

Optimization of Sputtered Layer Production for Photovoltaics



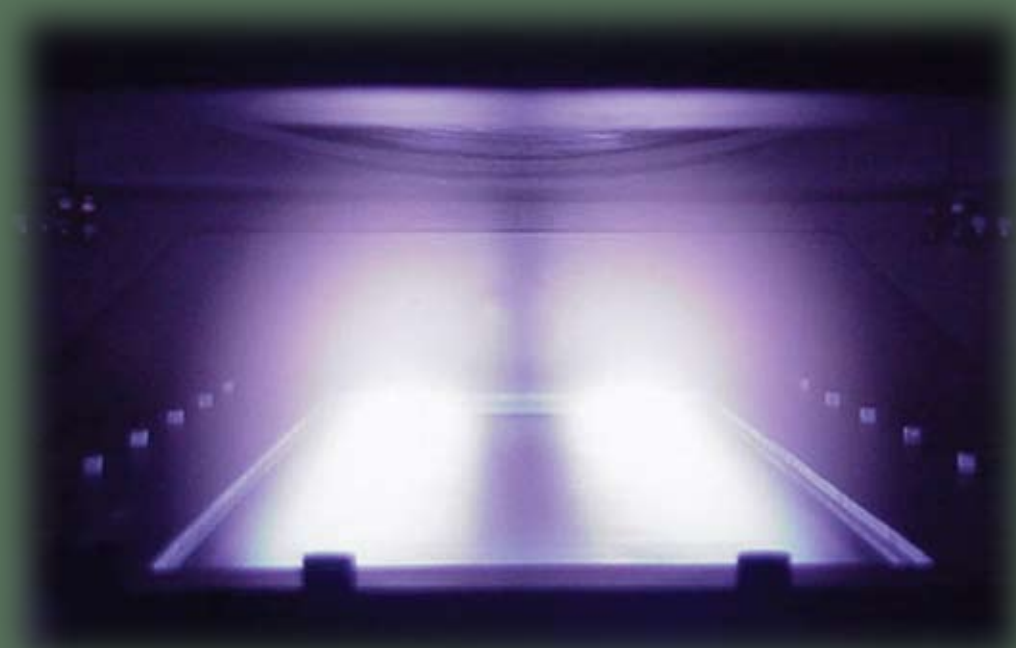
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Production of thin film based photovoltaics has matured in terms of the ability to readily create the desired structures and performance. Equally, magnetron sputtering has developed over the last 30 years into a highly refined technique for creating thin films on a large scale for different industry sectors. It is therefore no surprise that both these areas have come together to form a viable commercialisation route for the solar industry.

What are the technical challenges?

Broadly speaking the technical challenges are two fold:

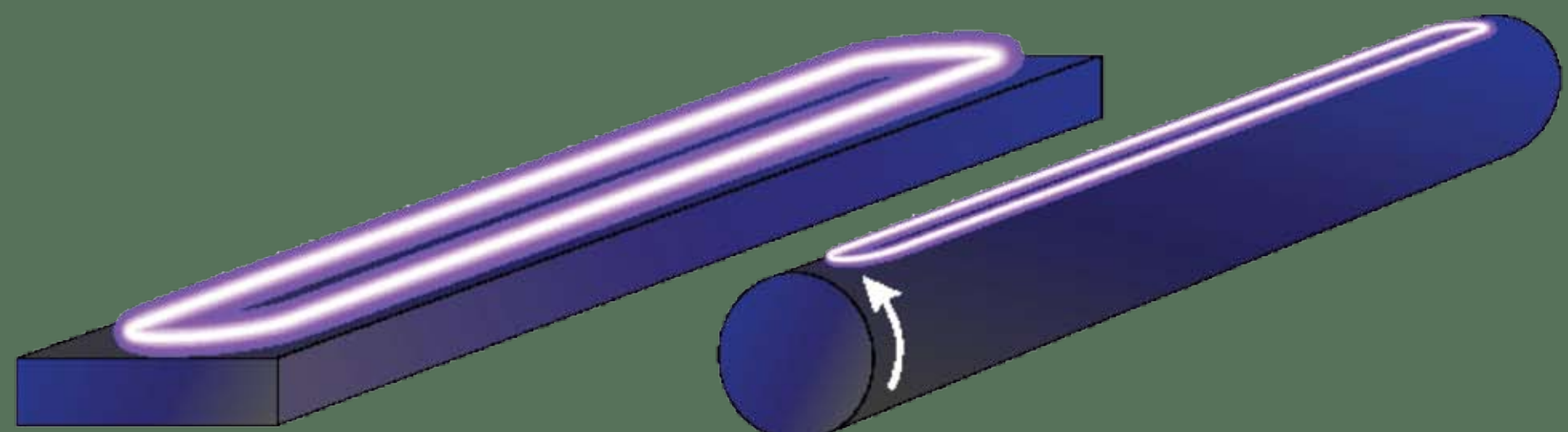
1. Optimize the economics of the production process
2. Optimize the individual layer and interface properties to enhance the device operation



Sputtering Economics

The cost of producing a sputtered film is complicated due to the number of the factors that affect the final cost. If the actual thin film properties are ignored at this stage, the cost elements can be summarized as follows:

1. Capital equipment cost
2. Reliability
3. Up-time
4. Consumable costs
5. Labour costs



Gencoa manufacture the sputtering cathodes, so this presentation will only deal with the cathode elements not the deposition equipment or running costs. The aim is to help in the selection of the most appropriate configuration of sputter cathode.

In terms of the sputtering cathode and process, there are two configurations on the market: planar and rotatable. The rotatable cathode has few variations in terms of magnetic design as the effectiveness of the product is dictated by rotation of the target tube. A planar magnetron has however very wide variations in performance based upon the type of magnetics fitted and the specifics of the design. In analyzing what provides the best economic fit for a specific process, it is useful to compare a matrix of advantages and disadvantages of the different options.

Magnetron	Magnetic type	Capital cost	Target use %	Mean time to target change	Maintenance	Target costs	Target cleanliness	Ceramic target quality	Reactive Processes
Rotatable Cathode	Simple 2 pole - moving target tube	*	>50%	****	*	*	****	**	****
Planar - Standard	Simple 2 pole - moving target tube	****	>25%	*	***	****	**	****	**
Planar - High Yield	Complex multi-pole	***	>40%	**	***	****	**	****	**
Planar - Metallizer	Simple or multi-pole	***	>35% or 50%	***	****	***	**	****	*
Planar - Full Face Erosion	Dynamic	*	>50%	**	**	****	***	****	***

Rotatable Cathodes

The main advantage of a rotatable cathode is the extended up-time it can create. This is a result of the large amount of target material on the outside diameter of the target tube. The action of the tube rotation means that the whole of the target material is sputtered on the tube. This also has the advantage of target cleanliness – there are no dead zones on the target surface where re-deposit can settle (except at the tube ends). In theory the target use should be very high 80-90%. However, in practice it can be as low as 50% if the magnetic field design and target design are not carefully performed to prevent a higher erosion rate at the plasma turn-around.



So a rotatable appears the natural choice for long term production. However there are some disadvantages that come with them – the target materials are much more expensive and the quality is not as good as planar types as they are commonly plasma sprayed (low density and purity). Some target materials are not compatible with rotatable targets as manufacture is un-economic. Other disadvantages are the fact that a water seal is broken with each target change, so the probability of a leak is ever present. Equally, there is a dynamic water to vacuum seal that will need to be maintained carefully and replaced at intervals. These disadvantages can be managed in most cases, although a planar magnetron in many ways is 'easier to live with'.

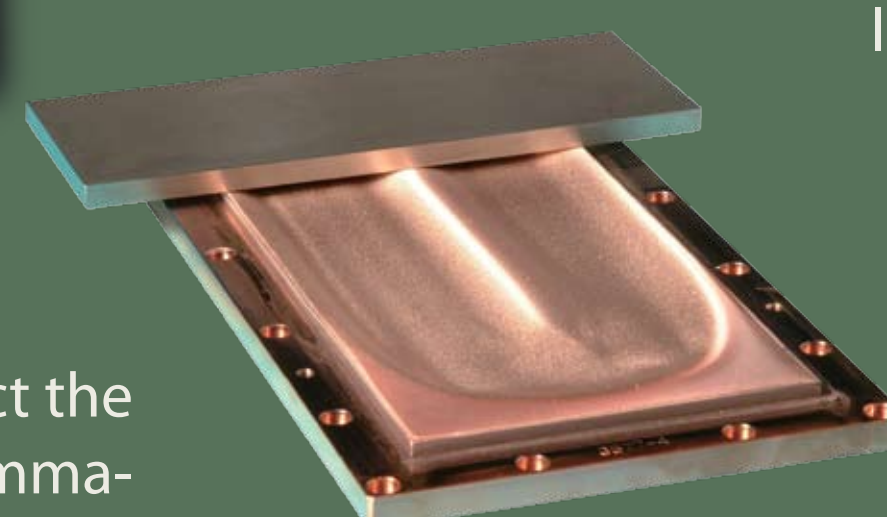
Planar Magnetrons

A planar magnetron has been used for over 30 years, so the basic technology is very well established. However the skill in designing a magnetic field and cathode that can improve target use, up-time and reliability means that careful choices still need to be made.

Broadly speaking the magnetic field drives the efficiency of the source. Most cathodes on the market still use fairly simple 2 pole magnetic systems. As the field loops from one pole to the other the plasma density is non-uniform. The result is a V or U shaped erosion track. The target use from these types of magnetic designs are in the range 25-30%. So clearly they do not offer the best performance in terms of material efficiency or up-time.



Improved magnetic designs are available that produce a much flatter magnetic field and hence have a more uniform plasma distribution which results in a better erosion shape and target use. These types of magnetic fields will produce a target erosion efficiency of 40-50%. If these type of magnetic fields are used in very wide large area targets (10-12" wide) with 1" -1.5" thick targets, the up-time can approach that of a rotatable system.



There are also more recently dynamic types of magnetics for planar cathodes which scan the plasma at high speed over the target producing a full face erosion. These magnetics will offer >50% target use and keep the target surface clean. Like a rotatable cathode however, it can come with a heavy price premium.



Planar cathodes do have some distinct advantages which can also be a disadvantage! A planar cathode has a active anode around the source. This gives excellent plasma stability and can be used to control the plasma energy at the substrate. However, it can also be a source of particles or lead to electrical shorts in long term operation. So the key is to provide an active anode for the plasma electrons and at the same time hide it from the majority of the coating flux to prevent coating build-up. This can be done by pushing the target in-front of the anode, to reduce the line-of-sight. Also, the 'Metallizer' type of cathode uses the target profile to hide the anode. This is however only possible for readily machinable target materials – see image.

Transparent Conducting Oxides (TCO's)

A key element of a photovoltaic device is a transparent and electrically conducting layer. This merits special mention as this is usually the most challenging part of the deposition process. Invariably sputtered forms of this layer are either based upon the Zinc oxide system or Indium Tin oxide. The economics has tilted the balance to the Zinc systems as the cost of indium is very high. Zinc oxide can be in the pure and intrinsic (i-ZnO) form. This is not an electrical conductor, so if sputtered from a compound target RF power is required (limits use to planar magnetrons only). Zinc oxide can also be deposited via a reactive process – sputter zinc in the presence of oxygen. Reactive sputtering is a large topic in itself, but it offers both low cost and high rate deposition and is very popular in other fields. The process is inherently unstable, hence a feedback controller, such as the one pictured here is an essential feature.



An alternative to reactive sputtering or RF power is to use an Aluminium doped ZnO target (Al:ZnO or AZO). This target type is sufficiently electrically conducting to use DC power, although a more reliable power mode is pulsed power or AC power in the 10-200 kHz range. The combination of the target material and power mode results in a stable and viable method of TCO layer deposition. Both a planar and rotatable cathode are capable of successfully depositing this material. Planar cathodes can create higher quality layers where the target densities are higher and the magnetic field strength and power modes (DC pulsed, RF/DC) can be optimized to reduce the target voltage and improve the sheet resistance of the deposited TCO. Planar cathodes however have the disadvantage that the anode and dead-areas on the target can be a source of particulates. For AZO deposition the re-deposit is in a powdery form and hence not well adhered to either the anode or target. So careful cathode design is needed to manage this problem. A rotatable target naturally produces a clean target surface, hence the dust issue is much less problematic.

Coating Property Issues

Whilst the cost of the equipment to produce the coating is important, so are the layer properties which will determine the devices efficiency. Control of the coating density, surface roughness and electrical properties can also be traced back to the cathode design. The key points are the magnetic shape and strength and the degree of interaction with the anode. Different levels of ion bombardment and heating of the film can be achieved by controlling the plasma at the magnetron and how the electrons in the plasma interact with the anode.

This is a common method to drive the coating properties in the right direction. In the same device structure certain layers may demand very low level of ion assistance, whilst other layers demand high bombardment. This can be achieved solely via the cathode design and power mode. As device are driven to become more efficient, it is expected that these aspects will play increasingly important