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The Rotating and Cylindrical Sputtering World for PV Solar Cells

In 2005, the total worldwide energy consumption rate was estimated at 16 TeraW with approximately 87 % coming from the combustion of fossil fuels – mainly oil, natural gas and coal. Aside from exhausting our natural resources, it is important to remember that the associated release of millions of tons of carbon dioxide is contributing significantly to global warming. And things might get even worse in the future: the global energy consumption rate is expected to grow to 28 TW by 2050, and to 46 TW by the end of this century.

Harnessing the sun

Fortunately, there has been a global acknowledgement that we have to invest heavily in clean and renewable energy generation. Our sun happens to be the ideal partner for this to happen: the influx solar energy rate at our earth's surface is close to 90 PW (Peta = 10^{15}), which is roughly 5 000 times greater than the total power consumption of today.
As a result, capturing and converting direct radiation of the sun may prove a viable option for meeting a substantial part of our energy requirements in the future. Two distinct groups of solar cell technologies have been developed during the last decades, and for both approaches innovative glass solutions play an important role. Thermal solar systems typically bundle sun light radiation towards a blackened absorber body to generate heat that is then transferred to a fluid and to a heat exchanger to extract the energy. Although coating of flat and concave glass to make high-quality mirrors plays an important role in the functionality of such a system, it will not be discussed further in this context. Instead, we'll focus on photovoltaic (PV) solar cells – systems that can convert solar radiation directly into electrical power.

Energy-generating PV cells

Although PV cells have existed for more than half a century, it is only in the last few years that this approach has been considered a serious solution for tackling the energy issue. The core of a PV solar cell consists of semiconductor material that absorbs light in order to generate electron-hole pairs, which are separated to opposite electrodes. Although the majority of PV cells uses crystalline Si wafers as semiconductor material (typically close to 200 µm thick); a new trend of thin film PV cells - in which the semiconductor material is deposited in a vacuum process (typically a few µm thick) - is growing rapidly. For both types, intelligent glass solutions may also play an important role, though in a totally different context. For the crystalline Si solar cells, glass is being used as a front cover of a module to protect the cells from environmental impact; and for the thin film solar cells, glass is being used as the most common substrate on to which the thin film solar cell layers can be deposited.

Thin film layer deposition

Thin film layer deposition is a crucial aspect for the fabrication of efficient solar cells: all layers are deposited mainly by vacuum processes. Crystalline Si solar cells, however, may also benefit from these technologies as well. A crystalline Si wafer typically has a grayish color, meaning that an important part of the incident light is reflected and cannot contribute to the energy generation process. Because of this, a passivation and anti-reflective layer is deposited onto the wafer, giving it its typical dark blue appearance and improving the light capturing capabilities enormously.

Such a layer typically consists of Si_3N_4:H and is deposited most frequently by LPCVD (Low Pressure Chemical Vapor Deposition). The front cover glass of a solar cell module may equally benefit from an anti-reflective layer to reduce bouncing off sun rays, especially at low-angle incidence.

Thin film solar cells rely even more on the deposition of thin layers (from a few tens of nm to a few µm). Besides thin film deposition of the absorbing semiconductor, the layer stack also consists of two thin film electrodes at both sides of the absorber layer: a transparent conductive oxide (TCO) layer at one side, allowing light to enter; and a back reflector metal contact at the other side. Each of these layers has to be deposited with tight control of composition, morphology and thickness in a uniform way, over ever-increasing substrate sizes. While a crystalline solar cell has a typical dimension of 156 x 156 mm^2, thin film solar cells are deposited on glass plates with an area up to 5.7 m^2 or even on continuous rolls of flexible substrates.

Historically, sputtering from planar magnetrons has proven to be a viable solution for all of the above requirements. However, planar technology does have a number of significant shortcomings. The limited utilization of approximately 25 % means that more than half of the high-quality material is wasted or has to be recycled. Plus, as the planar target plates or tiles have a limited volume, exchange of targets must be frequent, resulting in considerable downtime of the vacuum deposition system. Furthermore, the potential for higher-performing and more critical sputter processes to increase the deposition rate and coater system throughput is limited with planar magnetrons.

The introduction of rotating cylindrical magnetron technology

Since the Nineties, Bekaert has successfully introduced rotating cylindrical magnetron technology in the large-area glass coating for architectural and automotive applications. Increasing the target material utilization to more than 75% (three times higher) and having double the target material inventory available on a tube has improved the coater efficiency enormously, with substantially longer production campaigns. Plus, as higher power levels can be applied and more stable reactive processes can be sustained, a higher throughput in a reliable process and with reproducible layer properties can be achieved. It is no surprise, therefore, that in a period of about 10 years cylindrical magnetron technology has become the standard for producing high-quality and low-cost coating stacks on large glass plates.

A similar trend is anticipated for the photovoltaic industry. While 10 to 20 years ago solar cell fabrication was focused on achieving acceptable energy conversion efficiencies on a limited production scale, the current pull to high-volume production is changing the rules of the game. This means that the existing thin film coating technologies of LPCVD and planar magnetron sputtering must also evolve. Sputtering from appropriate cylindrical targets and with adequate rotatable magnetrons may realize an important breakthrough in this area. Below, we give two examples of new rotatable magnetron solutions, which achieve the same or better solar cell performance while reducing the cost of ownership considerably.

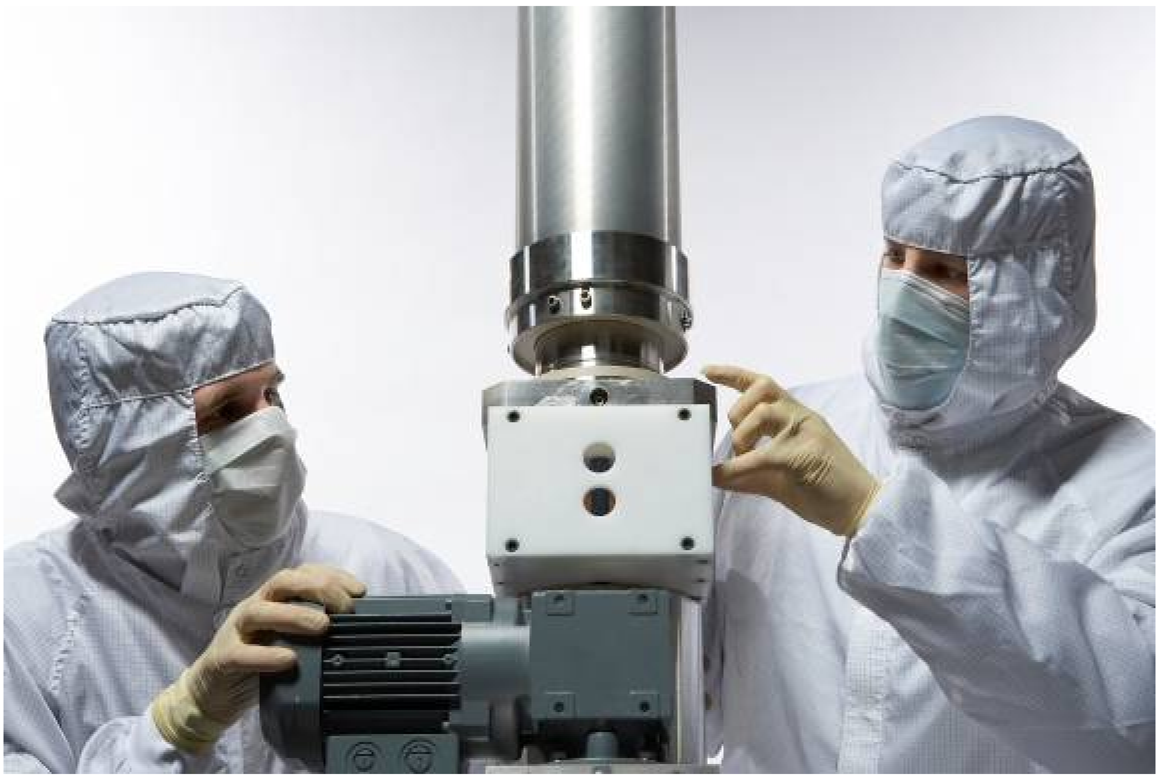
The passivation and anti-reflective layer on crystalline silicon solar cells is traditionally deposited in a LPCVD process, using typically dichlorosilane (DCS) and ammonia gases. Scaling uniformly to larger substrate areas has proven to be a challenge and high-volume throughput has to be balanced with regular maintenance. Depositing this high-quality layer by LPCVD may cost roughly 2.5 ¢/W. Moving to sputtering with planar cathodes may bring the cost closer to 2.0 ¢/W. However, Bekaert has recently developed a high-purity silicon target that may realize improved uniformity with higher deposition rate and a better optical performance for a total cost of less than 1.5 ¢/W. This performance opens up new possibilities for cheaper cell fabrication, boosting production throughput – even on existing coating lines – while maintaining equal cell conversion efficiencies.

For thin film PV solar cells, deposition of good TCO layers remain a significant challenge. High transparency must be combined with a low sheet resistance, while maintaining high stability over the lifetime of the solar cells.

One material of choice is aluminum Doped zinc oxide (AZO), which can be deposited by LPCVD or by sputtering. Sputtering from planar AZO targets is gradually being replaced by cylindrical targets while maintaining a dynamic deposition rate of up to 140 nm.m/min. Although this is one of the first successes of cylindrical sputtering technology within the PV production environment, Bekaert tries to push the limits even further. A newly developed AZO target has doubled the deposition rate while at the same time lowering the sheet resistance and maintaining similar optical properties. Again, this creates huge opportunities to increase the throughput, lower the production costs and improve solar cell performance all at the same time.

Developing rotatable magnetrons – and beyond

Bekaert's commitment to making better and cheaper solar cells doesn't stop here. Apart from working towards a complete portfolio of cylindrical target materials to cope with the requirements of the different solar cell technologies, Bekaert has a proven track record developing rotatable magnetrons. The success in the Nineties was based on combining the right target materials with the appropriate magnetrons so these targets could be mounted into the coating systems. Reliability in rotating seals has proven crucial and has allowed Bekaert to sell several thousands of three-to-four meter magnetrons worldwide.



During the past years, the accent has been developing new magnetron concepts to allow cylindrical technology in smaller coater designs than can be found today for flat panel display and solar cell fabrication. Different rotatable magnetron types have been commercialized and were introduced successfully in new coater designs, or as a retrofit solution to replace existing planar cathodes. Experience and further larger projects allowed Bekaert to extend the scope of the offering. Complete sputter modules, consisting of rotatable magnetrons and cylindrical targets – but also including power supplies, gas distribution, control and automation – allow for a fit-for-use total sputter solution for both new and experienced customers.

Expanding application areas, anticipated capacity and technological approaches – the world of solar cells moves fast. Various technologies have a good chance to contribute to future energy needs while preserving our environment. Success or failure may depend on the quality and performance of thin films being deposited at the lowest possible cost. Sputtering of cylindrical targets from rotatable magnetrons may play an essential role in making this happen.

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