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Solar Glass & Mirrors, Photovoltaics

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Glass is used in photovoltaic modules as layer of protection against the elements. In thin-film technology, glass also serves as the substrate upon which the photovoltaic material and other chemicals (such as TCO) are deposited. Glass is also the basis for mirrors used to concentrate sunlight, although new technologies avoiding glass are emerging.

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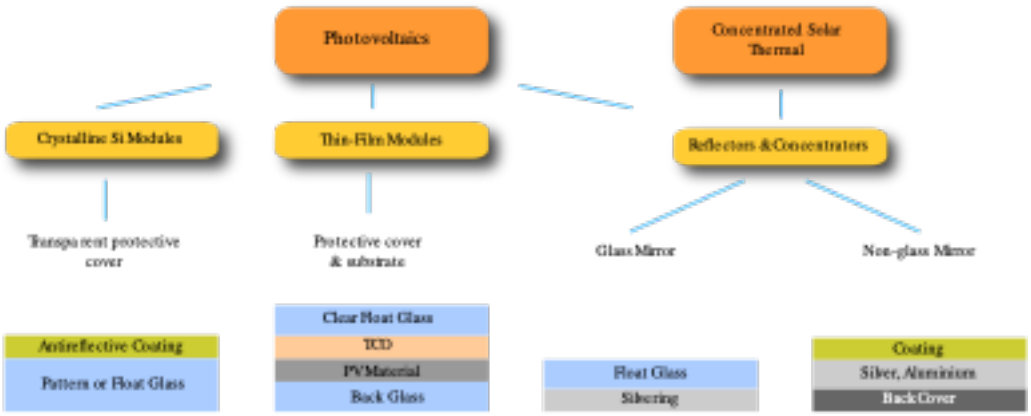
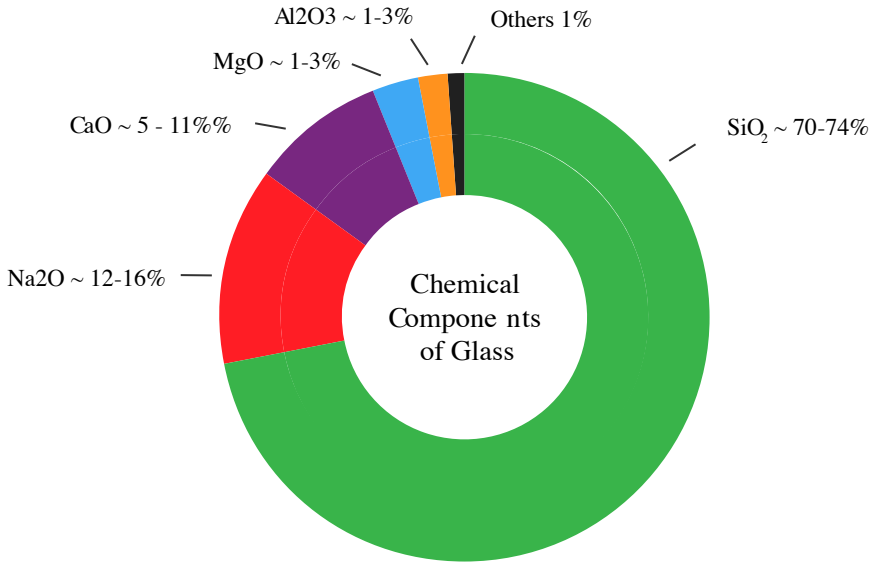


Solar Glass



Chemical Composition of Glass

Most commercial glasses are *oxide glasses* with similar chemical composition. The main component is Silicon Oxide, SiO_2, which is found in sandstone.

Annealed Glass: The components are heated in a furnace at temperatures above 1560°C and cooled down slowly after the forming process, resulting in annealed glass..

Tempering: Glass is heat-treated by heating annealed glass to ~620°C and then rapidly cooling by airflow. As a result, tempered glass is about 4 times stronger than annealed glass. In addition, tempered glass breaks into small fragments, reducing probability of serious injury.

Iron Impurities: Most glass contains iron impurities in the form of iron salts within the silicon oxide that impair tthe transmission of light through the material. Sources for low iron glass include low iron sand and limestone. To produce low iron flass, furnaces must be designed to handle higher melting and refining temperatures.

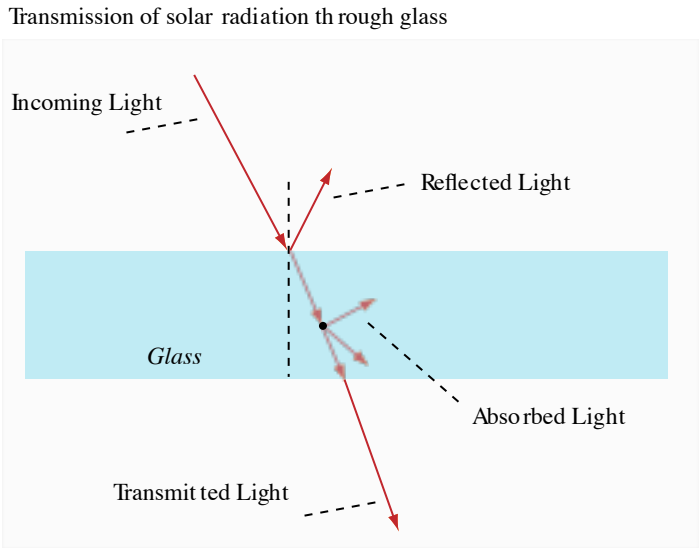
Coating: Thin layers of coating may be deposited on one side of the glass for anti-reflection, improved conductivity or self-cleaning.

Glass Characteristics

For solar applications the main attributes of glass are transmission, mechanical strength and specific weight.

Transmission

Transmission factors measure the ratio of energy of the transmitted to the incoming light for a specific glass and glass width.



Solar Transmission	Ratio of the total energy from an AM1-5 source over whole solar spectrum from 300 - 2,500nm wavelength.
Light Transmission	Ratio of the energy of the visible spectrum from 380 - 780nm
PV Transmission	Ratio of the total energy from an AM1-5 source weighted by the quantum efficiency of a typical crystalline silicon cell.

Base-line commercial glass has a solar transmission of 83.7%. I.e. 16.3% of the sun's energy do not even get to the PV material. The energy loss is due - in equal parts - to reflection on the surface and absorption within the glass due to iron impurities.

Specific Weight

The density of glass is about 2,500 kg/m^3 or 2.5kg/m^2 per 1mm width. Typical crystalline modules use 3mm front glass, whereas thin-film modules contain two laminated glass layers of 3mm each for front and back. As a result, assuming 3mm glass, 96% of the weight of a thin-film module and 67% of a crystalline module is glass!

Mechanical Strength

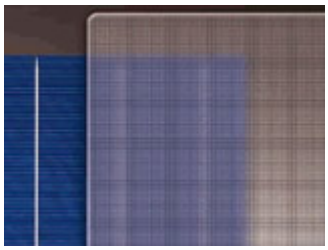
Glass has great inherent strength. However, as it can not not reduce localised stresses, it is subject to rapid brittle fracture. There are a number of measures for mechanical strength depending on the direction of the applied force. For the purpose of solar modules, the most significant measure is the **tensile strength**, a measure of pressure expressed in Pa (Pascal).

Type	Mechanical Strength
Annealed Glass	45 MPa
Toughened	70 MPa
Tempered	120 MPa

Flat Glass for Solar Applications

Solar applications require flat glass. So-called **Pattern Glass** is mostly used as front glass in crystalline modules, whilst **float glass** is used for both substrate and back glass in thin-film modules.

	Float Glass	Pattern Glass
Manufacturing Process	Molten glass is slowly cooled and fed off from the motlen tin.	Normal plate glass with pattern molded into the surface by passing plate through engraved rollers. Typical patterns are diamonds or just matt. The pattern enables easy lamination, provides non-blinding effect and better aesthetics of solar modules.
Capex for typical manufacturing line	€80 - 150m for 400 - 800 t/day	€30 - 45m for 240 t/day
Manufacturing Set-up Time	20 - 24 months	15 - 18 months

Energy required	1.75 kWh/kg (1,500 kcal/kg)	1.16 kWh/kg (1,000 kcal/kg)
Market Share of PV glass	~ 20%	~ 80%
Expected future demand	High	Medium
		

The Solar Glass Challenge

The objectives for solar glass are:

- Ultra-bright glass needed with high solar transmission to ensure high efficiencies in the overall pv module.
- Mechanical strength to withstand snow and wind.
- Depending on application, glass may need to be laminated and coated
- Self-cleaning characteristics would help to reduce maintenance costs.

Choice of Glass

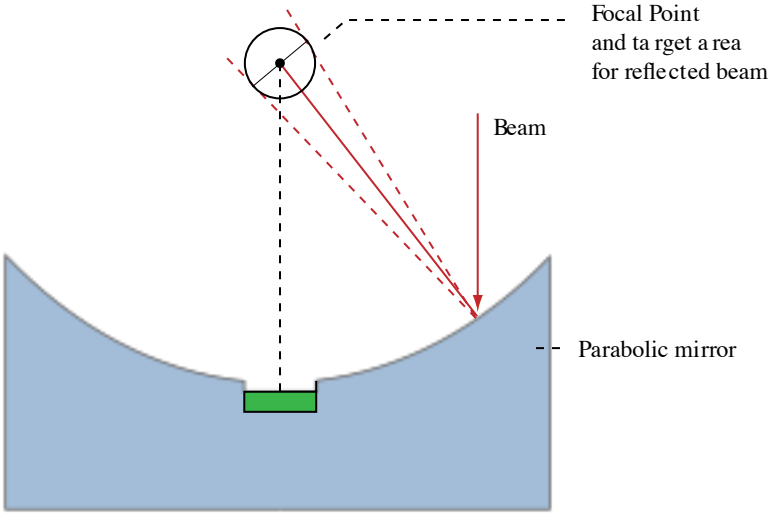
	Rationale	**Choice of glass**
Crystalline Silicon Module	High cost of photovoltaic materail per area requires top of the range solar glass	Pattern Glass with transmission > 91.4%, plus antireflective coating, resulting in total solar transmission > 94%
Amorphous Silicon, CdTe	Lower cell efficiency and cost per area do not warrant the marginal costs for ultra clear glass	89% float glass

Thin-film CIS / CIGS	Higher cost of pv material per area warrant cost for higher quality glass	Low iron float glass, solar transmission > 90%. Plus a cotaing of Molybdenum to optimize conductive characteristics of the CIS and CIGS layer. Molybdenum is a TCO (**Thermal conductive oxide**).

Mirrors

For the generation of electricity from solar power, mirror are used to concentrate the solar light onto either photovoltaic material or a thermal receiver.

Objectives



The reflector should have high solar reflectance and good specular reflectance properties. Similar to the definition of transmission in glass, for mirrors it is the ability to reflect:

Solar Reflectance	Ratio of total energy that is reflected from an AM1-5 source.
Specular Reflectance	Measures the ratio of the energy of the direct light that is reflected from an AM1-5 source. This is an important measure, as some light is reflected as diffuse light and can not be focused.

Precision of curvature	The precision of the mirror is usually expressed in the percentage of the energy of the reflected light that hits a target area around the focal point. For instance: 99.5% within 70mm, 98.8% within 60mm and 95% within 40mm target.

Household mirrors have a reflectivity in the 80% range. For solar mirrors, 93% would be an excellent value. However, net reflectivity must also take into account the cleanliness of the mirror. Typical value for cleanliness is 96%, which would have to be multiplied by the mirror's specular reflectivity.

The aim for solar mirror is for high specular reflectance over and extended lifetime.

Mirror Types

Type	Company	Description	Specular Reflectance	Cost [$/m^2]
Thick Glass	Flabeg	5mm silver-coated glass. Parabolic (or other non-flat) shapes can be acheived through hot bending at 700°C.	94%	40
Thin Glass	Naugatech	Stability may be an issue at 1mm.	93 - 96%	15 - 40
Aluminium Front	Alanod, Almeco (Vegaflex)	Aluminzed polished aluminium reflector with nano composite oxide protective layer. Weighs 6.8 kg/m^2 - less than thick glass. But lower reflectance.	> 87%	< 20
Laminate	Reflec Tech	Silverized polymer film on a polymer	94%	20 - 30

		substrate, laminated to aluminium. Needs a hard coat for required strength.		