

# Maximizing the Potential of Rotatable Magnetron Sputter Sources for Web Coating Applications

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## Introduction

Magnetron sputtering is the most widely used technique for creating a flux of vapour for the vacuum deposition industries. The flux of vapour is generated by a magnetically confined plasma over the 'target' surface which 'sputters' the target material ('target' is the name given to the source of the material). The common geometry of source material is a flat plate like target. In recent years a new form of magnetron source has become much more popular. This type of magnetron is known as a rotatable magnetron and uses a tube type target as the source of the vapour – see figure 1.

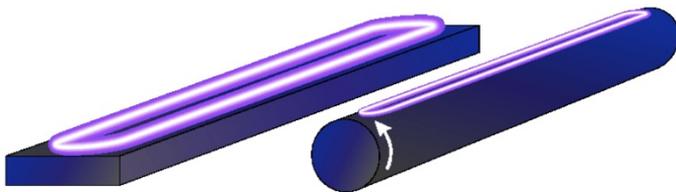


Figure 1. A standard planar target compared to a rotatable target geometry.

The rotatable magnetron has advantages of better material usage and longer continuous operation. The use of rotatable magnetrons has increased recently as the solar and display industries look for greater efficiencies and cost reduction.

Rotatable magnetrons therefore offer the same promise of enhanced productivity to the vacuum web industry. There is however one critical difference when applying rotatable magnetrons in the web coating arena, as the flexible web substrates are generally temperature sensitive.

The issue of temperature of the process from a planar magnetron compared to a rotatable magnetron becomes a critical one. There are large differences between the plasma confinement in a planar cathode and a rotatable cathode.

## Heat load on substrates from magnetron sputtering plasmas

In considering the heating effect on a given floating substrate from a magnetron sputtering source, there are several factors that contribute to the overall heat load:

1. Positive ions from the plasma.
2. Electrons from the plasma.
3. Thermal energy input due to the heat of condensation of the atoms.

The thermal energy from the coating flux is comprised of the standard enthalpy (heat of condensation) of the given material plus the kinetic energy of the atoms.

In a simplified model, and as a means to compare the heating effects of the two different magnetron configurations, this heating from the atoms can be presumed to be 'equal'. That is largely correct if the cathodes are operating with equivalent materials, powers and voltages.

That leaves the heating effect from the plasma electrons and ions. For a DC based magnetron discharge this can be as high as 75% of the heat load and 95% for an RF magnetron based plasma [1].

For more 'unbalanced' magnetron discharges secondary electrons have a much increased thermal power at the substrate [2]. An unbalanced magnetron is designed to release electrons to the process and prevent them from being 'lost' to the anode (dark space shield) around the planar magnetron.

Hence the indications from literature are that the electrons and ions play an important role in the heating of a substrate.

### Anode based plasma confinement in sputter cathodes

Raising the issue of an 'anode' is a major difference between the planar and rotatable configurations. In planar magnetron sputtering with a balanced magnetic configuration, the outermost magnetic field lines are designed to coincide

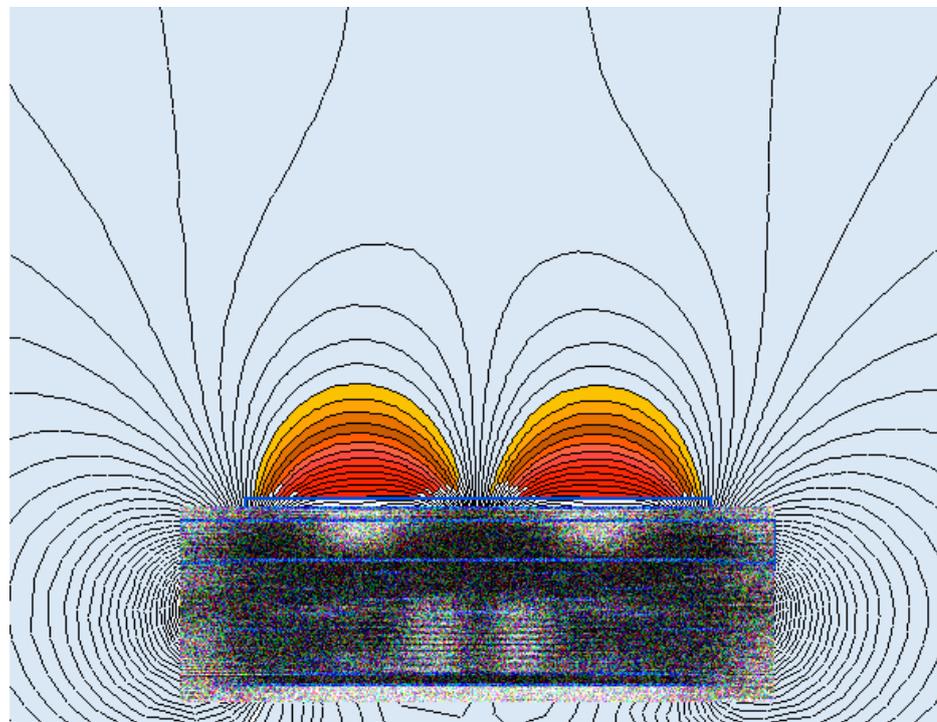


Figure 2. Anode and magnetic field interaction for a planar magnetron.

with the anode that surrounds the outside of the magnetron. As the plasma electrons spiral around the magnetic field lines they lose energy and migrate to the outer most magnetic field lines. If an earthed anode intercepts the electrons they will be consumed before being released to the process chamber and hence the substrate. The presence of the anode and magnetic field interaction provides a stable earth return for the plasma and extracts electrons before they can add the substrate heating effect, see figure 2.

If the magnetic field does not interact with an anode, then the plasma will be released away from the magnetron region towards the substrate. This is shown experimentally in figure 3, where a comparison of the plasma expansion with an anode that intersects with the magnetic field and one moved just 1mm to avoid a magnetic interaction.

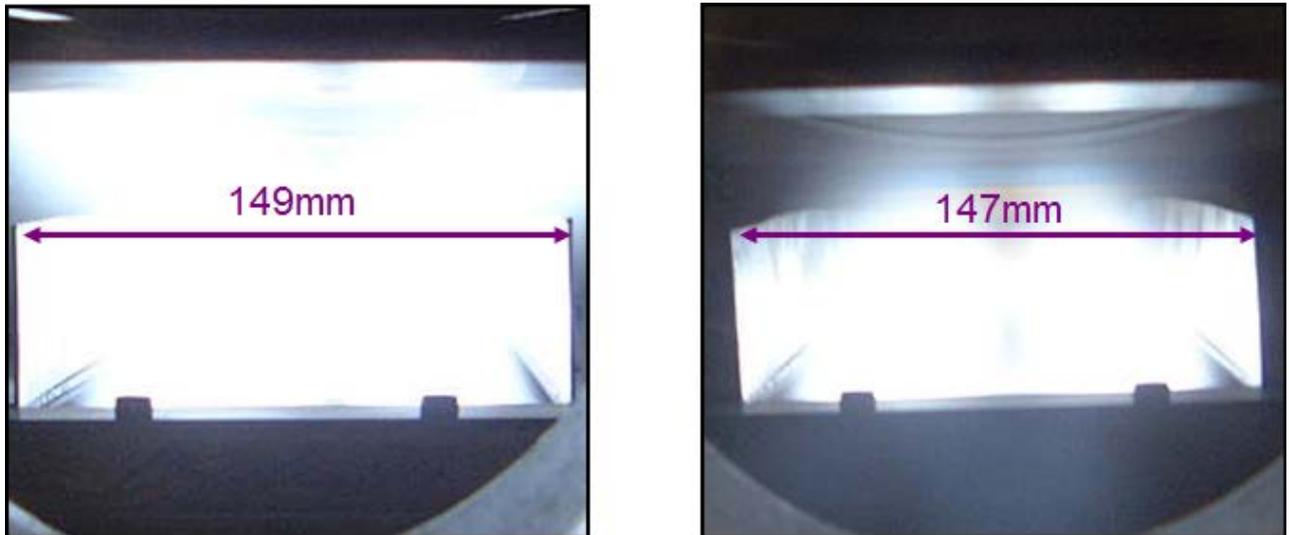


Figure 3. Anode and magnetic field interaction for a planar magnetron with magnetic field lines missing the anode (left image) and with magnetic field lines intersecting the anode (right image).

### Rotatable magnetrons

The use of a rotatable magnetron offers great 'cleanliness' as there are no areas of re-deposit on the target surface and a dark-space shield is not required adjacent to the target area to prevent stray discharges and coating of insulators. Generally, it's an advantage to keep the region around the target clear of any chamber architecture in order to minimize coating of such shields and parts which leads to the production of debris on the substrate. As with a planar magnetron, if an anode is inserted to cut into the magnetic field lines over the target surface it confines the plasma and limits substrate heating, but it will also reduce rates and increase particulates. As a consequence, if an anode is used, it would generally be to rear or sides of the target, or simply the chamber wall is left to act as the anode. The downside is that the plasma from rotatable magnetrons is un-confined and hence fill the chamber with plasma and will cause excessive heating of the substrate, see figure 4 below.

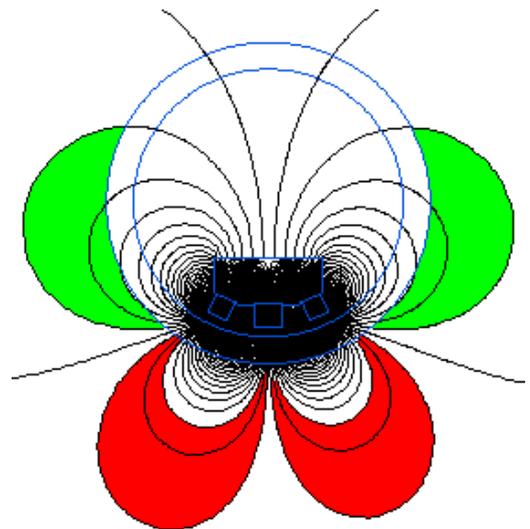
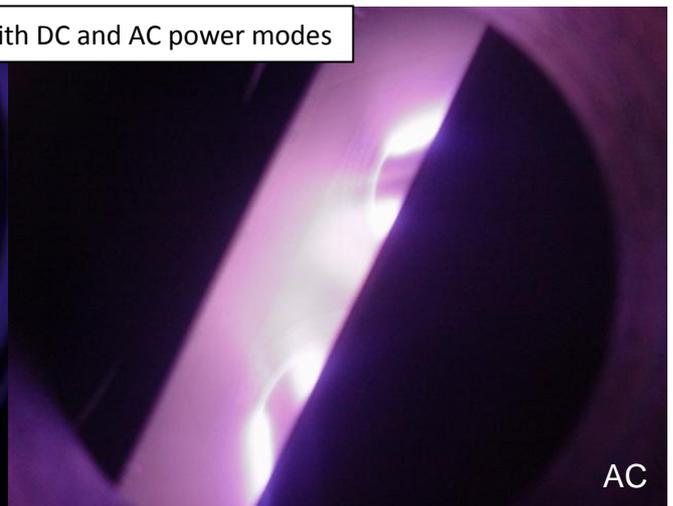
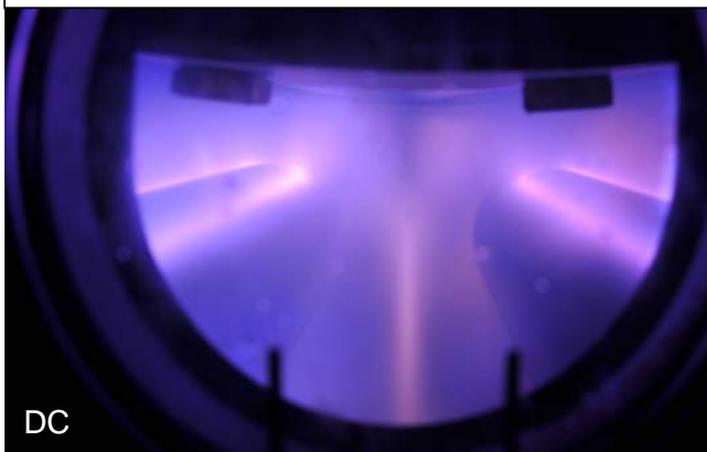


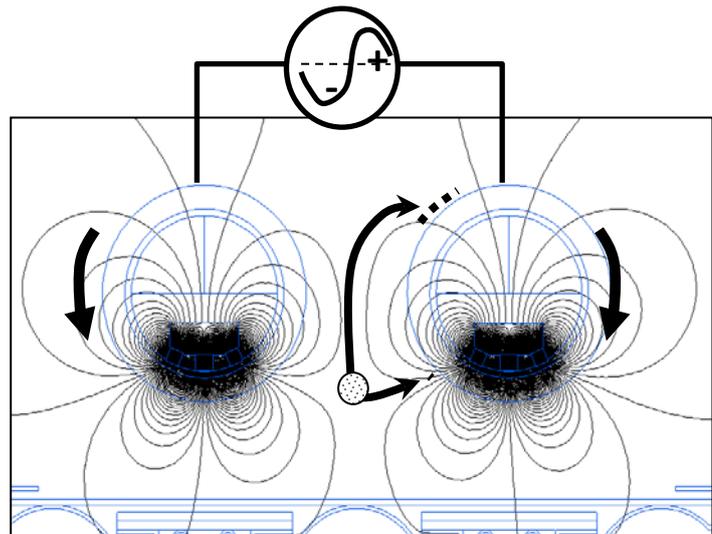
Figure 4. Plasma distribution for rotatable magnetrons with DC and AC power modes



If a dedicated anode is used remotely from the plasma area, the electrons will still complete their path to the outermost field lines of the magnetic trap and into the substrate region, so plasma spread and heat will be an issue. For such remote anodes a positive bias is needed to effectively collect the plasma electrons. The electrons are highly mobile and a positive anode will extract them from the chamber region much more effectively than an anode at earth potential.

## Magnetic design for double magnetron reactive sputtering with AC power mode

The technique of two targets working as a pair with AC power between the two for the reactive deposition of dielectric coatings is a critical aspect to the technology and forms a large part of the success of the technique. The principle advantage for reactive sputtering using rotatable targets is the self-cleaning effect as the target tube rotates. This prevents areas of re-deposit building up which is a common problem with planar magnetron as not all areas of the target surface can be sputtered



There is however one drawback with using this method to coat heat sensitive materials that lies in the plasma energy generated when the electrons move from one target to the other whilst passing over the substrate surface. The electron movement at typically 40 kHz between the targets ionizes the argon support gas present in the discharge. Large numbers of ions and electrons will be present in the area of the substrate. In the case of glass substrates this can be beneficial in terms of enhancing the layer properties as a result of the extra energy available for the growth process. However, when coating onto temperature sensitive films, this new source of heat is unwanted and will reduce the possible coating rate as the energy of condensation in the system needs to be reduced in order to compensate from the plasma heating load. It is hence desirable to reduce this heat load as much as possible and a solution exists.

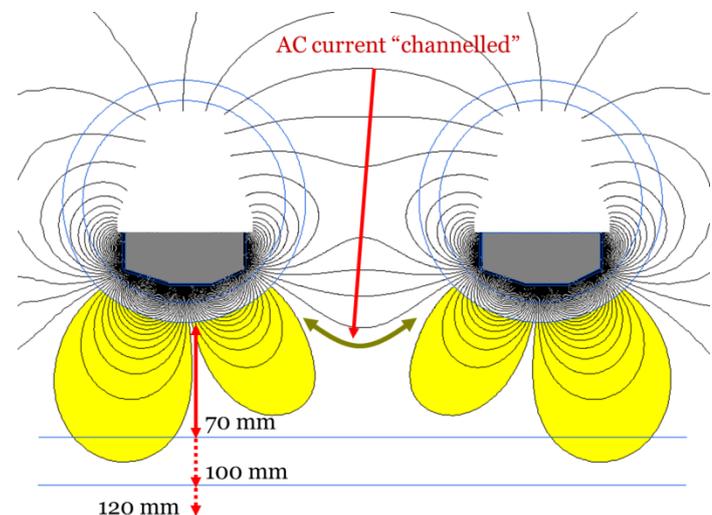


Figure 5. Comparison of a conventional rotatable magnetic design for AC sputtering (top) and the new Gencoa DLIM design for limiting plasma spread (bottom). Covered by Gencoa patent GB2454964, EP2186108, WO2009022184

It is hence desirable to reduce this heat load as much as possible and a solution exists.

As electrons are high sensitive to magnetic fields, a method has been developed (patented) that uses magnetic guiding of the electrons between the two targets in order to limit the impact of the plasma on the web. Figure 5 above shows such a magnetic confinement in front of the targets and the effect on the plasma for a reactive aluminium oxide process. The magnetic effect is created by linking the magnetic fields of the 2 cathodes in such a way that the electrons are channelled more effectively between the two cathodes. The advantage of this design is fourfold:

1. Reduced heat load on the web.
2. Less plasma bombardment of the growing film – lowers the resistivity of transparent conducting oxide layers.
3. A more energy efficient lower impedance plasma's resulting in lower energy use.
4. Better coating uniformity – reduced electrostatic charge on a floating substrate.

Figure 6. Plasma distribution in front of a dual rotatable magnetron pair with AC power, aluminium targets and oxygen gas.

Asymmetric and linked magnetic field distribution for dual cathode low impedance AC plasma.

Covered by Gencoa patent GB2454964, EP2186108, WO2009022184



The above magnetic design is now being used to very good effect in the creation of a range of different reactive oxide layers from transparent conducting oxides (TCO) to the widely used  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  gas barrier material systems for OLED based visual displays.

## DC rotatable magnetron discharges

For single magnetrons or double magnetrons operating with DC power, the absence of an anode will also lead to plasma expansion and heating of substrates. In order to maintain the anode position away from the coating flux it is necessary to magnetically guide the electrons into the anode. Figure 8 and 9 illustrate how this can be achieved. Further, by adjusting the angle of the magnetic array to the anode, the plasma spread away from the target can be controlled and substrate position can be brought closer to the magnetron – leading to higher deposition rates. In practical examples of using such an anode for a single DC magnetron, it was possible to increase the magnetron power by 3 times compared to the standard approach before damaging the web material.

The use of such an anode not only limits the plasma based heating of the substrate, but also improves the stability of the process and uniformity of the layers. These two enhancements are also a result of lower plasma interaction with the substrates and chamber walls. As the

substrates move past the target the plasma does not interfere and activate the substrate, which can lead to outgassing and pressure spikes. The electrons also have a stable path to complete the plasma electrical circuit; hence, as the chamber walls are coated and vary in electrical conductivity, the plasma impedance is unaffected.

## Conclusions

The difference between a planar magnetron plasma and a rotatable magnetron plasma are profound from a plasma confinement point of view. The absence of a dark-space shield around a rotatable magnetron allows the plasma to escape and heat up the substrate and chamber. For web coating applications, this negates the inherent benefits of using rotatable magnetrons. This weak point can be turned into an advantage when the stray magnetic fields around the rotatable targets are used to direct the electrons away from the substrate to prevent heating. For a double magnetron arrangement with AC power modes, the magnetics are asymmetrically designed and linked North-South to control the electron movement between the targets. For single magnetrons or multiple DC magnetrons, additional magnetic 'anodes' are required to guide the electrons away from the target.

## References

- [1] R.Wendt, K.Ellmer, J.Appl.Phys. 82 (5), 1 September, 1997.
- [2] M.Andritschky, F.Guimaraes, V Teixeira, Vacuum 44, 809 (1993).

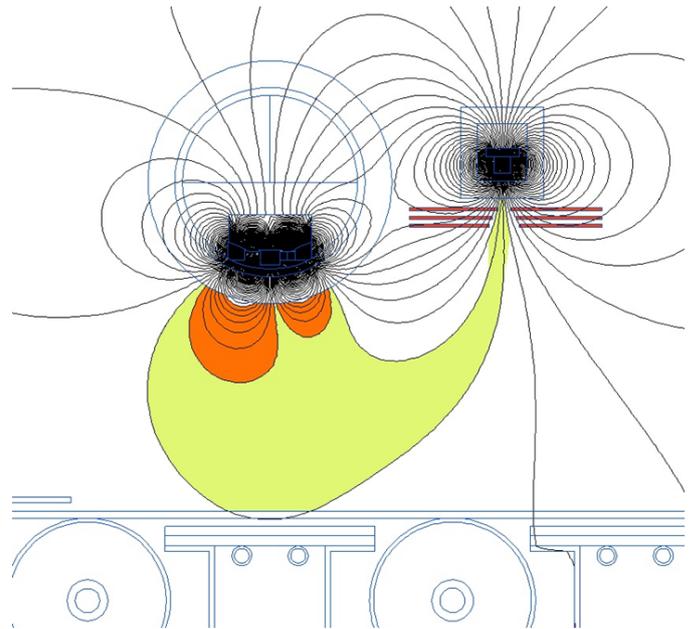


Figure 8. Use of a magnetically guided anode adjacent to a DC magnetron to limit plasma spread away from the target region. Covered by Gencoa patent GB2454964, EP2186108, WO2009022184

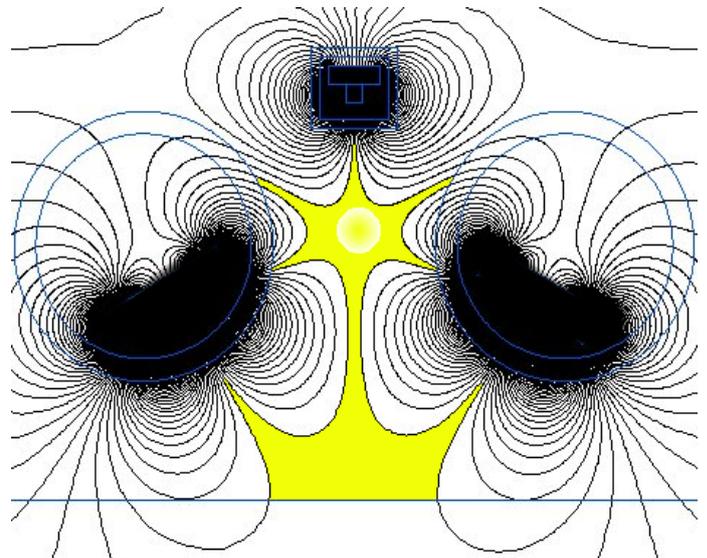


Figure 9. Magnetic 'bottle' for extraction of electrons to a single magnetically guided anode in combination with 2 rotatable magnetrons. Covered by Gencoa patent GB2454964, EP2186108, WO2009022184