# Cold spraying: The future for architectural applications?

From plain glass of the past to today's heated and photovoltaic glass, innovative technologies have always played a key role. Dr Julio Villafuerte* explains the impact of cold spray technology in the fabrication of modern glass for architectural applications.

Glass is the amorphous state of ceramics, metals or polymers obtained when liquids are cooled faster than the material would require to transform into a more thermodynamically stable crystalline structure. Common glass is obtained by cooling a blend of molten silica ($SiO_2$), limestone ($CaCO_3$/$CaMgCO_3$) and sodium carbonate ($Na_2CO_3$). For centuries, the properties of common glass combined with the widespread availability of the raw materials have made glass the choice material for a vast selection of products.

Modern windows are made from flat glass produced by forming glass sheets over a bed of molten tin in large float tanks. Over the last few decades, the window industry has witnessed innovative changes as a result of many improvements in the window design and construction process. From the simple glass of the past to today's insulated glazing units and sophisticated thin film deposition techniques, architectural glass has become a remarkable product that provides the highest levels of comfort, safety and efficiency.

## Screenprinting for heated glass

Heated glass is created to avoid fogging and icing. The latter occurs when the temperature of the glass surface gets below the dew point of the surroundings, especially in windows exposed to extreme temperature differentials. Applications include refrigerator doors and rear windows for automobiles. To create heated glass, a pattern of electrically conductive material (silver-based frit) is applied to the surface by screenprinting (silkscreening). The pattern is connected to busbars, which are also screenprinted along the two opposite edges of the glass sheet.

One of the drawbacks of screenprinting is that it often requires multiple surface treatment steps, including heating at elevated temperatures. Many of these secondary processes often limit the conditions under which a given glass sheet can be

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Fig 1. Thin-film heated glass. Photo courtesy of Thermique Technologies, LLC: www.thermiquetechnologies.com

Fig 2. Array of thin-film photovoltaic panels (12kW) made by First Solar LLC, powering an entire building at the University of Toledo Campus, Toledo, Ohio. Photo courtesy of the University of Toledo: www.utoledo.edu/research

processed. The printed lines are visible and interfere with vision. The process lacks flexibility and the costs associated with the process can only be justified for significantly high volume production. Soldering of metal lead-outs to screenprinted busbars usually involves stringent techniques to avoid damaging the printed pattern.

## Thin-film deposition

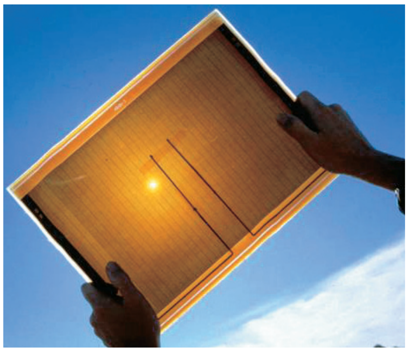
Today, modern heated glass manufacturing takes advantage of thin-film deposition techniques, such as physical vapour deposition (PVD) or chemical vapour deposition (CVD). These techniques not only allow the deposition of materials that provide electrical conductivity but also other materials that provide a wide range of optical and thermal properties to the glass. The additional functionalities become available without compromising transparency and aesthetics.

Some of the thin films used for heated glass include fluorine-doped tin oxide, indium-tin oxide and combinations of tin oxides and silver metal. These films are transparent, electrically conductive and of low emissivity (low-E). Thin-films are either thermally deposited during the manufacture of the glass itself or by PVD/CVD onto pre-cut sheets of glass.

The fast growing market for low-E glass is credited by high demands for low-cost tin oxide and metallic silver. Thin-film heated glass is very reliable, as the generated heat is rather evenly diffused over a large surface than concentrated in a small area. The uniform radiation - especially at moderate temperatures - is one of this technology's strengths, often requiring less overall energy for equivalent performance. The benefit is the heated glass that adds comfort, condensation control, frost control, energy efficiency and attractive aesthetics (see ***fig 1***).

## Photovoltaic glass

Another common application of thin-film deposition is in the creation of photovoltaic glass [1] used in solar cells. The technology of capturing solar energy and converting it into solar power relies on the well-known photoelectric effect displayed by a number of semiconductor materials.



▲ Fig3. Thin-film photovoltaic glass that uses polycrystalline silicon crystallised by a heating process. Photo courtesy of CSG Solar: www.cgsolar.com

Fig 4. Robotic low pressure cold spray system creating busbars on architectural glass. Photo courtesy of SST, a division of CenterLine (Windsor). ▶

Conventional solar cells are made from 200-400µm thick wafers of pure monocrystalline or polycrystalline silicon, providing energy conversion efficiencies up to 18%. These cells are normally opaque, but by substituting the carrier material with glass as well as spacing the solar cells further apart, semi-transparent modules can be obtained. Yet the high manufacturing cost of pure silicon combined with the relatively low energy conversion efficiency has limited the widespread use of conventional solar cells. Furthermore, it has been observed that only a few microns into the exposed surface of a solar cell are effective in converting solar energy.

Subsequently, thin-film deposition of silicon has evolved as a low-cost alternative to conventional solar cell making (see ***fig 2***). The drawback of this method is that thin-film deposition often yields amorphous silicon, which displays conversion efficiencies in the range of 4% to 6%; much lower than crystalline silicon. These low conversion efficiencies, however, have not discouraged the massive implementation of thin-film techniques to produce solar cells for many solar powered commodities such as calculators, watches and toys.

Today, the quest for higher solar energy conversion efficiencies has resulted in alternative semiconductor materials and deposition methods. Some of these materials include cadmium telluride (CdTe) and copper-indium-diselenide ($CuInSe_2$), which are claimed to reach conversion efficiencies as high as 12%. New methods to improve conversion efficiencies include the use of amorphous silicon deposited by chemical vapour deposition onto textured glass surfaces, which is then converted into polycrystalline silicon by controlled heating (see ***fig 3***).

In photovoltaic windows, a semi-transparent photovoltaic composite film is incorporated on the exterior glass of glass units. Similar to heated glass, electrical connectivity can be attained by creating busbars from which individual panels are interconnected to others, building up an entire system. Transparency can be increased by selectively removing narrow strips of the film using a laser beam, allowing as much as 12% of the incident light to pass through.

Even though the cost of this technology is still high, savings in building materials, electricity, and cooling loads are expected to offset the cost of photovoltaic glass. While this technology is already available in Europe, it is still carving its way into the US market through pilot programmes developed by the US Department of Energy.

## Low pressure cold spraying

Representing an innovative step forward from the old screenprinting of

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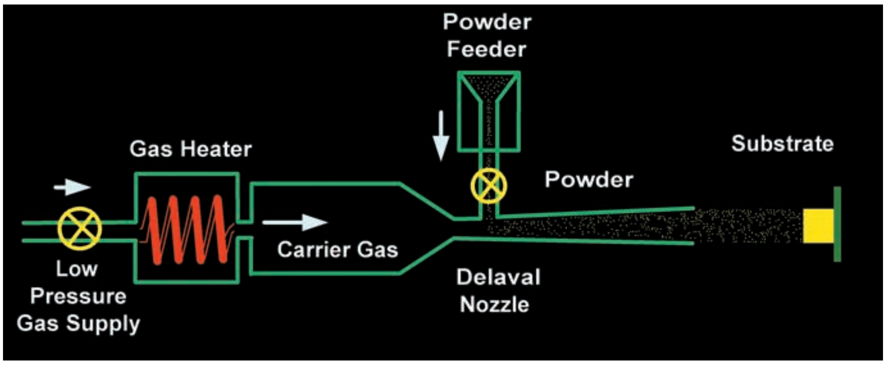
Fig 5. Schematic of low-pressure cold spray process.




silver frit, today's low pressure cold spray technology offers an economical and reliable solution for producing busbars on heated and photovoltaic glass (see ***fig 4***). In contrast to all other techniques used in architectural glass production, the low pressure cold spray process is characterised by simplicity and reliability, features that bid for widespread implementation of cold spray for architectural glass manufacturing.

Cold spray is an emerging solid state spraying process in which the coating materials are not melted. Instead, the kinetic energy of supersonically accelerated solid particles is converted into interfacial heat upon impact with the substrate. During low pressure cold spraying (see ***fig 5***), pressurised air or nitrogen (60-140 psi) is heated and directed to a convergent-divergent (DeLaval) nozzle. At the divergent part of the nozzle, the expanding gas accelerates to supersonic speeds while its temperature sharply decreases to less than 100°C. Powder feedstock is injected downstream at the diverging section of the nozzle [2] where it gains velocities of up to 600m/s. Particles charged with this kinetic energy impact the substrate, producing a combination of metallurgical and mechanical bonding [3].

Cold spray is capable of producing thick coatings that exhibit extremely low porosity (<1%), with avoidance of oxidation, phase transformations and tensile residual stresses for a wide selection of metals, cermets and other material combinations. With the conductive materials being sprayed at very low temperatures, the cold spray process does not affect the glass, nor does it require any special surface preparation.

Robotic low pressure cold spray has already been successfully used to create busbars on thin-film heated glass (see ***fig 6***) using a proprietary blend of non-ferrous materials. Cold sprayed busbars exceed the bond strength and electrical resistance requirements set forth by the industry. Since cold spray does not require any special pre- and/or post-treatment, cost savings associated with this process have sparked interest from glass manufacturers.

Some of the advantages of cold spray over traditional screenprinting processes for busbars creation are:

- Minimum setup is required.
- Low-cost materials.
- No pre- or post-treatment of glass is required.
- No masking of glass is necessary.
- High flexibility and easy changeover.
- Consistent bonding properties.
- No residual stresses in the coating.
- Low porosity of the busbar.
- Low oxygen content.
- Can be used on any glass surface profile.
- No special procedure required for lead-free soldering of lead-outs.

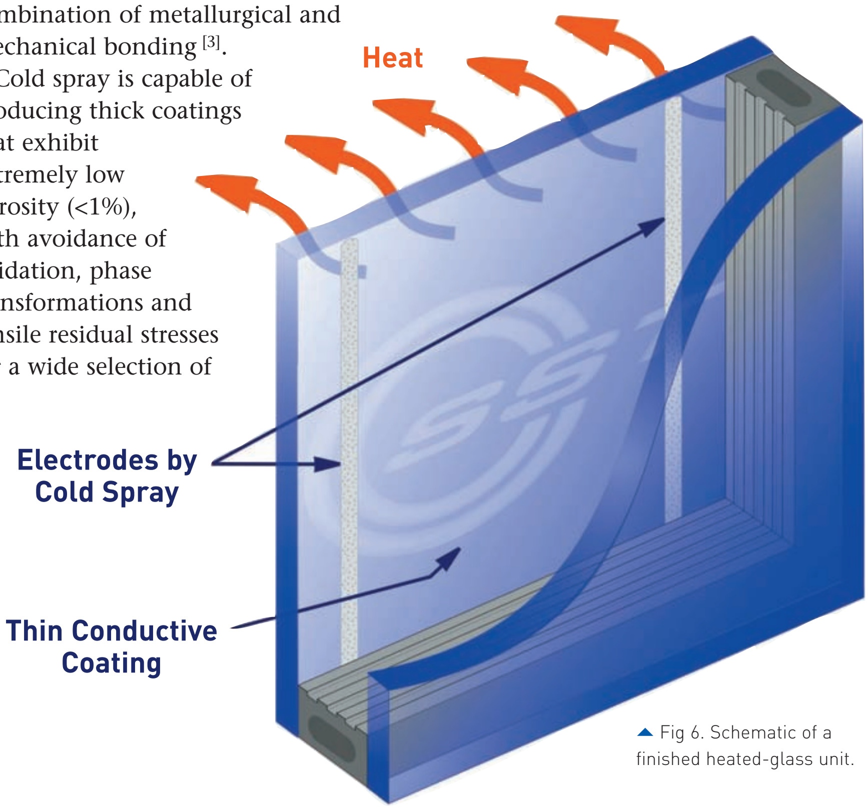



Fig 6. Schematic of a finished heated-glass unit.

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## References

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