stresses

The thermal gain in the un-bonded tube was sufficient to cause linear expansion of the tube sleeves. So much so that the welded containment ring was deformed (see Figures 4 and 5). The testing of this tube was curtailed at this point. None of the other tube designs exhibited any discernible mechanical stresses that would hamper target behavior.

Figure 4. Deformed Welded Retaining Ring without Sleeves

Arcing

Arc rate was measured for each of the target configurations. Arcing was an issue only for the tube incorporating the conductive paste. When the conductive paste became heated and began weeping through the gaps in the sleeves, a high arc rate was noted. Otherwise, arcing was only seen when the thermocouple was brought into contact with the tube.

Interpretation of Results–Implied Operating Envelope

Figure 5. Deformed Welded Retaining Ring with Sleeves Mounted

For every test, the monolithic target ran cooler and provided consistently high sputter rate. No problems were encountered that would indicate that 10kW is the upper limit for this design.

The mechanically mounted sleeves augmented with conductive paste also preformed well. Containment and control of the paste was an issue and would require design improvement to ensure that the paste is stable throughout the life of the tube. Although this design configuration recorded the highest sputter rate, variations in testing make this less significant. It is possible that target heating may have contributed to increased sputter rate.

Similarly the indium bonded target met the 5 kW power requirement set for commercial viability. It also exhibited unstable heat transfer at 10 kW, after which the bond integrity was diminished and the target would no longer run consistently at a power setting greater than 7.5 kW. Since this test was accelerated, it is not possible at this juncture to determine what the nature of bond integrity would be for prolonged operation at a power setting of 5 to 7.5 kW. The effect of target mass and surface topography might have an effect as the target is eroded over time. Indium melts at 156.6°C. The surface temperature up to 7.5kW was less than the melting point, beyond the 7.5kW the temperature was above 200°C. Any changes in water delivery volume or temperatures, even for a short time period, could cause spontaneous bond failure.

CONCLUSION

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Several different designs were evaluated in a practical manner. This was accomplished using typical deposition technologies with readily available hardware. It was demonstrated that the potential increase in deposition performance is greatest for targets that provided the best dissipation of heating effects of the plasma. The slip on sleeve performance was very limited, possible contributing factors were eccentricity in the backing tube and lack of conduction along the length to the retaining rings. Sleeve designs with a coherent heat transfer medium to fill the gaps between the ID of the target sleeve and the OD of the backing tube, worked well. Each of these concepts will benefit from improvements in medium selection, tighter tolerances and assembly. Optimization in these areas will lead to higher and more consistent performance.

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