SVC Topics

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PVD Processes: Solar Control & Low-E Window Coatings

Energy management is an important factor in window design. Vacuum-deposited coatings on windows play a large role in energy conservation if designed and used properly. Generally, architectural windows are double-glazed to control conduction and convection of heat through the window. In some cases, the coating is deposited directly on the glass, while in others the coating is deposited on a polymer film that is then attached to the glass ("window films") or suspended between the glazing panels.

The composition of the thermal-control coatings for windows differs, depending on the end result desired. If the object is to keep solar radiation from entering through the window, a coating is used to reject solar radiation (solar-control coating). This type of coating is particularly important in hot climates. If the object is to keep heat in the room, a coating is used to reflect the low-temperature (long wavelength) infrared radiation back into the room (low E-coating) and allow solar radiation to enter the window. This type of coating is particularly useful in cold climates. Solar-control coatings are also used on other windows—such as those for automobiles, where the glass may be formed at high temperatures ("slumped") into various curved configurations. In the past, in these applications, the coatings were deposited on the coatings that are stable under the forming temperature and environment, thus allowing the glass to be coated before forming. Coated glass, usually in the form of window films, is also used in the automotive industry for "privacy" windows.

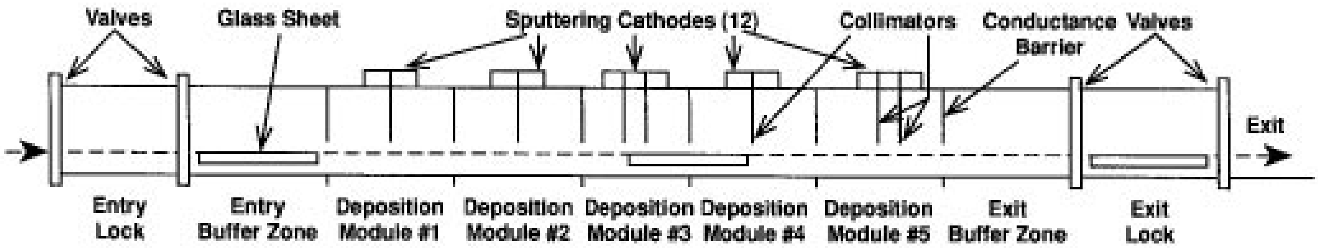
Coatings on architectural windows only became feasible after the introduction of the float glass process by Plinkington in 1959. Before that time, window glass was made by rolling or drawing and had many surface imperfections. The addition of a coating made the defects more evident. The float-glass process yields glass with very few imperfections.

Solar-control coatings utilizes a metal or compound layer to control the transmission of incident solar radiation through the glass in a range of 10 percent to 50 percent. The reflecting layer may be chromium, a chromium alloy or a compound material like titanium nitride. The thickness of the reflecting layer can give color to the coating by interference effects or another layer, such as an oxide, can be added to the coating to give interference effects. The uniformity of the color over large glass panels requires very close tolerances on the deposited film thickness and optical properties. Initially, this was done with great difficulty using e-beam evaporation on vertical glass panels passing in front of the evaporation sources. Today, the depositions are done on horizontal panels passing underneath magnetron sputtering cathodes. Typical solar control coatings are: glass-TiO_2-Cr-TiO_2, glass-Cr-TiN, and glass-SnO_2-NiCr-TiN.

For temperate and cold climates, a reflective layer of metal, usually silver, is used to reflect the low temperature (long wavelength) infrared (IR) back into the room and give relatively high transmission (50 percent to 60 percent) for the visible spectrum. Because emissivity is the complement to reflectivity, the coatings are called low-emissivity (low-E) coatings. To achieve high transmission in the visible, anti-reflective (AR) coatings, usually of tin oxide or zinc oxide, are added to both surfaces of the silver layer. To protect the silver layer from oxidation during the reactive deposition of the SnO_2 or ZnO, a very thin protective layer of a metal such as titanium (Ti) or nickel-chromium (NiCr) is deposited. Often, the last layer of the thin film stack is an abrasion-resistant coating of a material such as TiO_2 or Si_3N_4.

A typical low-E optical coating stack might be: glass-ZnO-Ag-Ti-ZnO-TiO_2 or glass-SnO_2-NiCr-Ag-NiCr-Si_3N_4-SnO_2. For very high IR reflectivity, "double low-E" coatings can be used. A typical double-E coating might be: glass-SnO_2-NiCr-Ag-NiCr-Si_3N_4-SnO_2-NiCr-Si_3N_4-SnO_2, which increases the IR reflectance to 96 percent. Obviously, the low-E coatings are more complicated to manufacture than are the solar-control coatings. In double-glazed windows, the glass surfaces are numerically identified from the outside to the inside. Low-E coatings are typically applied to surface number 3, where they are protected.

Early, simple, thermal-control coatings were applied by chemical means. In the late 1960s, simple thermal-control coatings were deposited in vacuum using electron beam (e-beam) evaporation onto vertical glass plates passed in front of the e-beam evaporation sources. In the mid-1970s magnetron sputtering allowed non-reactive and reactive sputter deposition onto horizontal glass sheets, which passed underneath the sputtering cathodes. This, along



Schematic of a large flat-glass in-line architectural glass coater. Shown are the sputtering cathodes (12), conductance barriers ("tunnels"), which isolate processing zones and collimators to control area over which the film is being deposited. Not shown are the entry and exit washing modules and the extensive vacuum pumping used to confine gases to their respective processing zones.*

with the development of in-line, air-to-air vacuum coating systems, has become the major production technology in this area.

The figure shows a schematic of the vacuum-deposition portion of a large in-line system for coating 100 x 144 in. (3.2 x 6.0 m) flat sheets of architectural glass.* Not shown are the entry and exit washer and dryer modules. The system is about 16 ft wide and 200 ft long, including washer modules. The vacuum chamber is about 140 ft long, with five deposition zones having 12 sputtering cathodes and more than 50 high-vacuum diffusion pumps. The cathodes are shielded by collimators that confine each deposition to a limited region of the deposition zone. Specific gas compositions are restricted to individual deposition zones by the limited conductance between zones and high pumping rates in the zones. This eliminates the need for isolation valves and allows deposition to begin on one end of a sheet before it ceases on the other end. The cycle time is one minute, with a line speed of about 12.5 ft per minute. Such a system is capable of producing up to 12 x 10^6 ft^2 of coated glass per year. There are currently several hundred architectural glass-coating systems in operation in the world. Improvements in the nucleation and stability of the silver film and the durability of other layers continue to bring improvements to the coated glass product.

Many countries and cities are incorporating thermal-control criteria in their building codes. This is particularly true for commercial buildings. It is expected that the market for coated glass will expand. The ability to coat glass before forming allows lower-cost curved coated windows. This will increase the application of thermal-control coatings in the automotive industry and decrease the use of window films that are glued to the glass surface.

Other types of thermal-control coatings are used to absorb solar radiation (solar thermal absorbers), to absorb solar radiation and not emit infrared radiation (selective solar absorbers) or enable surfaces to be cooled by radiation by having a high emissivity. Inexpensive solar absorbers are prepared by painting. An interesting solar absorber is gold soot, which appears very black, and is prepared by gas evaporation. Gas evaporation is performed by evaporating a material into a relatively high gas pressure where vapor phase nucleation occurs and "nanoparticles" are formed. These particles then deposit on surfaces forming a very low-density coating. These coatings act as radiation traps and are used on bolometers, which measure total incident radiant energy from weak radiation sources such as stars.

Ideally, a selective solar absorber should have 100 percent absorption below 2.5 microns and 100-percent reflectance (zero emittance) above 2.5 microns. Some metal carbides are good selective solar absorbers. Very efficient selective solar absorbers can be formed using multilayer vacuum-deposition processes that combine absorption and antireflection into the design of the film stack. One such selective solar absorber coating stack that is being deposited on copper foil is: copper-chromium carbide (layer 1)-hydrogenated amorphous carbon/chromium carbide composite (layer 2)-amorphous carbon (layer 3—*i.e.*, Cu-CrC-αC:H/CrC-αC). Layer 1 acts as a diffusion barrier to prevent diffusion of the copper into the stack and is deposited by magnetron sputter deposition. Layer 2 is deposited by magnetron sputter deposition and it, along with layer 3, acts an absorber and as antireflection coatings. Layer 3 is deposited by Plasma Enhanced CVD (PECVD) and also acts as a protective coating. The total coating thickness is 160 nm.

Thermal-control coatings play a large role in energy conservation and personal comfort. This role will increase worldwide as the capabilities for depositing the coatings become more widespread. P&SF

**Schematic and data based on a large BOC Coating Technology glass coater.*