Multilayer Partial Coating Technology for Large Glass Substrates

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Abstract

Multilayer partial coating represents an advanced method for depositing multiple thin-film layers on precisely targeted areas of large glass substrates. This approach facilitates the application of distinct coating materials at the same location, creating tailored functional zones without the need to coat the entire surface. The process is conducted within a single vacuum environment, eliminating intermediate handling steps and reducing the risk of contamination, thus ensuring a high level of coating purity. One of the key advantages of this method is the precision of layer alignment. The ability to deposit multiple coatings in one processing cycle enhances efficiency by minimizing process time and reducing the consumption of source materials. Additionally, the technology operates with compact equipment, requiring e.g., a smaller footprint and lower initial investment compared to traditional coating systems designed for full-surface coverage. The flexibility of multilayer partial coating extends to the ability to process both flat and shaped glass substrates. This is achieved through interchangeable modular components, enabling the system to adapt to a variety of geometries. This feature is particularly beneficial for industries requiring customized glass solutions, such as in architectural, automotive, or electronics applications. The elimination of redundant steps, such as transferring substrates between coating processes, further accelerates production and contributes to resource efficiency. By integrating all steps into a single, closed vacuum system, the method not only reduces energy consumption but also supports the sustainable use of coating materials. In conclusion, multilayer partial coating technology addresses key challenges in modern glass processing, providing a scalable, precise, and resource-efficient solution. Its ability to handle diverse substrate shapes and enable multifunctional coatings with high alignment accuracy positions it as a significant advancement in thin-film deposition methods.

Keywords

Thin-film deposition, Multilayer coatings, Vacuum process, PVD

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1. Introduction

Multilayer partial thin film deposition represents an innovative approach to glass processing, enabling precise one- or multi-layer coatings on specific areas without unnecessary material waste or additional processing steps. Conventional glass coating methods require large and expensive equipment, limiting flexibility and increasing production costs. Furthermore, coating shaped glass presents additional challenges, often leading to increased material waste when excess coating needs to be removed afterward.

This paper examines the operating principles of multilayer partial coating, and its advantages compared to conventional methods. Key benefits include precise layer alignment, material efficiency, acceleration of process speed and the ability to coat both flat and shaped glass. Potential applications in various industries, such as construction, automotive, and electronics, are also explored, where customized and functional coatings offer new opportunities. Finally, the sustainability, economy, and future development needs of this technology are discussed.

2. The Need and Significance of the Technology in Glass Processing

The glass processing industry applies coatings for a wide range of applications, requiring large-scale and valuable machinery to accommodate entire glass panels within the coating system. Typically, these machines are at least three to four times larger in length than the processed glass. The larger the equipment, the more expensive and complex its components become, with a typical coating line costing millions of euros.

Additionally, glass shape poses a challenge in coating, as the coated surface must remain at a constant distance from the material source throughout the process. Any variation in distance results in changes in deposition rate, affecting coating thickness uniformity. This can cause optical distortions or color shifts in the coated area. For instance, when coating sensor areas on windshields, a significantly larger area is typically coated than necessary, with the excess material later etched away. In the worst cases, this removal process must be performed after each layer, increasing labor and material waste. If the multilayer stack can be applied precisely to the intended area without intermediate etching, production time can be significantly reduced.

Multilayer partial coating technology allows for more cost-effective production of existing and new glass applications by reducing equipment investment, factory space requirements, labor and material waste.

3. Definition of Multilayer Partial Coating and Its Distinction from Traditional Methods

The primary difference between traditional coating and multilayer partial coating is that the latter is applied only to a specific, targeted area. Conventional methods require masking to define the coating area, often resulting in blurred or inconsistent edges due to material scattering under the mask. This necessitates post-coating etching to achieve clean and well-defined edges. Furthermore, during conventional coating processes, the glass moves beneath the material source multiple times, as the deposition source is typically optimized for full-width coatings, requiring successive layers to be applied one at a time. As a result, conventional equipment is often extremely long to prevent material cross-contamination during sequential coatings.

In the developed multilayer partial coating method, area definition is achieved through equipment design and a specialized adjustable aperture that controls material deposition. Each material source operates in its own chamber and is sequentially directed to the coating aperture, preventing cross-contamination between materials. The same aperture can also be used for additional preparatory processes, such as plasma etching.

4. Operating Principle of the Technology

4.1. Layer Alignment and Material Selection

Layer alignment and material selection are critical in multilayer partial coating, as precise targeting and appropriate material choices directly affect the quality and performance of the final product. Since the coated area is fixed, the glass must be accurately positioned in the coating system. As neither the glass nor the equipment moves during the process, the desired multilayer stack forms precisely at the targeted location. The coated area size can be slightly adjusted after the glass is positioned. When selecting coating materials, factors such as adhesion to glass and material compatibility must be considered. Practically, any material used in sputtering processes can be employed in this method.

4.2. The Role of the Vacuum System in Ensuring Purity and Precision

A vacuum system plays a crucial role in ensuring process cleanliness and precision by minimizing contamination risks and providing a controlled environment for coating formation. In traditional methods, glass must be meticulously cleaned before entering the system and maintained in a highly controlled environment throughout processing to prevent contamination. Typically, this necessitates a cleanroom-like setup.

With partial coating being localized, the entire glass panel can be pre-cleaned, but only the coated area requires final cleaning just before deposition. Certain cleaning steps can also be integrated into the pre-pumping phase, enhancing moisture removal and further improving coating quality. Since the glass does not encounter ambient humidity between coating steps, the risk of oxide formation between layers is minimal. If necessary, surface treatments can be applied to improve adhesion before deposition.

5. Benefits and Features

Multilayer partial coating offers several advantages and new features:

- **Perfect Layer Alignment and Accuracy**: Since the entire multilayer stack is deposited in a single operation, there is no need for separate alignment between coating steps. The glass remains stationary while material sources are sequentially directed onto it. The coating area can also be adjusted during the process to accommodate layers of different sizes or provide protective top layers against mechanical wear.
- **Material and Energy Efficiency**: Only the required amount of base material is used, and material waste is virtually eliminated as post-processing is often unnecessary. By optimizing material source sizes to match the coated area, the need for large material sources is avoided. Consequently, energy consumption remains low due to the reduced power requirements of smaller sources.
- **Process Simplicity and Speed**: The glass undergoes the vacuum process only once, minimizing unnecessary pre-pumping and optimizing the efficiency of each coating step. The absence of intermediate pumping times further accelerates the process, except when gas composition changes are needed. Deposition rates are well-defined and primarily dependent on pressure, energy, and substrate distance—all of which can be precisely controlled through equipment design.

6. Adaptability to Various Glass Forms

Since only specific areas of the glass are coated, this method allows for precise and controlled deposition on both flat and shaped glass. The equipment is designed with adaptive counter-surfaces that optimize coating adherence to the glass surface. These counter-surfaces are interchangeable, enabling the coating of both flat and shaped glass using the same system. They are also designed for easy replacement and maintenance, enhancing system flexibility and longevity.

Furthermore, the compact size and flexible processing method of the multilayer partial coating system allow it to function both as an inline solution within existing production lines and as a standalone unit. This versatility provides manufacturers with greater freedom in integrating the system based on their production needs. Compared to full-scale coating lines, this system requires significantly less space, offering greater flexibility in factory layout and production planning.

7. Applications and Potential Use Cases

Customized and functional coatings in the construction, automotive, and electronics industries create new business opportunities, offering competitive advantages and added value to glass processing. Innovations developed in one industry, such as coatings in the vehicle sector, can often be adapted for use in architectural glass with minimal modifications. By utilizing localized coating, applications that were previously unfeasible due to cost, expertise or equipment requirements can now be realized. Advanced functional coatings, such as hydrophobic or optical coatings, open new commercial opportunities and enhance competitiveness.

8. Sustainability and Economic Perspectives

Reducing the carbon footprint is an ongoing challenge in manufacturing, with tightening regulations demanding more sustainable production practices. By coating only the required areas and minimizing post-processing, material waste is significantly reduced. Lower energy consumption also decreases the cooling requirements of the system, further enhancing efficiency. Additionally, optimizing the size of the coating chamber to match the coated area minimizes raw material usage.

This technology has a number of advantages in terms of small size, lower initial investment and lower operating costs. As previously mentioned, the compact physical footprint allows for the use of smaller components, some of which can be sourced as refurbished parts. Utilizing recycled components supports sustainability goals while also lowering overall equipment costs, making the system significantly more cost-competitive.

9. Challenges and Future Development Areas

The main challenge in adopting this technology lies in overcoming preconceived notions about new manufacturing methods, even though multilayer partial coating is built on well-established industrial processes. This familiarity reduces technical risks, as the method utilizes proven coating techniques with extensive research and industrial experience. The primary change lies in the handling of glass rather than in the coating process itself.

Economic considerations, particularly initial investment and production-related costs, present another key challenge. However, maintaining existing coating methods without innovation results in stagnant solutions and limits the development of disruptive new products. To remain competitive, industries must be willing to explore and integrate new technologies.

Further research is required to fully leverage the potential of multilayer partial coating technology. Since applications often consist of multiple components, including functional coatings, they may require complementary advancements in electronics and other fields. Many of these supporting technologies already exist in sectors such as display technology and embedded electronics, enabling their adaptation to glass processing without the need for complete reinvention.

Successful commercialization of this technology will require close collaboration between companies, research institutions and universities. Continued development efforts could open new business opportunities and significantly expand the role of glass processing in high-value applications.

10. Conclusions

Multilayer partial coating represents a significant advancement in glass processing, offering enhanced precision, efficiency and flexibility over traditional coating methods. Key advantages include precise layer alignment, minimized material waste, improved energy efficiency, and the ability to coat both flat and shaped glass. Additionally, its compact and modular design enables cost savings and broad applicability across various industries.

The technology presents opportunities in construction, automotive and electronics industries, where customized and functional coatings provide substantial competitive advantages. This innovative approach mitigates challenges associated with traditional coating processes, such as high equipment costs, excessive material usage and prolonged production times, while also facilitating more cost-effective innovation and commercialization.

While the technical challenges of multilayer partial coating are manageable due to its reliance on well-established industrial coating techniques, the primary obstacle remains industry resistance and unwillingness to adopt new methods. Widespread implementation will require further research, pilot projects and collaboration among companies, research institutions and universities.

The adoption of successful cross-industry innovations, such as the integration of thin-film electronics into automotive glass, demonstrates the potential for transferring proven technologies across sectors. Similar approaches could unlock new applications and expand the impact of multilayer partial coating technology. By fostering continuous innovation and exploring new applications, this method has the potential to drive transformation within the glass processing industry, paving the way for more sustainable and economically viable solutions.