CORNING

Photovoltaic Glass Technologies

Physical Properties of Glass and the Requirements for Photovoltaic Modules

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Corning has a long history of life-changing innovations

Glass envelope for Thomas Edison's light bulb

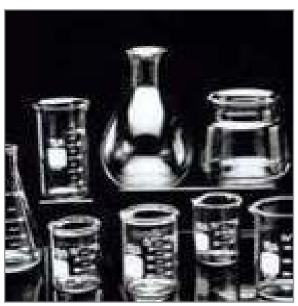
Dow Corning silicones

Glass ceramics

Specialty glass for NASA space missions

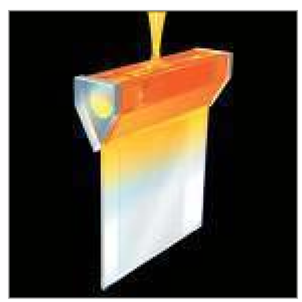
Ceramic substrates for automotive catalytic converters

1879 **1915** **1934** **1947** **1952** **1960** **1970** **1972** **1984** **2006**



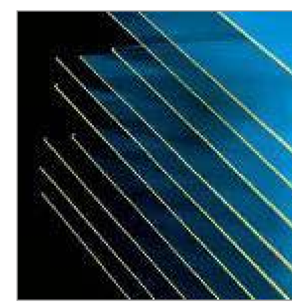
Heat-resistant Pyrex® glass

Processes for mass producing the television bulb



Fusion draw process

First low-loss optical fiber



AMLCD glass for TVs, notebook computers & monitors

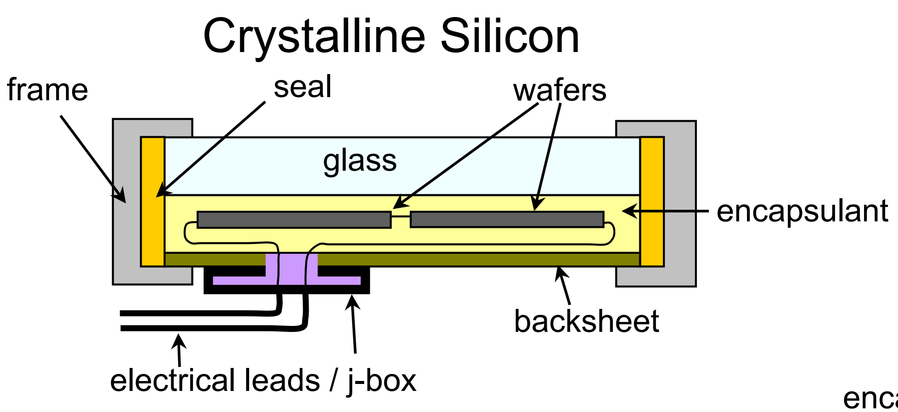
Why is glass attractive for PV?

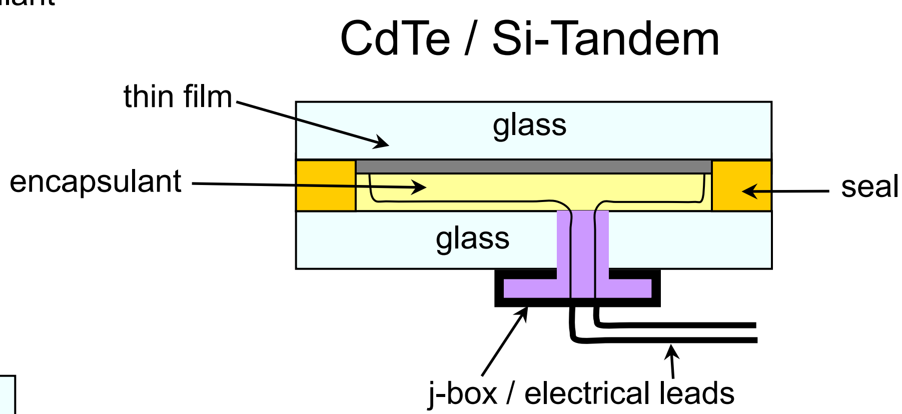
- Transparent
- Hermetic
- Durable
- Acceptable Strength
- Low Cost

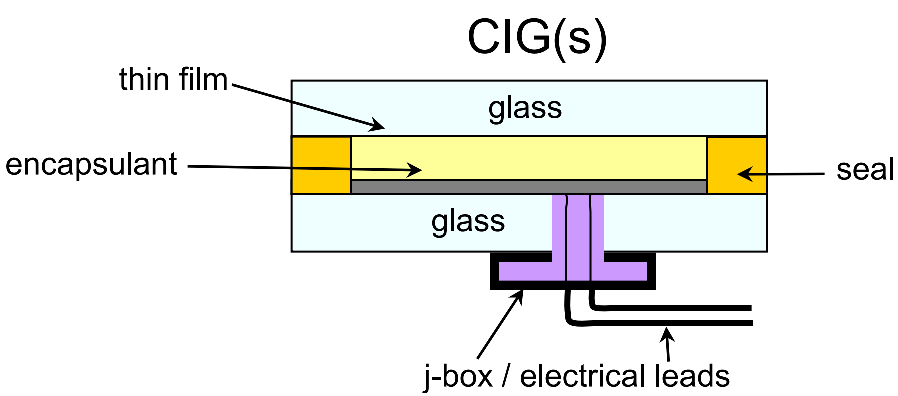
PV Module Requirements – where does glass fit in?

	Efficiency	Reliability	Weight
c-Si	✓	✓	✓
CdTe	✓	✓	✓
Si-Tandem	✓	✓	✓
CIGS	✓	✓	✓

Glass configurations for PV modules

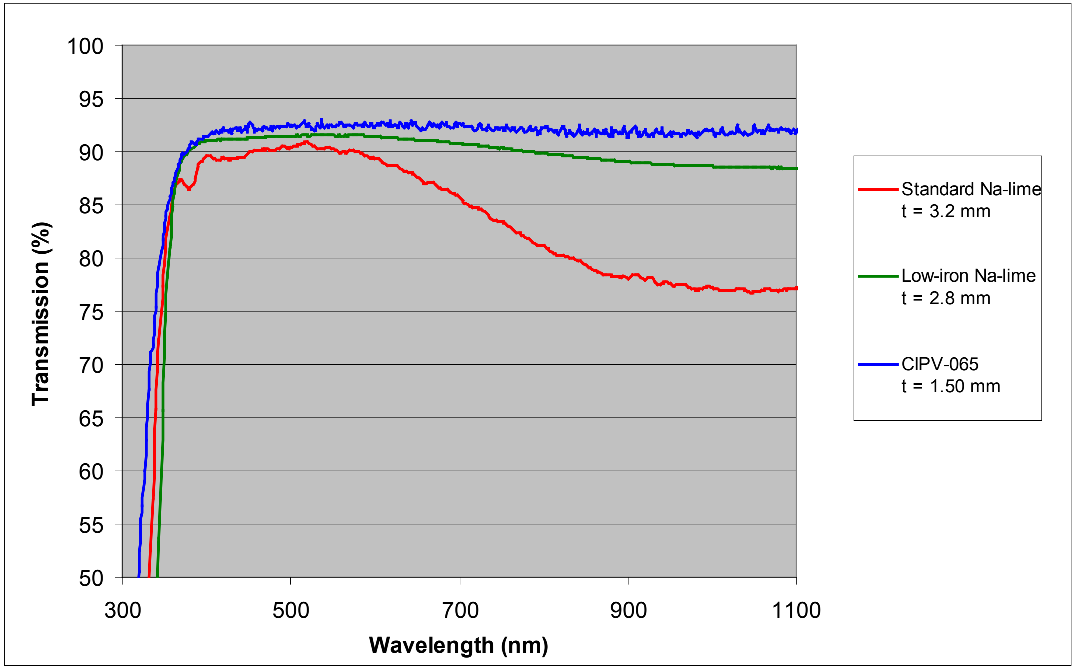






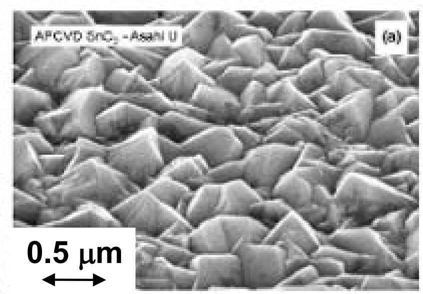
Glass can increase conversion efficiency

- Higher transmission
  - c-Si and thin film technologies
  - low-Fe and specialty glasses
- Enhanced light trapping
  - c-Si and thin film technologies
  - particularly Si-tandem

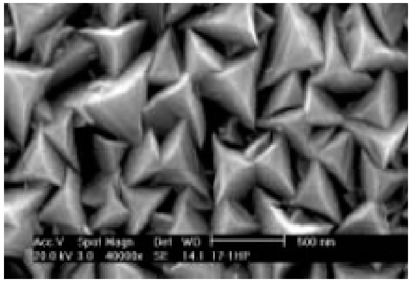


Light trapping demonstrated with TCO's for Si-Tandem

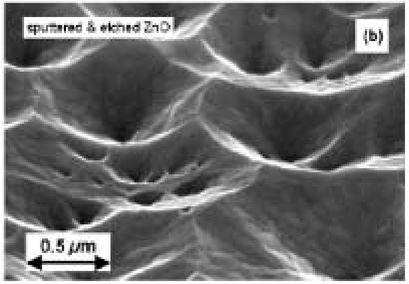
Similar opportunities for glass



SnO$_2$:F
Asahi, NSG, Guardian



ZnO:B
Oerlikon



ZnO:Al
Applied Materials

The highest efficiency CdTe cells have been produced on Corning's specialty glass

Organization & *Author*	Glass	Cell Efficiency	Author's Hypothesis
NREL *X. Wu*	Corning 7059	16.7%	• High temp • Cd stannate TCO
University of South Florida *C. Ferekides*	Corning 7059	15.8%	• High temp • Thin Cd Sulfide
University of Toledo *A. Compaan*	Corning 1737	14.0%	• Lack of impurities

Mechanical reliability assessment is composed of modeling, characterization, and testing

Modeling

Module size and support configurations

Stress analysis

Characterization

Surface and edge strength

Fatigue

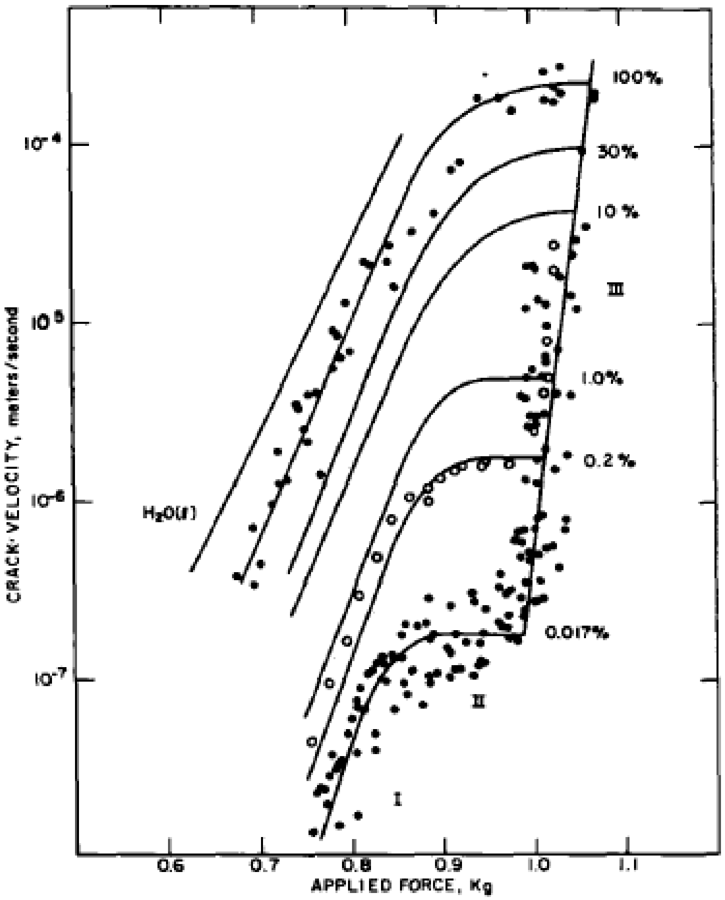
Testing

Snow load / hail testing

Wind load testing

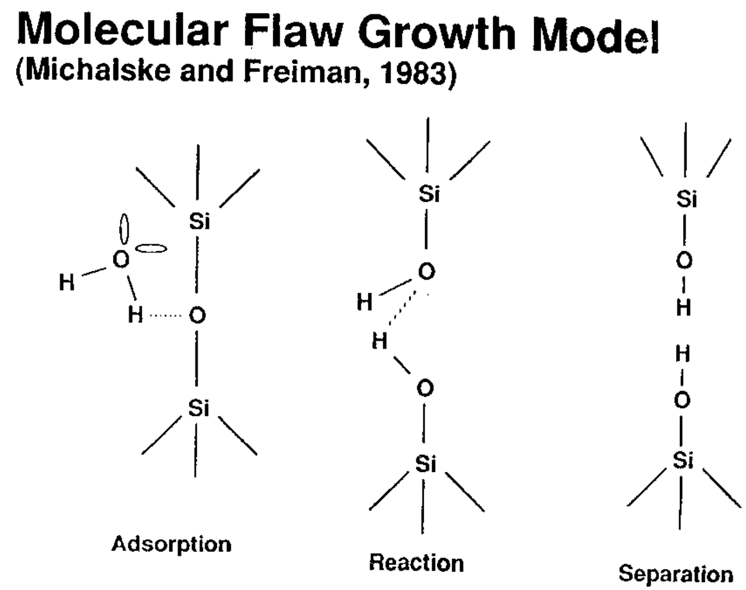
Reliability assessment
- Reliability requirement
- Calculated reliability

Glass fatigue – moisture effect on crack growth



S.M. Weiderhorn
"Influence of Water Vapor on Crack Propagation in Soda-Lime Glass"
J. Am.Ceram.Soc., Vol 50, No. 8, 407-414, 1967

SiO_2 + H_2O +Stress ⇨ Si $(OH)_4$



$$v = aK_I^n$$

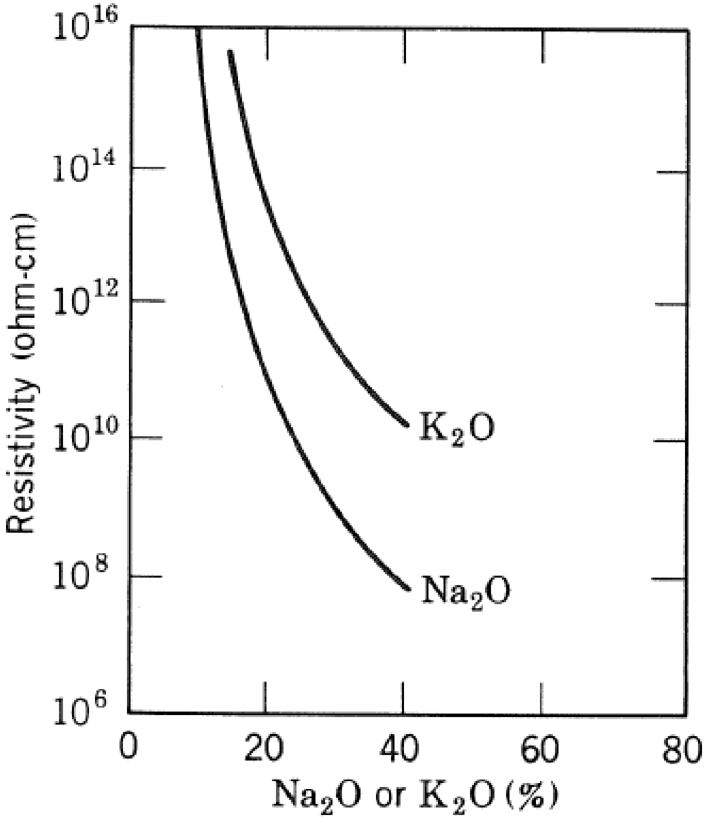
n = fatigue exponent

Increased fatigue exponent increases strength

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

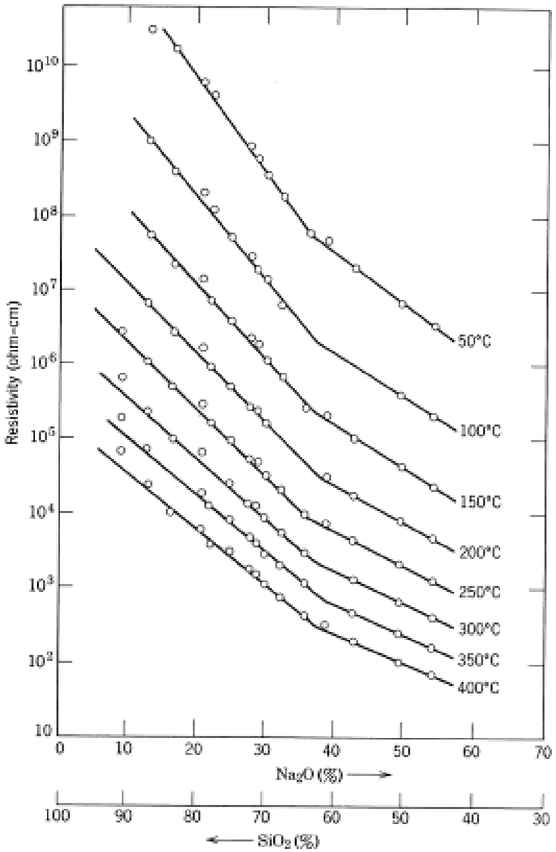
Specialty glass is ~50% stronger than soda lime

Glass resistivity decreases as alkali content increases



Resistivity of sodium and potassium-silicate glasses

Fulda M. (1927). *Sprechsaal*, **60**, 810.

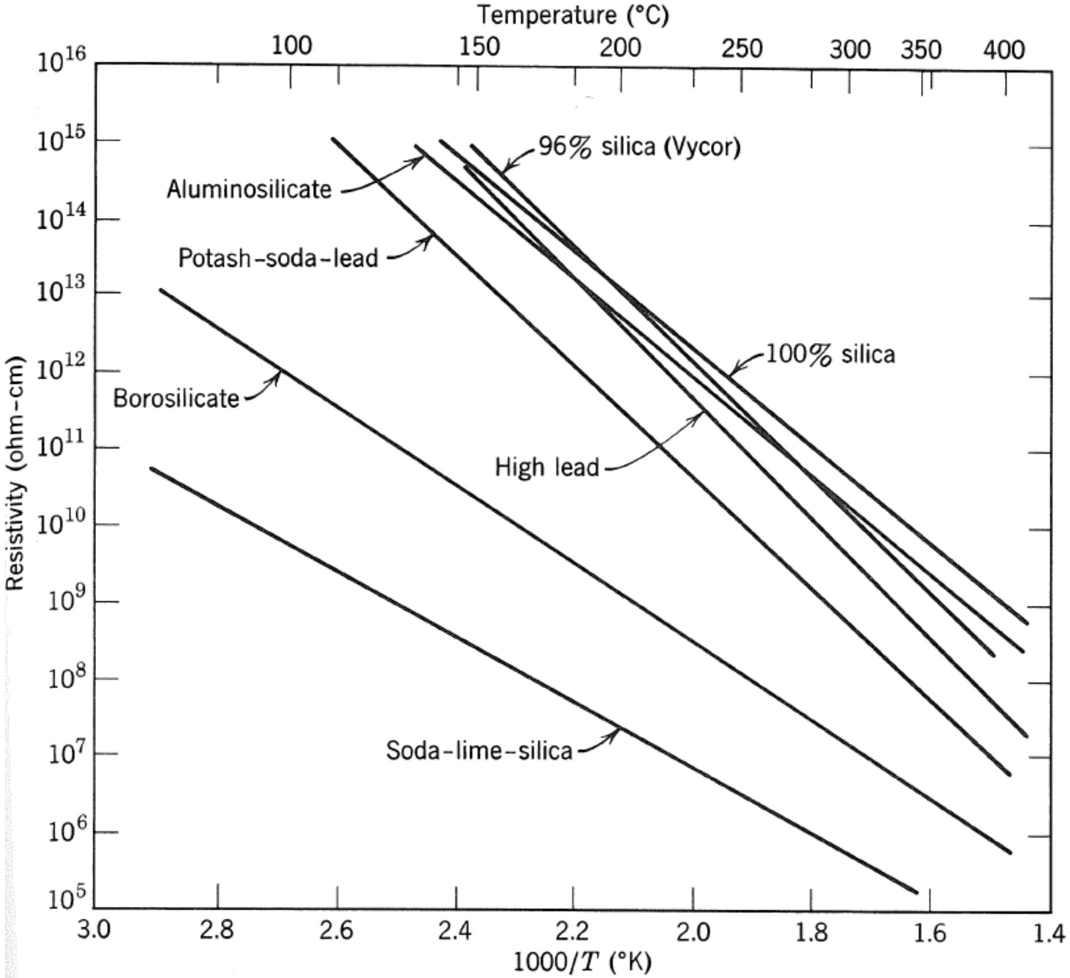


Resistivity of sodium-silicate glasses

Seddon E., Tippett E. J., Turner W. E. S. (1932). The Electrical Conductivity of Sodium Meta-silicate-Silica Glasses. *J. Soc. Glass Technol.*, **16**, 450.

Higher resistivity can improve electrical isolation performance

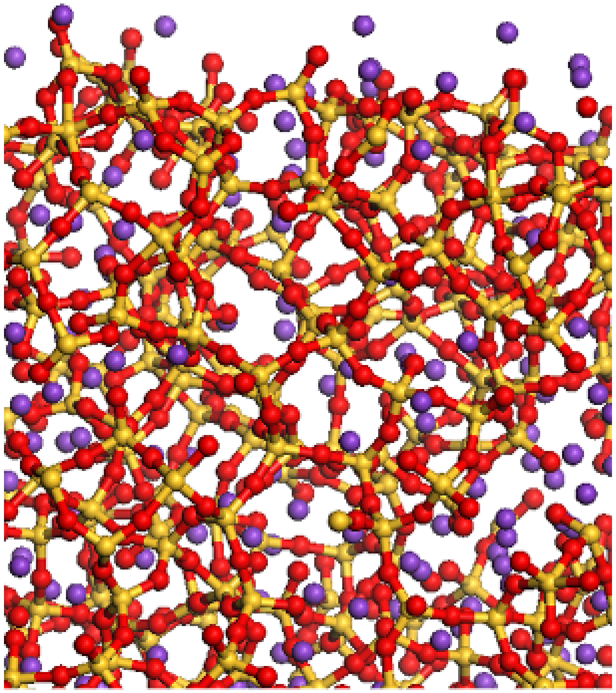
Specialty glasses can have resistivities up to 8 orders of magnitude higher than soda lime silica glasses



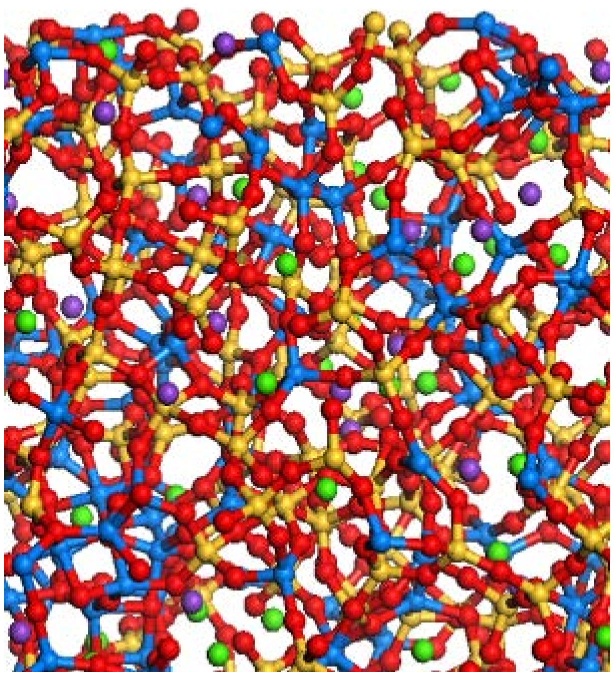
DC volume resistivity of commercial glasses

Kingery, Bowen, Uhlman (1976) *Introduction to Ceramics (2nd Ed.)*, p. 885, John Wiley & Sons

Glass structure modifications can improve durability



Multi-component silicate glass with non-bridging oxygens

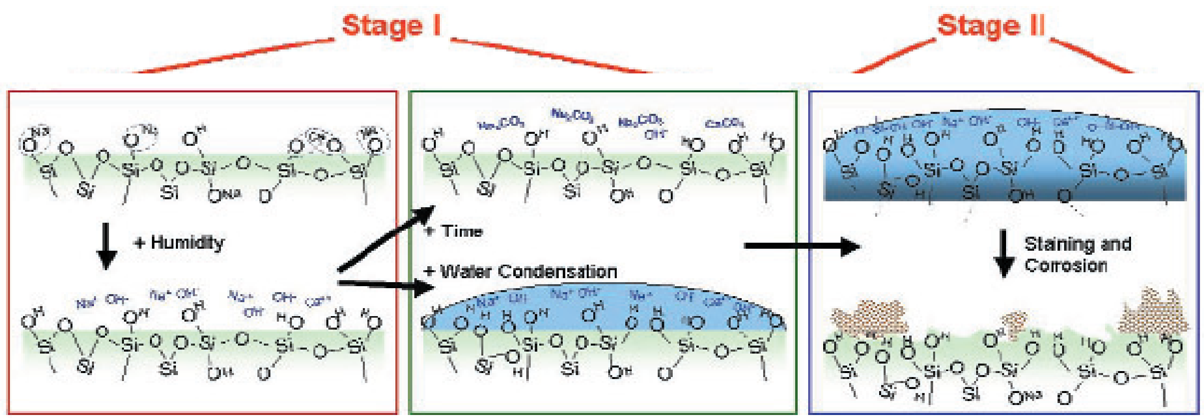


Fully polymerized multi-component silicate glass without non-bridging oxygens

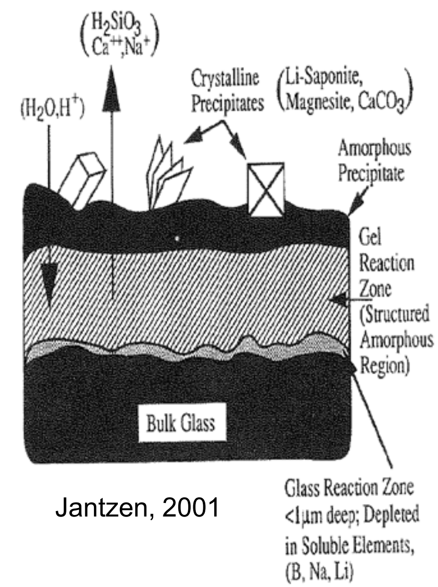
Leed, E. A. and Pantano C.G. (2003). Computer Modeling of Water Adsorption on Silica and Silicate Glass Fracture Surfaces, *J. Non-Cryst. Sol.*, **48**, 325.

Elimination of non-bridging oxygens closes glass structure, significantly slows alkali and alkaline-earth migration, and improves chemical durability

Mechanisms of glass corrosion



R. A. Schaut, Pantano C.G., The Glass Researcher (2005)



Jantzen, 2001

- Weathering of float glass can be categorized into two stages:
  - "Stage I": Ion-exchange (leaching) of mobile alkali and alkaline-earth cations with H^+/H_3O^+, formation of silica-rich surface layer, pH rise in liquid film, and formation of soluble precipitates

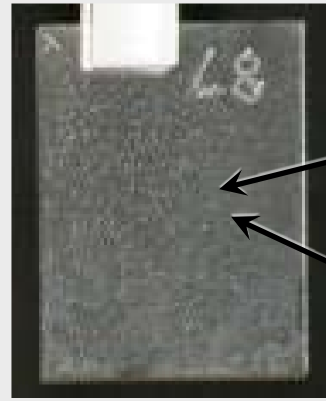
$$\equiv SiO^- R^+ + H_2O \rightarrow \equiv SiOH + R^+OH^-$$

  - "Stage II": Dissolution of silica-rich glass network at pH >9 with degradation of surface and formation of insoluble precipitates (permanent staining)

$$\equiv M\text{-}O\text{-}M\equiv + H_2O \leftrightarrow \equiv M\text{-}OH + HO\text{-}M\equiv$$

Weathering of glass – 30 days at 85°C / 85% r.h.

Soda-Lime-Silica



hazing crystalline precipitates

non-uniform surface chemistry

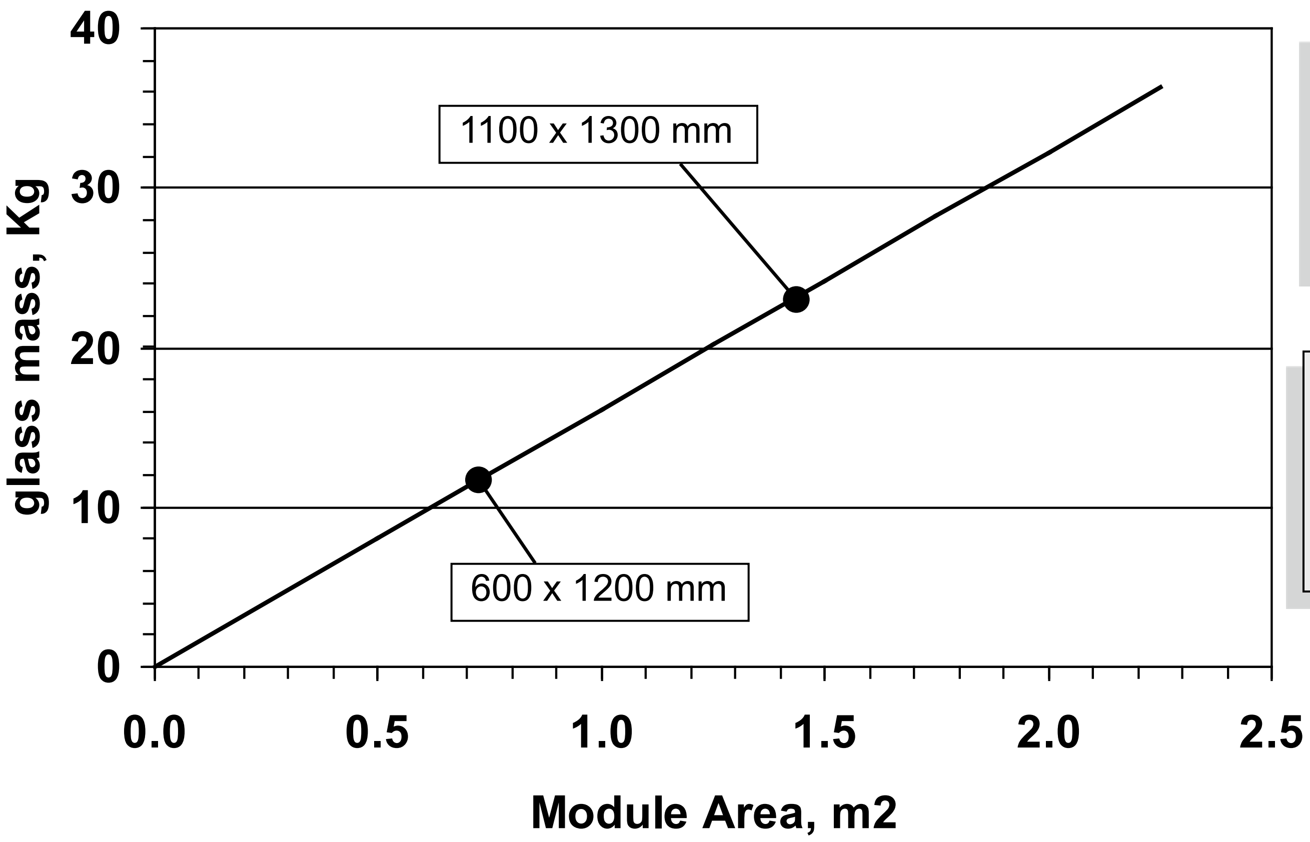
Specialty Glass

clear glass with little or no hazing

uniform surface chemistry

Specialty glasses corrode much less than soda-lime-silica
Corrosion may negatively impact long-term module performance in field

Module weight driven by module size glass mass



Assumes thin film module with 2 sheets of 3.2 mm soda lime glass

Density = 2.5 g/cc

Typical Glass Densities

2.2 g/cc – Fused Silica
2.5 g/cc – SLG
3.1 g/cc – Lead Crystal

Thin glass and glass density can decrease module weight

In summary, glass has an important role in module performance and reliability

- Glass can:
  - increase module efficiency
  - improve mechanical reliability
  - improve electrical isolation performance
  - improve module durability
  - decrease module weight

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