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New Rotary Magnetron Magnet Bar Improves Target Utilization and Deposition Uniformity

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Abstract

Rotary magnetrons are a favored choice for sputter deposition on large area substrates such as architectural glass, polymer webs and metal strips. They have excellent target cooling and avoid the erosion 'V' groove of planar magnetrons. A weak point in performance has been excessive wear at the ends of the target tube. When measures such as 'dogboning' are done to improve utilization, the deposition uniformity across the substrate suffers. New rotary magnetron magnet bar design was developed with a magnetic field design that simply and elegantly solves both the utilization and uniformity challenges. In this paper, the new patent pending design is reviewed and target tube utilization and uniformity data is presented.

Introduction

Though the original magnetron sputtering inventions by Clarke (Sputter Gun) and Chapin (Planar Magnetron) and McKelvey (Rotary Magnetron) are decades old, there continue to be apparatus improvements and advancements in understanding of magnetically confined plasmas. This is seen in many new patents for large area thin film apparatus and processes. Recently, a new rotary magnetron magnet bar design was invented to solve two of the more intractable problems of large area sputtering: The non-uniformity of sputtering at the ends of the target and the less than ideal target utilization.

An Explanation for Rotary Magnetron End Sputtering Non-Uniformity

As with planar magnetron cathodes, the ideal magnetic field for magnetron electron confinement is a uniform strength magnetic field around the racetrack. If a uniform field is not maintained, as occurs at the turn-around ends of most planar and rotary magnetrons, an effect termed 'electron blowout' occurs and deposition uniformity suffers. Here is our explanation for this phenomenon: According to physics, electrons cannot cross magnetic field lines and instead are turned to spiral around these lines. In the presence of an electric field from a sputter magnetron, they move parallel to the cathode surface in the Hall direction. In a constant strength magnetic field, the electrons move around the racetrack over the target. If the magnetic field over the cathode surface suddenly becomes weaker, say at the turn-around, it can be viewed that the stronger field lines have disappeared into the target. Since the electrons were drifting in the constant strong magnetic field, they are now forced to 'cross' magnetic field lines and move along the weaker field lines above the cathode. At the start of the opposite straight-away, the field gets strong again. Now the electrons, moving in the weaker turn-around field, find those weaker magnetic field lines are moving further away from the target. Since the electrons can't cross field lines (to move back down into the stronger field at the cathode surface), the electrons dutifully follow the weaker field lines up and out of the dark space into the racetrack plasma. In the plasma, the electric field disappears and the electrons are no longer confined in the racetrack. This sudden increase in electrons causes increased plasma density at the turnaround and a distinct increase in the positive glow. We call this effect ‘electron blowout’. Figure 1 shows a planar magnetron with electron blowout at the turn around.

Figure 1. Planar Magnetron with Electron Blowout at the Turn-around

The result of a non-uniform magnetic field racetrack and electron blowout is increased sputtering at the point where the blowout occurs. This causes a groove to wear in the target on the far side of each turn-around. The other detrimental effect is the racetrack electron density drops after the blowout point. This causes a drop in sputter rate along the racetrack until the electron density builds back up. From experience, the racetrack recovers 300mm or so after the blowout zone. On the substrate, this scenario shows up as increased coating thickness near the end followed by a dip in thickness and then a stable deposition rate for the rest of the straight away (until the same effect is encountered at the opposite end). Figure 2 shows the how this ‘cross-corner’ effect appears on the target.

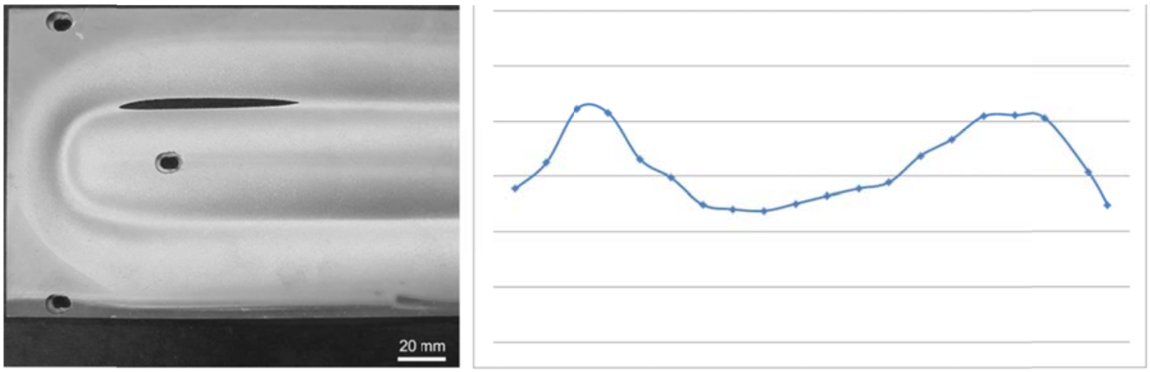

Figure 2. Typical Planar Magnetron Target Erosion at Turn-around due to “Cross-corner” Effect

A Solution to both Coating Uniformity and Target Utilization

To reiterate, the ideal magnetic field for a magnetron cathode has a completely uniform, constant magnetic field around the full racetrack. When this is done, electron blowout goes away, there is no loss of electron density around the racetrack and the desired result of uniform sputter deposition along the full racetrack is achieved. Figure 3 shows a rotary magnetron in operation with a uniform magnetic field race track. Note the lack of any discontinuity at the turnarounds.

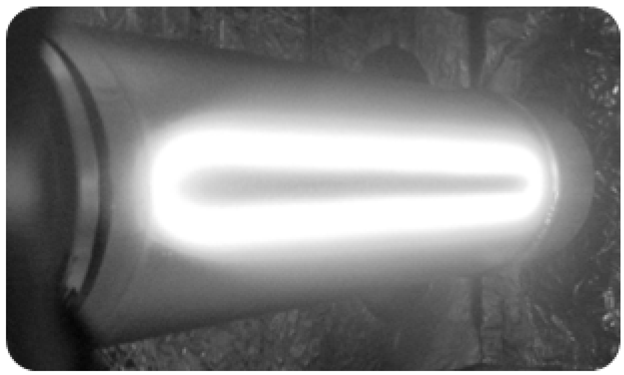

Figure 3. Uniform Magnetic Field Racetrack Plasma on Rotary Magnetron

The good news is uniform rotary magnetron sputter deposition is attainable. The bad news is uniform sputtering of the racetrack will cause faster erosion at the turnarounds. This is due to the fundamental issue that the rotating tube sees more plasma at the turnaround than along the straight-away. As is often the case, one problem is solved only to create another!

The rotary magnetron issue of faster erosion of the turn-around is a well-known in the industry and several solutions have been patented and implemented. The most common solution is to ‘dog bone’ the target tube, that is, make the ends of the target thicker. While, dog-boning helps with target utilization it causes sputter non-uniformity. As explained above, for constant electron density – and a uniform sputter rate – the magnetic field over the target must be constant around the racetrack. It’s easy to see that with a dog-boned target the stronger magnetic field lines present over the nominal target thickness will disappear in the thicker dog bone ends. This in turn produces blowout and poor end sputter uniformity.

A new magnet bar magnetic design provides a solution to both keeping the magnetic field constant around the racetrack and improving target utilization. The patent pending method is to shape the turn-around magnetic field such that, as the target erodes, the racetrack moves slightly outward. In doing this the extra end erosion goes into the side wall of the unused target material – not into forming a deep groove in the target. Figure 4 shows a fully eroded aluminum target tube implementing this new magnetic field concept. Note that there are no moving parts to accomplish this. The small outward movement of both end racetrack is accomplished by magnetic design only. Figure 5 shows how this is done.

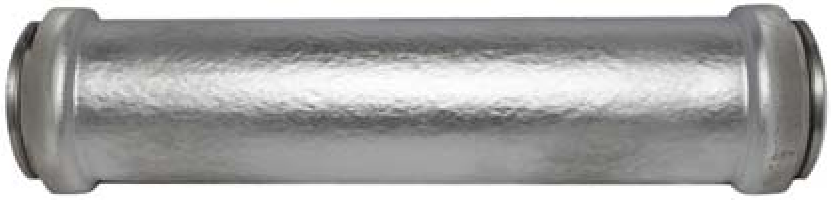

Figure 4. Fully Eroded Aluminum Target Tube implementing New Magnetic Design

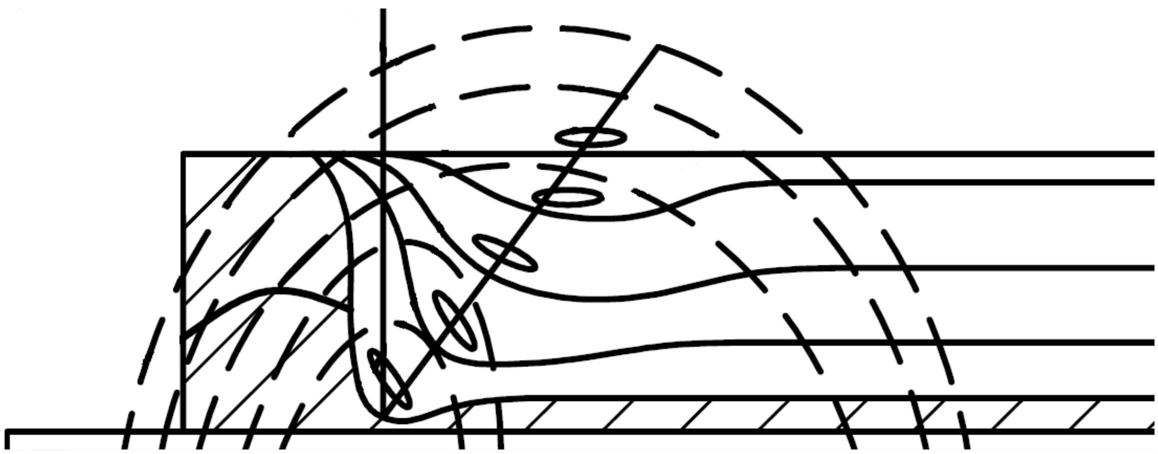

Figure 5. Magnetic Field Lines of Patent Pending New Magnetic Design

Improved End Uniformity = Increased Uniformity Zone

An unexpected benefit comes from maintaining a constant magnetic field around the racetrack: The overall uniformity zone, the zone over which the required deposition uniformity is achieved, is widened. Figure 6 shows the uniformity zone for a typical dog-boned rotary target and Figure 7 shows the expanded uniformity zone for a constant B field racetrack.

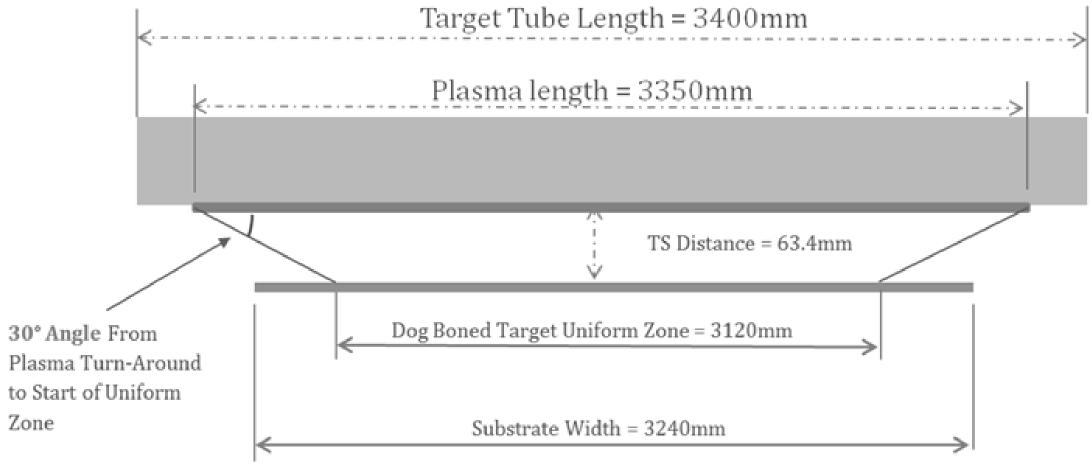

Figure 6. Uniformity Zone of Typical Dog-boned Rotary Target

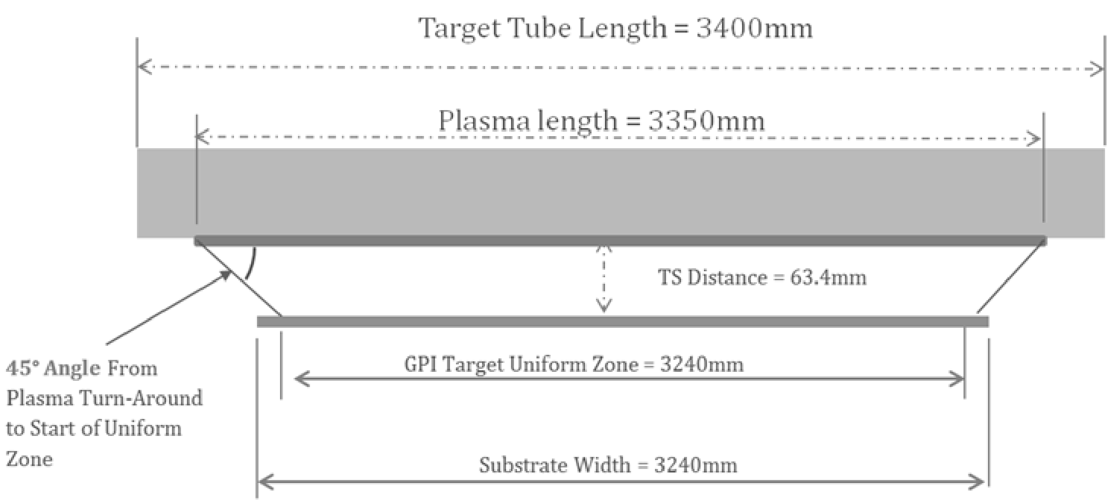

Figure 7. Expanded Uniformity Zone of Rotary Target with New Magnet Bar Design

By widening the uniformity zone, the area of coated glass is increased per load and this is achieved at no coat to the manufacturer. The sputter target length doesn‘t change, the sputter power input is the same and all other cost factors (manpower, gas, glass, etc.) are uneffected. Table 1 shows how this can add up for a 2540mm wide glass line in terms of coated glass output.

	Dog-boned Target Tube	Straight Tube with New Magnet Bar Design
Angle to Uniformity Zone	30	45
Width of Uniformity Zone	2303.3	2449.8
Percent of Glass Uncoated	9.32%	3.55%
Glass Coated per Year, m^2	10,950,486	11,646,788
Increase in Coated Glass per Year, m^2		***+696,301***

Assumption

Target to Substrate Distance	100	mm
Width of Glass	2540	mm
Length of Plasma Racetrack	2650	mm
Length (conveyor direction) of Glass	3657	mm
Number of Glass Loads per Year	1,300,000	loads

Table 1. Calculation of Increase in Production Throughput using New Magnet Bar Design

Conclusion

A working solution to sputter magnetron end deposition uniformity and rotary magnetron target tube utilization has been invented. By maintaining a uniform magnetic field around the racetrack, the new magnet bar design eliminates the cross corner effect and electron blowout. The innovation - to erode outward into the target side wall instead of down - allows a strong magnetic field to continue at the turn-around while achieving good target utilization. An unexpected advantage of improving end uniformity is the overall sputter uniformity zone is enlarged. This allows users to produce more square meters of product for the same machine cycle time and materials costs.