Managing Anode Effects and Substrate Heating from Rotatable Sputter Targets.
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Abstract

Rotatable cylindrical cathodes have been lagging behind in some of the basic plasma engineering groundwork that can be found in the planar magnetron sputtering sector. Although there has been much progress in the area of endblock design, the same is not necessarily true in the areas of rotatable process and plasma technology. Among those areas that affect plasma properties such as overall plasma confinement, plasma impedance and anode design, the progress has been limited at the best and mostly lacking. Based on more than 20 years of work in planar magnetron sputtering design and manufacturing, the authors have applied these principles to some critical aspects of the design of rotatable cylindrical cathodes [1]. The present paper presents results in the area of thermal load control onto sensitive substrates; substrates for example of great technological importance such as those which make many of today’s applications such as OLED encapsulation, solar control web, thin film PV, touch panel display and mobile technology. Many of these processes need an economy of scale which involves high power and high throughput within some of the vacuum deposition manufacturing steps, thus the necessity to design improvements which can lead to optimum production at the same time as limiting thermal damage of the delicate substrates. The introduction of magnetically guided anodes and low impedance plasma couplings offer improvements on this area of thermal load control during the deposition process.

Introduction

Rotatable cylindrical cathodes have been adopted as the main method to increase productivity in large area magnetron sputtering applications. Rotatable cylindrical cathodes were introduced just 10 years after the first planar cathodes came to market, however, difficulties in certain aspects of the technology made the progress of cylindrical rotatable cathodes very slow in comparison with the use of planar targets. During the first 20 years most applications were restricted to glass coating and some web coating applications where very long campaigns were desirable. It was the advantages of reactive dual magnetron sputtering with respect to dual planar sputtering that tilted the technological growth in favour of rotatables cylindrical cathodes. When comparing the extent of work in planar cathodes with rotatables we can see that the planars have been benefiting from more process related advances and magnetic design as compared to the rotatables where the focus has mainly been on the design of suitable end blocks. The natural restrictions due to patent protection issues plus the limited availability and high price of cylindrical target materials has had a detrimental effect on real process advances within the first 25 years after the introduction of rotatables in to the market place. Somehow, relatively speaking, the technology and depth of knowledge has been always lagging behind of that from planar cathodes and remains the case today.
Temperature in Magnetron Sputtering deposition

Magnetron sputtering deposition is a PVD technique where there is kinetic energy transfer from a colliding ion to a target surface. A schematic of the energy exchange process can be seen in Figure 1. The energy collision will produce secondary electron emissions and will eject particles from the solid target into the vapour phase. Those particles could be neutral or charged, either positively as it would happen with most metals, or negatively as it would happen with electronegative elements such as oxygen. Generally those particles are very energetic as they have their origin in a high energy impact measured in hundreds of eV. In addition the ions carry additional “electrochemical” potential energy as they would need neutralisation. As these particles come in contact with a solid surface, they will pass from high energy vapour into a solid. The energy involved in that phase transformation will cause the substrate temperature to increase. In addition to these collisions, there are joule effects due to the electron circulation, especially if the coated substrate has an anode function establishing a current from the cathode to the anode. Additional energy to the substrate could be due to wave absorption, as the capacitive and inductive elements of the discharge could couple an effective current with the substrate. Heat radiation from the plasma emission is also a source of heat.

Figure 1.- During magnetron sputtering deposition there is a thermal load on the substrate due to different energy sources such as kinetic energy of neutrals condensing from the vapour phase in to a solid, ion bombardment, electron current, plasma radiation, etc.

The heat load on the substrate will raise the temperature on the substrate. The temperature increase would depend on the heat capacitance of the substrate, absorption and emissivity of the substrate and thermal contact cooling, gas cooling, etc.

The effect of the anode

Magnetron sputtering plasma properties are governed by the specifics of the process such as pressure, gas mix, target material properties, cathode power, etc. However, once these are fixed, the essence of the magnetron sputtering plasma properties are based on the basic magnetron trap which is shaped by the magnetic and electric field components in the plasma volume and target.
and anode surface boundaries. Traditionally more attention has been paid to the magnetic field while the electric field has been largely neglecting in many of the developments both for planar and rotatables as seen in Figures 2 and 3.

Figure 2.- Anode position has a key influence in the electric field limiting the extension of the plasma as seen in this planar magnetron sputtering example where the anode position has only been changed by 2 mm. In the larger opening (left) the plasma extends very far from the target substrate bringing a strong interaction with the substrate while on smaller opening (right) the plasma is confined away from the substrate surface (courtesy of Nick Butcher, Bobst Manchester).

Figure 3.- Dual rotatable in DC mode (left) and AC mode (right) the electrons follow the lowest impedance path towards the acting anode (represented by the arrows), created sometimes non uniformity or excessive heat load in the substrate or certain areas of the deposition equipment.

This path for the electrons will bring energy into the anode and or substrate depending on such possible interaction [2]. The plasma low impedance path is usually a combination of magnetic guidance of the electron plus the pull from the electric field.

Traditionally planar cathodes have a more defined plasma interaction, while in most of the rotatable cathode that function is largely ignored and some elements of the chamber take the role of anode. During maintenance cycles changes in the chamber environment, for example change of shields or uniformity masks, could bring about a different interaction and may cause a non-uniformity in the resulting plasma discharge and subsequent deposition. Plasma - substrate interactions would typically affect the safe target to substrate distance which needs to be
maintained. This, in turn, has an effect on deposition rate, coating uniformity distribution and coating properties such as density, conductivity, etc.

New magnetic designs that would enhance the position of the low impedance path have been previously presented by the authors elsewhere [2].

![Figure 4. Example of inhomogenous magnetic fields on electron current paths and plasma interaction with the substrate.](image)

**Experimental Setup**

The experimental setup can be seen in Figure 5. The setup included 2 sets of cantilever mounted SCI endblocks. SCI endblocks are typically made for 152 mm target diameter and they were adapter to use 75 mm target diameter. New Gencoa GRS75 magnetic arrays were installed, together with a magnetically guided active anode. Target material was Al 6061 alloy. Active target length was 360 mm. Sputtering atmosphere was pure Ar (99.995%). Magnetically the anode is suitable for 152 mm target diameter as well as 125, 100 and 75 mm diameter targets. Different magnetic arrays for the sputtering cathode would be required for different target diameters.

The targets were DC bias and the anode was tested in different bias configurations. A plasma view of the magnetically guided active anode in operation can be seen in Figure 6.
Substrate configuration can be seen in Figure 7. Substrates were placed on an aluminium surface 10 mm thick x 250 mm wide x 400 mm long. For thermal studies a glass surface 3 mm thick (100 mm x 100 mm) was used on top of the aluminium plate to minimise thermal loss on the measurements. OLED stencils were used in order to evaluate the damage on the device due to thermal load. Crystal sensors were used in order to evaluate deposition rates. Temperature sensitive graduated strips were used mounted on 75 mm x 25 mm x 1 mm glass slides which were positioned over the larger glass. The sensors received the deposition coating. After aluminium deposition a suitable wet chemical etching was used in order to reveal the thermal colour change of the temperature strips.
Results

Target V/I characteristics were studied for different power and pressure levels and different anode Bias voltage. One example can be seen in Figure 8.

Due to the separation between the 2 rotatable cathodes, when testing a static deposition there is a different uniformity distribution across the width in the direction of separation between cathodes. For different cathode separation uniform distribution is achieved at a different target to substrate distance. In Figure 9 it can be seen that at 200 mm T/S separation the uniformity distribution across the width would be +/- 1%, compared to +/-6% at 100 mm T/S separation.
Figure 9.- Static coating uniformity distribution across the width from two 75 mm diameter rotatable (+anode) at 220 mm separation from centre to centre and different Target-Substrate distances.

Uniformity distribution along the cathode length was also measured at various target to substrate distances. For a target to substrate distance of 150 mm, the 360 mm target length gave +/-3% uniformity over 150 mm length and +/-6% uniformity over 200 mm as can be seen in Figure 10. The values of length and width uniformity gave a relatively wide area of uniformity which enabled the static deposition tests for the OLED devices.

Figure 10.- Static coating uniformity distribution along the length for the 75 mm rotatable, 360 mm target length at 150 mm target to substrate distance.

Deposition experiments followed a very wide spread of conditions from which certain temperature patterns could be seen. As the set of experiments was mainly driven by the end
customer, gathering and filtering of meaningful results was not always so straight forward. However some general trends could be seen, as for example in Figure 11 and Figure 12, which show how the deposition temperature on the OLED device would depend on the deposition rate (for a similar deposition thickness of 300 nm). Also the substrate temperature reflects the target voltage, which in turn relates to the neutral energy. Higher target voltage would produce more energetic particles. This is a similar outcome as experienced by traditional CD/DVD and general plastic metallisation.

![Temperature vs Deposition rate](image1)

**Figure 11.** Maximum temperature during static deposition at different deposition rates for similar coating thickness (300 nm).

![Temperature for same thickness vs Target Voltage](image2)
Figure 12.- Temperature on substrate versus target voltage representation. Some experimental data grouping would indicate that the lower the target voltage the lower the deposition temperature, due to lower energy of the neutrals, as similarly seen in coating of plastic substrates (e.g. web, CD/DVD, decorative).

Due to the complexity of the designed experiments set up some of the aspects of the research gave some paradoxical effects. For example Figure 13 shows how the biasing or floating voltage condition would give different behaviour between 2 magnetic array configurations. These configurations were corresponding to 2 different degrees of unbalancing. In general the balanced configuration, as expected gives a lower temperature on the substrate. Unbalanced configurations would give a higher temperature on the substrate [3]. The plasma proximity to the substrate and the consequent ion bombardment between balanced and unbalanced configurations is different. The anode potential on those 2 cases would have a completely reversed effect. Due to the lack of time within the framework of the experimental setup there was no enough confidence in these results as a basis of a sound conclusion. More experimental work would be needed.

Figure 13.- Two experiments using different biasing condition for the anode and magnetic experimental configurations (A & B2). In this graph the magnetic active anode were either floating (measuring -30 V) or positively biased (+30 V). The 2 experiments show contradicting results, as they were affected by other factors that were not properly controlled (exact magnetic configuration). Due to the time allocated to the experiments these experiments could not be fully cross checked, so the results should be taken as indicative but not conclusive.
Conclusions

A magnetically guided active anode was implemented for a dual cylindrical rotatable metallization process. With this configuration, the coating uniformity across the width and along the length was determined. It appears that the temperature on substrate increases with deposition rates and with target voltage discharge. The presence of an active anode reduces the plasma impedance and thus the target voltage. Lower sputtering voltage reduces the energy of neutrals. The electric field deflection by the presence of the magnetically guided anode removes some of the anodic effects and plasma interactions with the substrate.

Some paradoxical effects appear when floating or biasing the magnetically guided anode. These effects have been attributed to different magnetic unbalance degree which would produce some energy from ion bombardment and the plasma ability to come closer to the substrate.

Some more experimental data would be required in order to corroborate some of these effects.

References