“On the Fly” Cathode Uniformity Tuning

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ABSTRACT

Thin film coating systems must be maintained at regular intervals to optimize product quality and throughput. Loss of production due to non-preventative maintenance issues must be avoided and tuning the thin film thickness uniformity is one of the key culprits. By automating the procedure for tuning a sputtering magnetron, while still in a production mode, the user can maintain both quality and system throughput. This paper describes one such method.

INTRODUCTION

Sputtered thin films often require uniformities better than +/- 2.0 % across the substrate, with a width as great as 3m, while achieving target utilization of ~ 40 %. These specifications are expected throughout the duration of target life and targets can be as thick as 30mm. Although there are many “triggers” to help tune uniformity, a common practice is to adjust the magnetic field shape and/or intensity to meet the highest priority specification which is the uniformity. It is difficult for any magnetic design to hold all these specifications and often the end-user will sacrifice yield loss or system uptime when the product begins to drift out of tolerance. The process may be stopped prematurely to either replace partially worn targets or to adjust the system dynamics. In either case this is a costly practice due to the fact that the system is not making product. Venting, pumping, and maintenance requirements will consume hours of costly production time

Magnet assemblies can be designed to have adjustment capabilities which can accommodate non-uniformities in the range of up to +/- 10 %. Required adjustments which typically involve movement of magnet configurations fall under the downtime/system vent category or lost production time. A unique yet mechanically simple approach has eliminated the need to stop production for corrective uniformity action. By altering the magnetic field and providing the end-user with real-time feedback on the adjustment position of the magnetic component, down-time or lost product can be nearly eliminated. More importantly the changes can be made *in-situ*, anytime during target life, so that as the environment changes the magnetron can accommodate and stay in production , within specification.

ALTERING THE MAGNETIC FIELD

Although magnet assemblies within the sputtering magnetron can be assembled with individual magnet tolerances tighter than 1%, this does not guarantee that the performance expectations of the assembled magnetic components can be met. In producing high uniformity thin films the overall system design and performance is equally important to the magnetron so that process effects such as pumping, gas flow-distribution, anode design, … all work together. Unfortunately this is the exception rather than the rule. Workarounds to a non-uniform thin-film profile can include changes to gas distribution or “trim-shields”. Although effective, the workaround methods are most effective over a larger length of uniformity and are subject to change as coatings build up in thickness and change anode or gas distribution dynamics. These workarounds are also less effective in small local areas of non-uniformities. Alterations to the magnetic field can accommodate both large and small areas of non-uniformity.

Figures 1 and 2, depict the configuration of a linear planar magnetron and its magnetic flux which is often used in architectural glass coating. Figure 1 shows the cross-section of this magnetron with target thickness of up to 30mm while Figure 2 represents the magnetic flux lines produced at the target surface for this magnetic design. It is known that the deposition rate can be locally changed by altering the shape and intensity of the flux profile. Figure 3 is the same magnet design as Figure 1 but with a shunt incorporated. In the case of Figure 3 the shunt is located in a “null” position so that there is no change to magnetic flux at the target surface, however the ability to change the flux is present if the shunt were to be moved. In this design the movement of the shunt is to the “center” magnet and lies on the horizontal plane (or 1 degree of freedom). Figure 4 shows the resulting magnetic field density with the “fully shunted” position. Figure 5 is a

505/856-7188
56th Annual Technical Conference Proceedings, Providence, RI April 20–25, 2013 ISSN 0737-5921

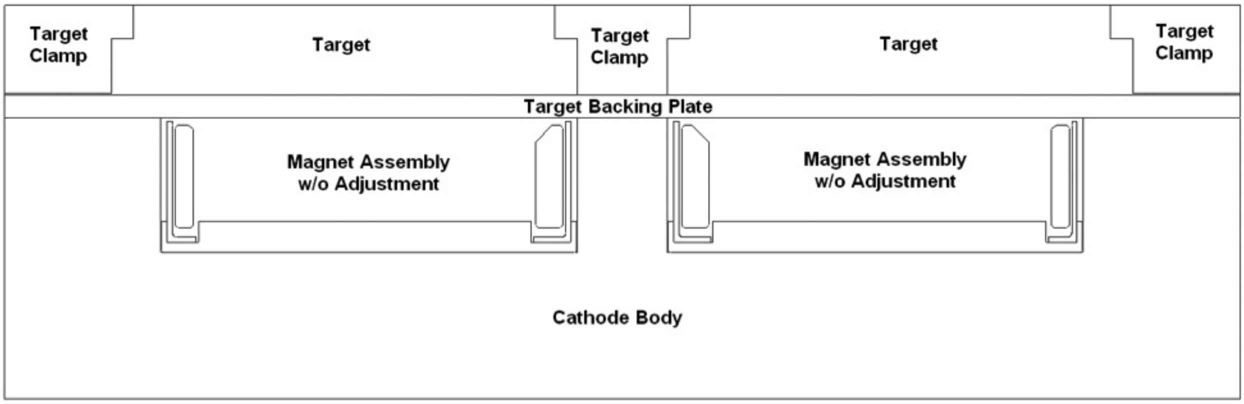

Figure 1: Standard Magnetron Design for Architectural Glass Coating. No adjustment capability.

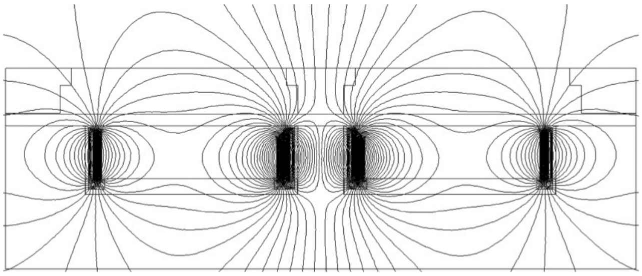

Figure 2: Magnetic flux profile for Standard Magnetron Design.

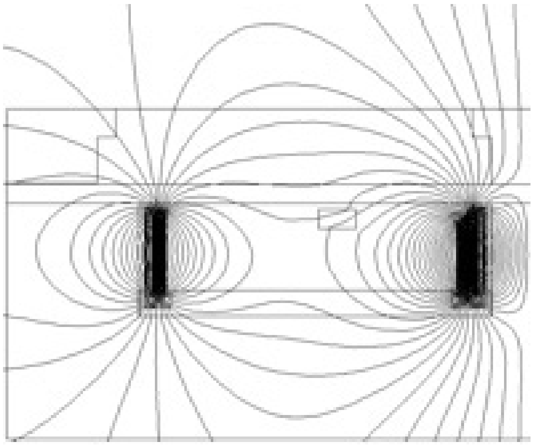

Figure 3: Shunt incorporated into Standard Magnetron Design in the "Null" position.

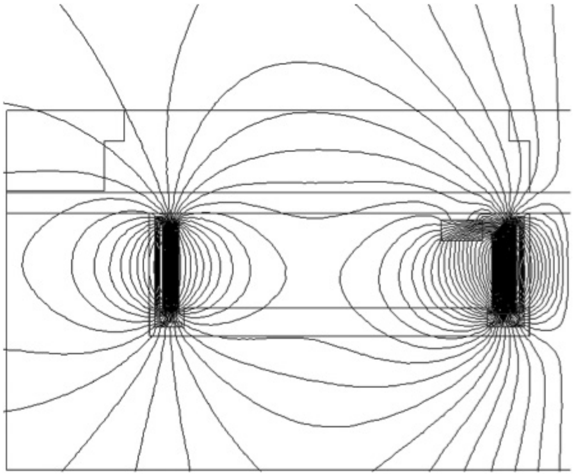

Figure 4: Shunt incorporated into Standard Magnetron Design in the "Fully Shunted" position.

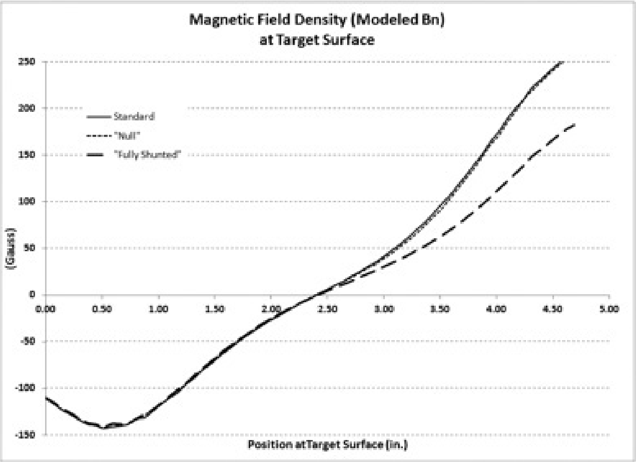

Figure 5: Comparative Plot of modeled magnetic field density at the target surface. For this design; a) There is near ideal agreement between the "Null" model and the "Standard"; b) There is a large difference seen between the "Null" and "Fully Shunted" positions.

comparative plot of the produced ‘Normal’ field density, at the target surface, and how it can be compared to the “Null” shunted position and the fully shunted positions.

Applied results from production environments have show that the deposition rate is proportional to the magnetic field density. That is, as the field density is increased the deposition rate is likewise. Further, uniformity changes for this design can be approximated at 1 % film thickness per 1mm of shunt adjustment.

To this point the presented schematics and plot show that a mechanism for changing the magnetic field can be incorporated into the magnetic design. The change varies from a no effect position (or “null” position) to the full effect and movement is along a single axis.

The effect of the shunt can be altered by choice of shunt material and geometric configuration. If the required resolution is better than +/- 2-3 % then a magnetic stainless steel might be employed and for “gross” uniformity corrections the device might even require another magnet.

MOVING THE SHUNT WITHIN THE MAGNETRON

The lateral motion of the shunt has a range of ~19mm total movementf. A number of methods for mechanically/electro-mechanically moving the shunt within the cathode body were explored, but confined by the following criteria:

- All components must fit within the available space
- Components and control must withstand voltage spikes of ~1500V as well as the constant operating voltage for sputtering
- withstand the surrounding environment (cooling water)
- Generate sufficient force to hold or move the shunt in small increments, to a fixed and repeatable position, withstanding the magnetic attraction between the shunt and the surrounding magnets.

To meet this criteria an electro-pneumatic solution to the problem was developed. Figure 6 shows the configuration for a single module being tested in water, where several modules are typically combined to create the cathodes magnetic path. The design generates a maximum shunt movement of ~1mm. All components are compatible in water and there is no electrical feed into the magnetron required for shunt activation.

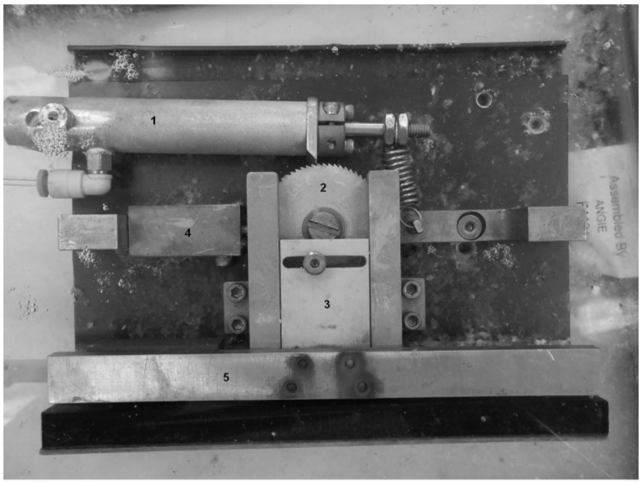

Figure 6: Magnet assembly with “alpha” shunt movement design. The components include; 1 – air cylinder, 2 – Ratchet gear, 3 – Guide for shunt movement, 4 – Ratchet lock assembly, 5 - Shunt.

SENSING THE SHUNT POSITION

A challenge in making changes “on the fly” is to know the magnitude of change each movement will incur as well as the starting position of the shunt. With no feedback the user would question;

- “What if there is an electrical or mechanical failure when moving the shunt such that the movement is not as expected?
- What if historical data is misplaced? How do I know if I moved the shunt?
- If I moved the shunt too far or in the wrong direction, how do I get back to where I started?”

It has been found necessary to provide the end-user with working knowledge of the shunts location to address the questions above. Since the development involves working with magnetic fields it makes sense to use a Hall Effect sensor. It is not necessary to obtain absolute values, but only that the readings be repeatable , stable, and offer significant resolution dependant on the position of the shunt. A sensor has been mounted on the underside of a shunt and reads the magnetic flux density to the nearest magnet (or center magnet). Utilities for the sensor and the sensor itself are protected within the air supply line which activates the air cylinder. As the shunt is adjusted or approaches the magnet, the sensor indicates an increase in flux density and just the opposite for the shunt moving away from the magnet. Figure 7 is a side-view of the module assembly showing the sensor location in the test unit and Figure 8 indicates the sensor value v. the actual shunt position.

Figure 7: Plot 2: Allegro A1302A Hall Effect Sensor attached to shunt, in the magnetic region of the sputtering magnetron.

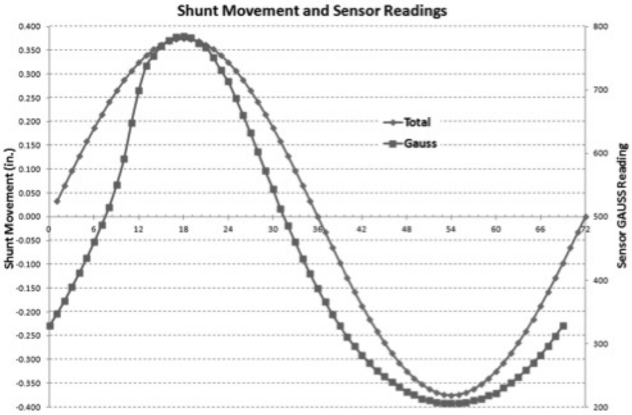

Figure 8: Plot 2 depicts the sensitivity of the shunt movement as well as the step size for each movement.

TEST: PROCESS AND ANALYSIS

Magnetic modules (6 – Auto Shunt & 10 – Manual adjust), were installed into a 60" "HRC" type cathode with both Manual and Auto Shunts position at 12mm (measured distance from Center magnet) within their range of travel (Figure 9). The utilities for the Auto Shunts are protected in a compressed air environment and fed through the existing water inlet and outlet. Aluminum thin films (~ 60 ang.) were sputtered from a 1" thick, clamped 6061 aluminum target, in argon at 4mT operating pressure. The substrates were borosilicate laboratory slides spanning +/- 22" length below the magnetron. For this length magnetron, uniformity expectations would be ~ +/- 20". The borosilicate glass slides used as substrates were transported through the deposition zone (~50 mm/sec, 1 pass) in a load locked batch system . The produced thin films were immediately removed from the the system and optically analyzed with the results converted to physical thickness through optical modeling software. Preliminary uniformity profiles were obtained and plotted (Figure 10) which includes the results for the magnetron as assembled and the uniformity after full adjustment of the Auto Shunts , which did not require a break of the vacuum. Although the initial uniformity was quite "gross", it was decided to not address the system issues and see how much tuning capability the shunts were capable of. Because the shunts had been adjusted to their full range of travel in this initial trial, it was decided to remove the cathode, adjust the Manual shunts to the previous Auto Shunts position so that the Auto Shunts could be returned to the middle of their range of travel. Figure 11 shows the results immediately after Manual shunt adjustment and the achieved uniformity by moving the Auto Shunts with again, no break in the vacuum system . The requirement of +/-2 % uniformity had now been achieved.

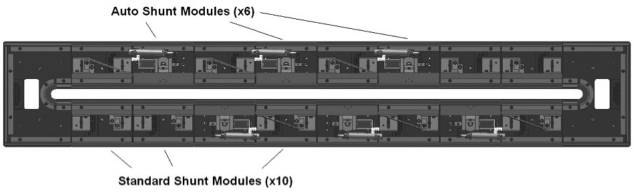

Figure 9: "Auto" shunts installed in every other position, directly opposite a manual shunt assembly.

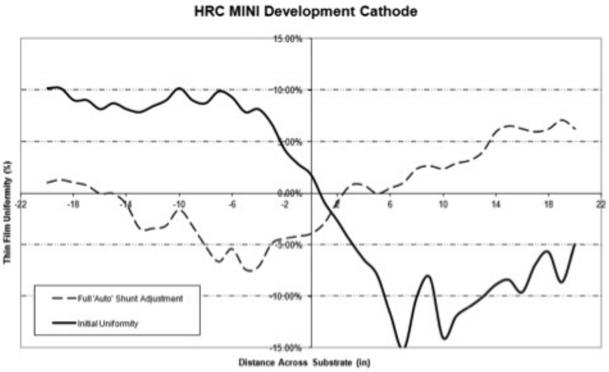

Figure 10: Initial uniformity; a) with shunts centered (+ 10 %/ - 15 % and b) Auto Shunts fully extended +/- 7 %).

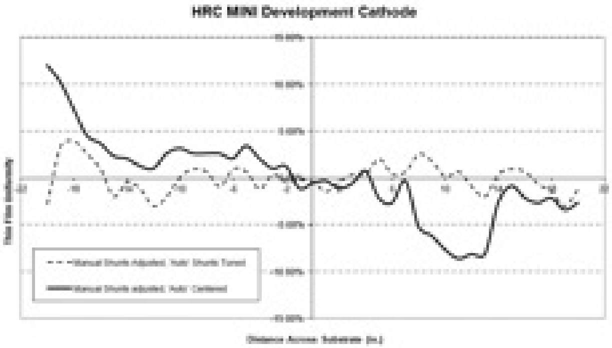

Figure 11: Uniformity after adjusting manual shunts a) Auto shunts re-centered b) Auto shunt used to tune in to +/- 2 % goal.

The initial uniformity from the arrangement in Figure 10, with all shunts centered within their range of travel is seen in Plot 3 and after adjustment, the required uniformity results in Figure 11.

To this point in the development, experimental results suggest that a single shunt can accommodate deviation of >+/- 5 % and with two shunts (one on either side of the racetrack) a total of up to +/- 10 % of uniformity tuning. The next effort would be to maintain this uniformity throughout target life. To achieve this the magnetron was run continually with uniformity checks and minor Auto Shunt tuning alterations made on a daily basis. During the course of this test it was found that although we had full control of the Auto Shunt positions, the uniformity which extends beyond the last module (+18") had drifted beyond the range of control. For all other data (Figure 12) it is seen that we were able to maintain and hold a +/- 2 % uniformity.

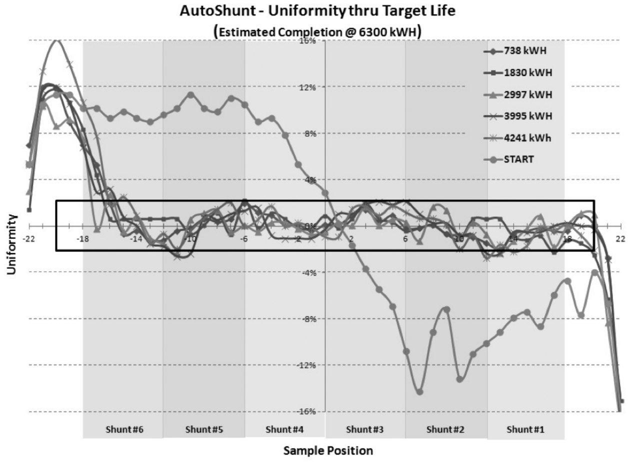

Figure 12: Thin film uniformity over target life.

For comparison, Table 1 shows the shunt positions at the start and end of the test. Note that for the left side of the cathode which was on the thick side of the uniformity, all shunts are adjusted nearly to the extent of their inward travel while on the right side or "thin" side, all shunts are adjusted to nearly the extent of their outward mobility.

This patented development will continue with fine tuning of the uniformity but first it is obvious the system baseline must be addressed. The next endeavor will include a variation in shunt material and geometry so that even tighter uniformities can be achieved and held while lifetime operation cycles continue.

CONCLUSION

It has been shown that not only will the use of shunts allow for tuning produced thin film uniformity from a linear sputtering magnetron, but that this tuning can be accomplished in real-time production with no costly and lengthy system downtimes. The solution is modular in approach and for this cathode (among others) does not require a whole new magnetron but rather can be retrofit into existing space.

Table 1: Shunt Gap Requirements to Achieve the Measured Uniformity.

Shunt # / Position	1 (-12 to -18")	2 (-6 to -12")	3 (0 to -6")	4 (6 to 0")	5 (12 to 6")	6 (18 to 12")
Start Gap (Manual and Auto)	12 mm	12 mm	12 mm	12 mm	12 mm	12 mm
End Gap (Manual)	19 mm	19 mm	19 mm	1 mm	1 mm	1 mm
End Gap (Auto)	14 mm	13 mm	11 mm	2 mm	6 mm	4 mm