Thin Films

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This brief manuscript is only an introductory overview of the subject matter. It is not intended as a tutorial, instruction, reference or problem-solving document.

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Abstract

Thin films have been in widespread use in many industries. Their design and fabrication require a systems approach to the selection of materials, deposition systems and processing. This whitepaper provides several examples of coatings that are within the expertise of *Materials Queries* and a list of some key considerations concerning their properties and deposition.

Thin Films

Thin films are in wide industrial use. This overview focuses on optical thin films with a special emphasis on coatings on glass. Optically thin refers to layer thicknesses that are about or thinner than wavelength of light, e.g., 380nm-780nm (nanometers) in the visible spectrum, or thinner. When applied to solid surfaces, these films modulate its optical reflectance through a combination of reflection and absorption[1]. For a transparent substrate, for example glass, the transmitted light through the coated substrate is similarly modulated. The reflectance and the absorption of the coated system are in turn determined by the respective real (n) and imaginary (k) components of the indices of refraction (N = n +ik) of all the layers and the substrate. N, the complex index of refraction of a material, is a function of its electronic density, which varies with its composition, mass density, crystal structure or thickness. It is possible to estimate N using *a priori* methods, but given the complexity of the above properties, for most practical purposes it is measured experimentally. However, if accurate values of N are available, other optical properties of a substrate may be calculated using commercially available optical models.

Optical thin film stacks are essentially optical filters with broad industrial applications ranging from coatings systems for ophthalmic, optical instruments, and specific band pass applications, for example. Among the last group, low emissivity (Low-E) or solar control glass coatings have wide applications in architectural and automotive industries[2] and are one of the main areas that *Materials Queries* has extensive insight and experience in. Examples of our other areas of experience include conductive thin films, e.g., for deicing applications on transparencies (automotive, aircraft), and antireflective or diffusion barrier coatings for solar panels.

The Materials Science of Thin Films

In spite of extensive research in the materials science of thin films[3], any specific coating system requires its own special consideration. We have provided a review of a primary example of the materials science of thin films, i.e., heat load reduction and low emissivity coatings previously[4]. While coatings based on noble metals, silver in particular, function as both transmission filters for solar radiation, and for reflection of room temperature blackbody radiation, conductive oxide coatings act only as the latter, i.e., Low-E films. Silver based films consist of at least three but also up to 20 layers or more of different materials stacked contiguously. The different layers act as reflectors (visible and infrared radiation) anti-reflectors, nucleation layers, and chemical and physical protective layers. Each layer impacts the optical properties of the coating, thus requiring a systems design approach.

Optical Design

The reflectance and transmittance of the coated glass not only impacts its functional properties, but they also determine its visible attributes with appreciable aesthetic impact. To achieve the target profile of the coating it is necessary to select a complementary set of materials with appropriate complex indices of reflection and optical thicknesses. These materials must additionally meet multiple constraints imposed by the deposition system and process cost.

Mechanical and chemical properties

Each material layer has its own intrinsic mechanical and chemical durability properties. In the above heat load reduction coating example, silver is a soft and reactive metal prone to both physical and chemical degradation. However, the as-deposited properties of every thin film layer also depend on its deposition conditions, and the condition of the layers immediately next to them or further away. A few key attributes of the materials science of optical thin films to consider include:

- Bulk properties of each material
- Thickness and thickness dependent properties
- Interfacial structure
- Internal stresses
- Resistance to thermal stresses and interdiffusion
- Substrate properties and surface quality

A thorough understanding of the deployed materials, their above properties and their deposition conditions is necessary but not sufficient for developing a useful product.

Deposition Methods

Various processes including chemical vapor deposition (CVD), physical vapor deposition (PVD), atomic layer deposition (ALD), and their subcategories are available for the deposition of optical thin film stacks. Although all of these processes, including their subcategories remain in use, PVD, sputtering in particular, has become most prominent.

Understanding the deposition process, critically in reactive deposition methods, and developing the means for controlling the process, are key to cost control and product quality. Digital means for process control and monitoring have been developed by the equipment manufacturer and their end use industries. Often these means are complementary, but especially when developed by the end use industry, are part of their intellectual property.

Conclusion

This brief overview lists some of the key consideration for the development of commercially viable optical thin films. Many other uses of optical coatings, their respective attributes, and deposition processes, require detailed review and further development. With our deep hands-on experience, *Materials Queries* can support your team in road mapping projects, enhancing your process methods, or resolving difficult challenges with existing technologies.

References

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