CORNING

Photovoltaic Glass Technologies

Thin Specialty Glass for Reliable Thin Film PV Modules

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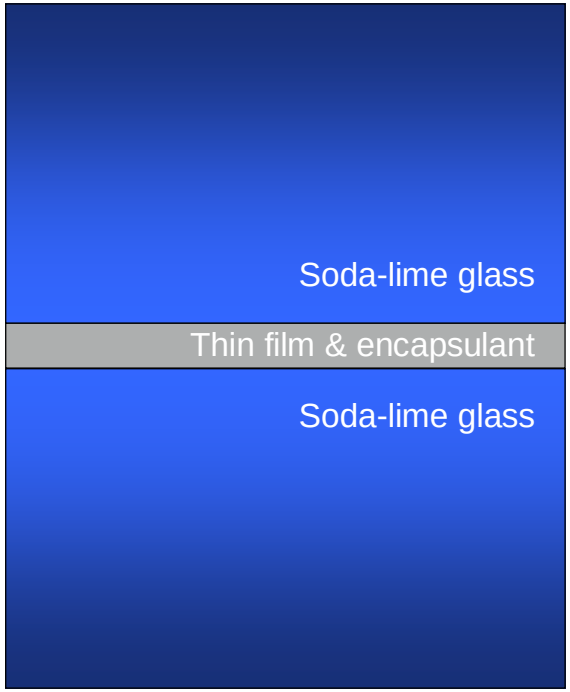
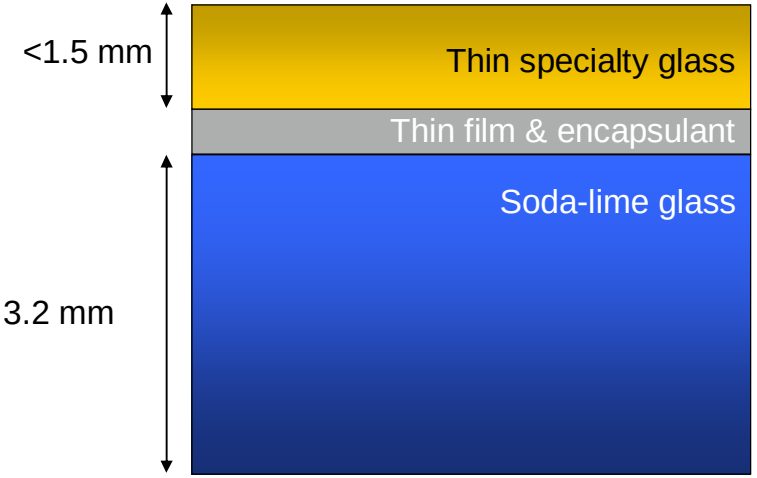
Thin specialty glass enables increased conversion efficiency

- Enables increased conversion efficiency
  - Higher transmission
  - Higher processing temperature
- Lowers manufacturing and BOS costs
  - Shorter heating times
  - Shorter cooling times
  - Reduced weight

Typical PV module cross section

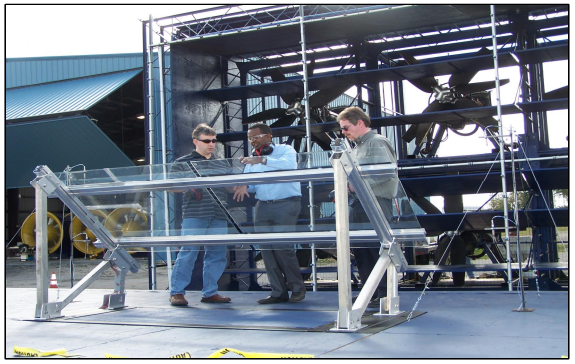


Cross section with thin glass

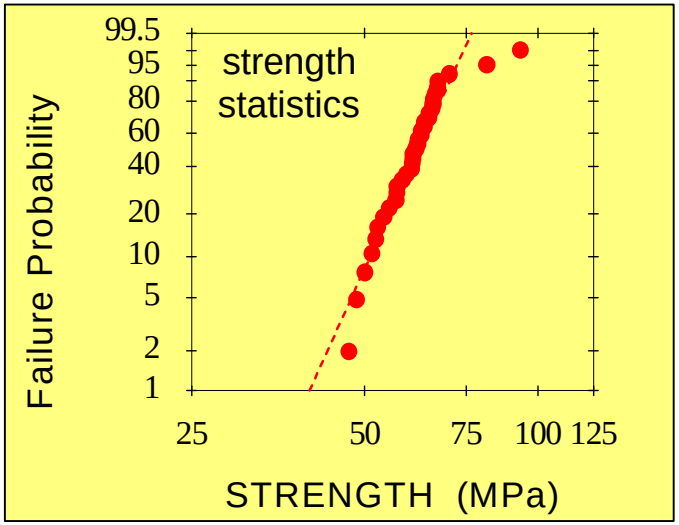


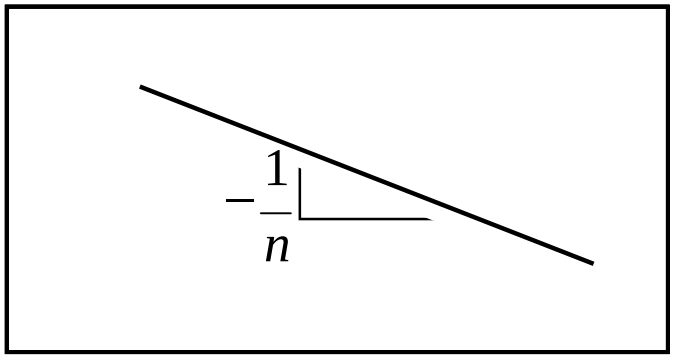
Thin glass must meet reliability requirements

- 25 to 30 years - no glass breakage
  - Wind, rain, hail, snow, blowing sand
- IEC 61646
  - Hail Impact
    - 25mm ice ball at 23 m/s
  - Wind load test
    - Uniform 2,400 Pa pressure to both sides
    - Total 6 hour duration
  - Heavy snow load test
    - Uniform 5,400 Pa pressure



Glass strength can be affected by statistics and time





Probability Factor $F_P = \left[\ln\left(\frac{1}{R}\right) \right]^{\frac{1}{m}}$

Area Factor $F_A = \left(\frac{A_{test}}{A_{product}} \right)^{\frac{1}{m}}$

Fatigue Factor $F_F = \left(\frac{1}{\tau} \right)^{\frac{1}{n}}$

n = fatigue exponent τ = stress duration

R = reliability A = area

S_0 = Weibull characteristic strength

m = Weibull modulus

Allowable Stress = (F_P x F_A x F_F) S_o

Surface imperfections and fatigue determine strength over time

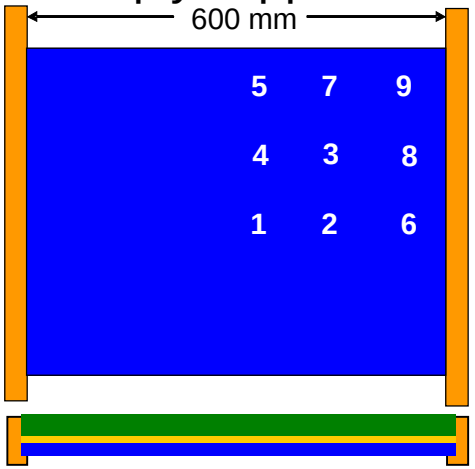
Not all glasses are created equal; Different glasses have different fatigue resistances

Glass	Fatigue Exponent	Relative Strength (30 Year Life)
Soda-lime	~15	1.0
Corning PV glass	~20-23	1.4 – 1.6
Fused Silica (space shuttle windows)	~33	2.0
TiO_2 doped Silica (telescope mirrors)	~45	2.4

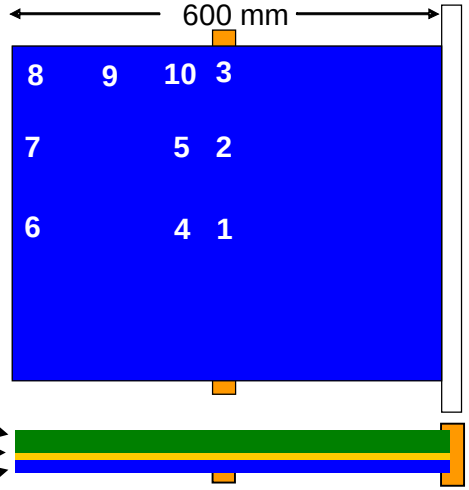
Resistance to fatigue is quantified by fatigue exponent
large exponent is better

Thin glass passed hail impact testing

simply supported



cantilevered

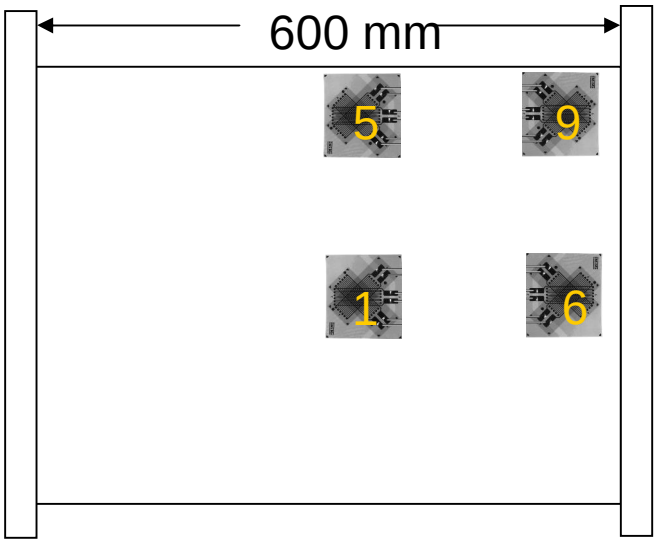


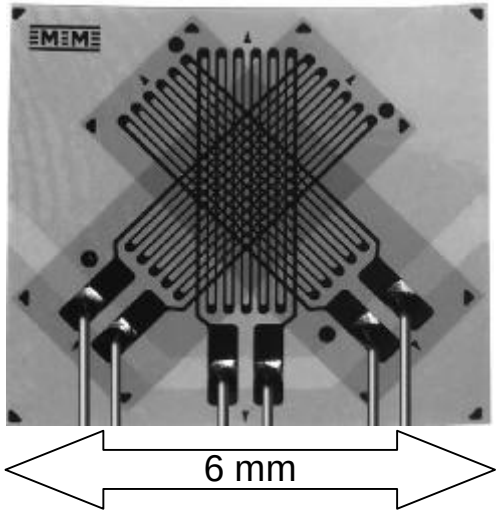
Heat strengthened 3.2 mm soda-lime
0.76 mm PVB
0.7 – 3.2 mm thin specialty glass

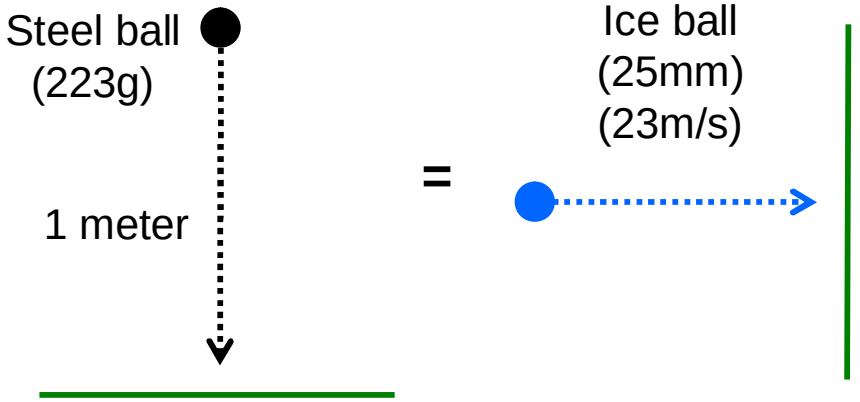
Experiment details
95- 500 X 600 sub-modules
25 mm diameter ice ball
23 m/s velocity
18 to 20 impacts each

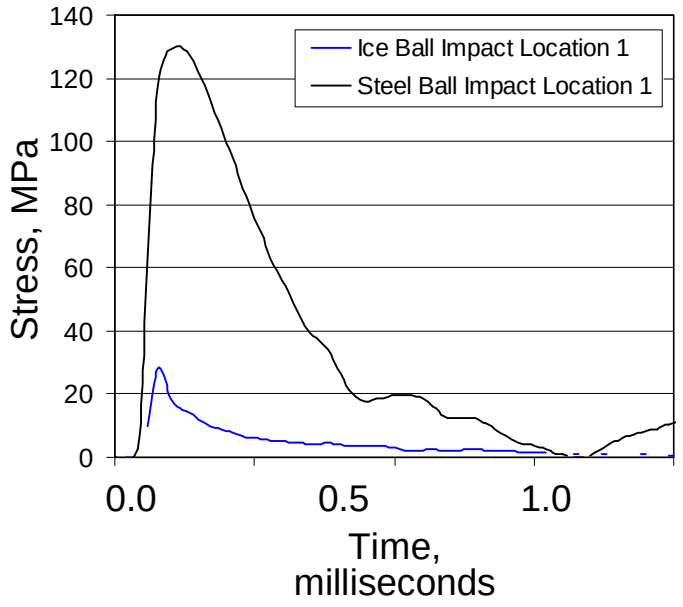
Thin glass
5 thicknesses 0.7 to 3.2 mm
400 grit bullnose edges

Ice ball generates lower stresses than steel ball at equivalent impact energy

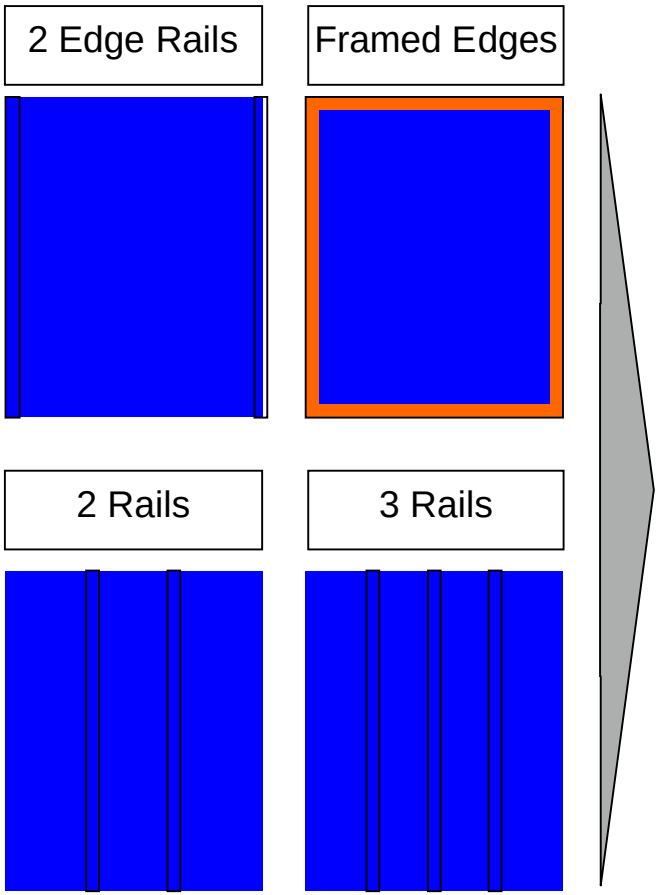


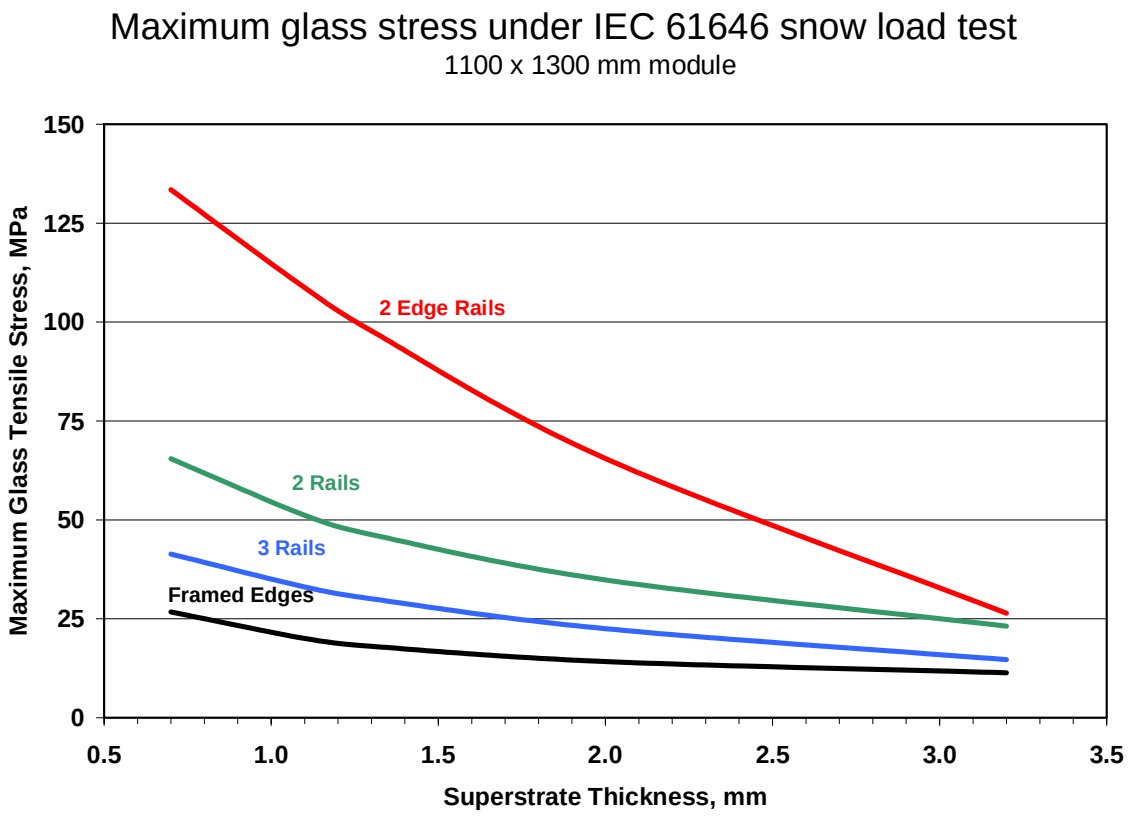






Modeling of mounting configurations indicate that mounting is more important than glass thickness

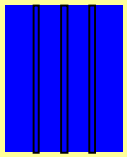
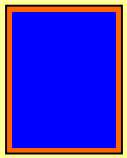
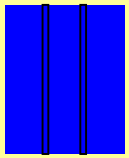
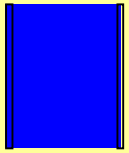




Model predicts thin specialty glass to pass heavy snow load test

Model results of IEC 61646 wind and snow load test

1100 x 1300 mm module

Support Configuration	Glass thickness (mm) 0.7	1.1	1.3	1.5	3.2
3 Rails 	●	●	●	●	●
Framed edge 	●	●	●	●	●
2 rails 	●	●	●	●	●
2 edge rails 	●	●	●	●	●

In summary, thin specialty glass is reliable and recommended for thin-film PV applications

- Glass strength is determined by surface imperfections and fatigue over time
- Not all glasses are created equal. Glass composition affects long term strength
- Thin specialty glass withstands severe testing
  - Ice ball impact
  - Heavy snow loads
- Wind and snow load stresses depend primarily on mounting design
  - Optimal and more cost efficient mounting configuration must be considered