Materials used as Greenhouse covers

Part I Rigid materials

- Glass
- plastic sheets

Aus: Reisinger & Max 2011

Bild: Max, 2013

Glass

…was the first and for long time the only greenhouse covering material

… is the most common greenhouse covering material in central and norther Europe until today

Glass

Etymology:
The word “glass” origins from the old Germanic term “glasa” (glossy, shiny, shimmering)

Glass is an
inert
non-conductive
inorganic
amorphous
(non-crystalline)
material

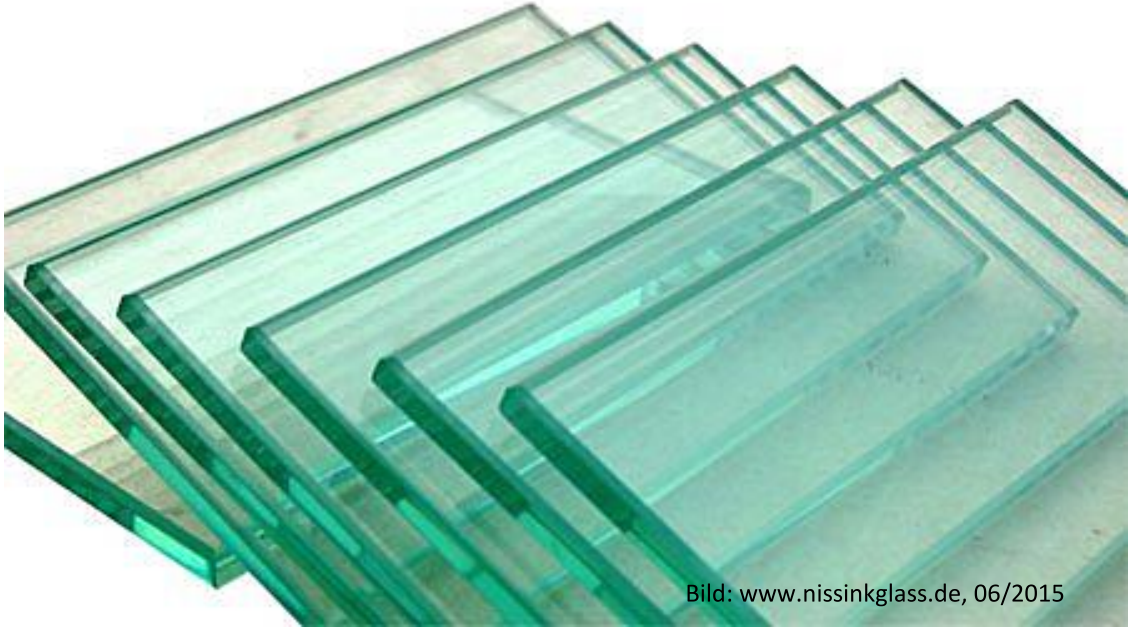


Bild: www.nissinkglass.de, 06/2015

Glass ingredients

The major fundamental constituent of glass is Silica (SiO_2)

glass made from chemically-pure Silica (Quartz sand) would have a very high melting temperature (1723 °C) and thus be very difficult to process

To lower the glass transition temperature sodium carbonate (Na_2CO_3, "soda") is added, resulting in an unwanted increased water-solubility

To again increase the chemical durability lime (calcium oxide CaO, usually obtained from limestone), magnesium oxide (MgO) and aluminum oxide (Al_2O_3) are added

Hence, the resulting glass type is referred to as soda-lime-glass

Today, 95 % of all commercially produced glasses Glass are soda-lime-glasses, also simply referred to as “window glass”

Average composition of soda-lime-glasses (%)

SiO_2	69–74
Na_2O	12–16
CaO	5–12
MgO	0–5
Al_2O_3	0–3

Glass

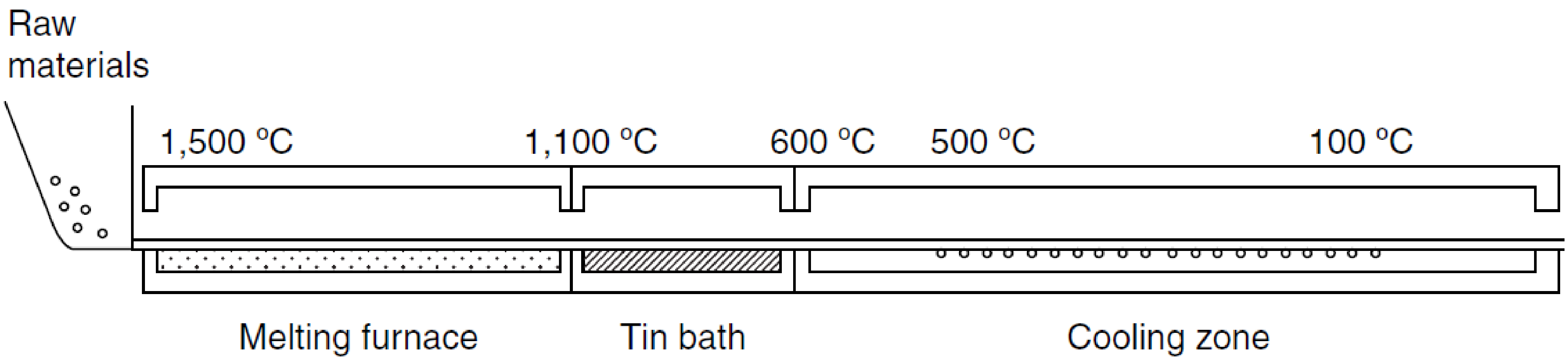
is normally produced by smelting processes

Today commercial flat glass production is dominated by two processes

Float glass process

Cast glass process

The float glass process




www.siemens.de, 09/2018


www.scinexx.de, 09/2018


www.morningglass.co.uk, 09/2018

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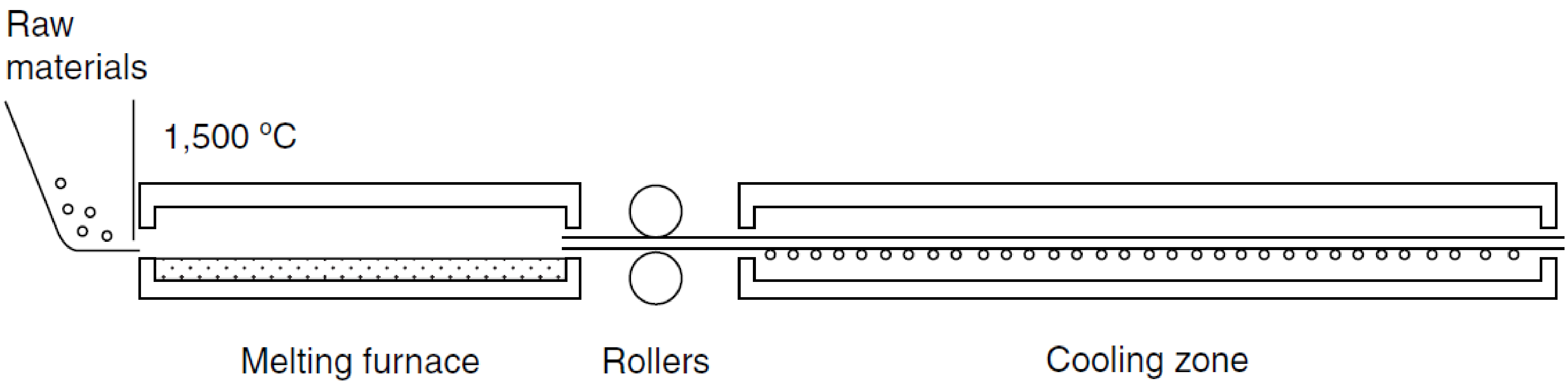
The cast glass process



After the forming of the glass it is cooled

Cooling is done fast, to prevent crystallization

Glass, therefore can be **defined** as
an "inorganic molten product,
essentially solidifying without crystallization" (DIN 2001)
Or
"a frozen super-cooled liquid" (Haase 1956)

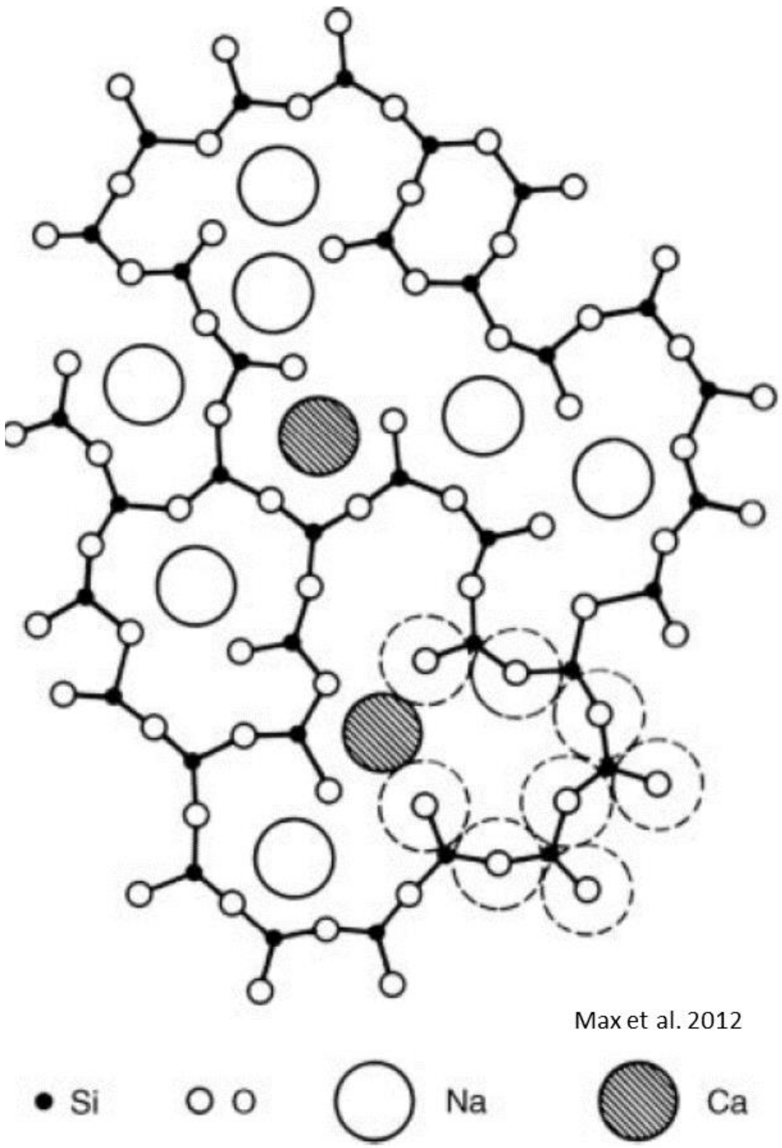
Due to the rapid cooling of the melt only crystal nuclei are formed since there is not enough time for a complete crystallization

Glass

density: ca. 2,5 g cm^{-3}

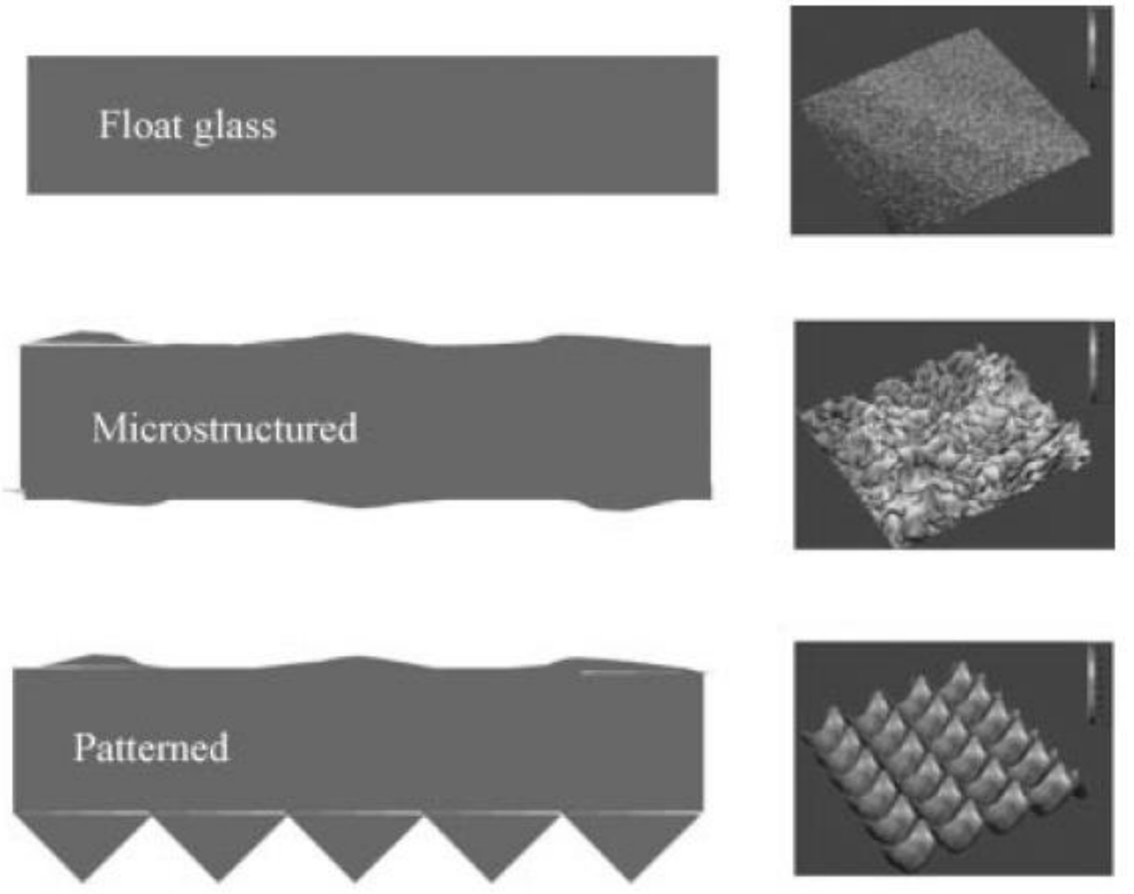
Hence, the result is an amorphous structure, due to which glass differs distinctly from crystalline materials

The glass structure can be described as a
three-dimensional %
amorphous network
of interconnected SiO_4 tetrahedra irregularly interrupted by the other elements contained,
that is, Na, Ca, and Mg and without a long-range order

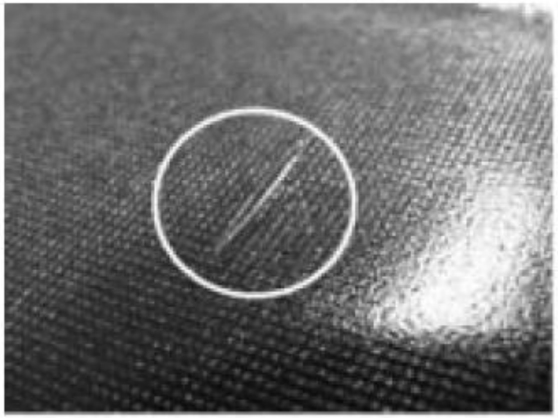


Max et al. 2012

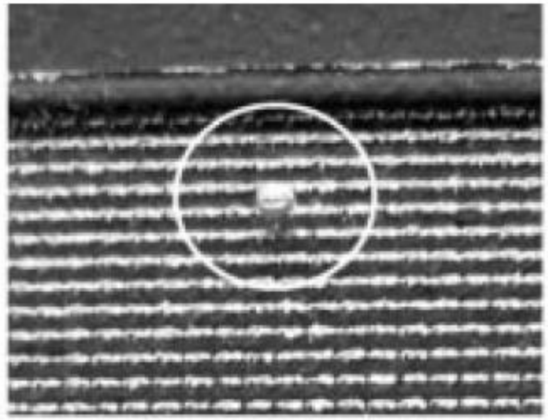
surface structure of Glass in dependence of the manufacturing process



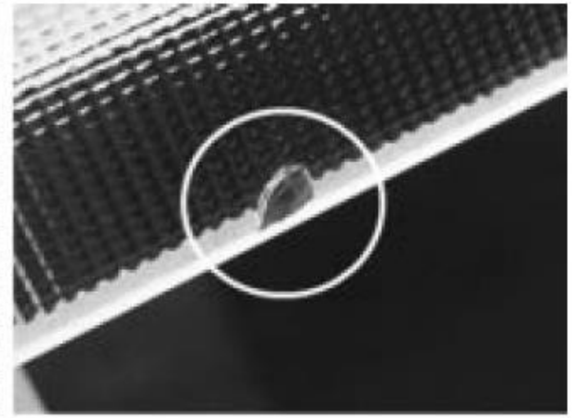
Aus: Max et al. 2012



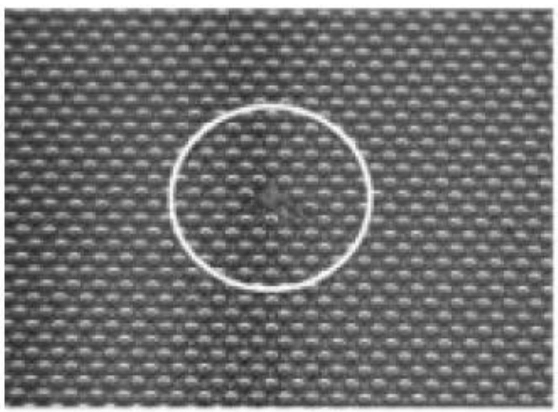
Bubbles longitudinal



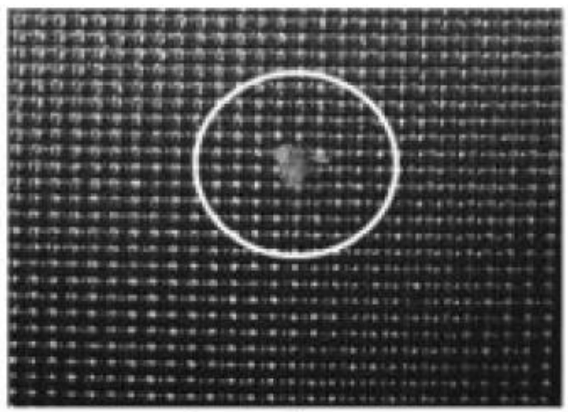
Bubbles spherical



Edge shells, chips



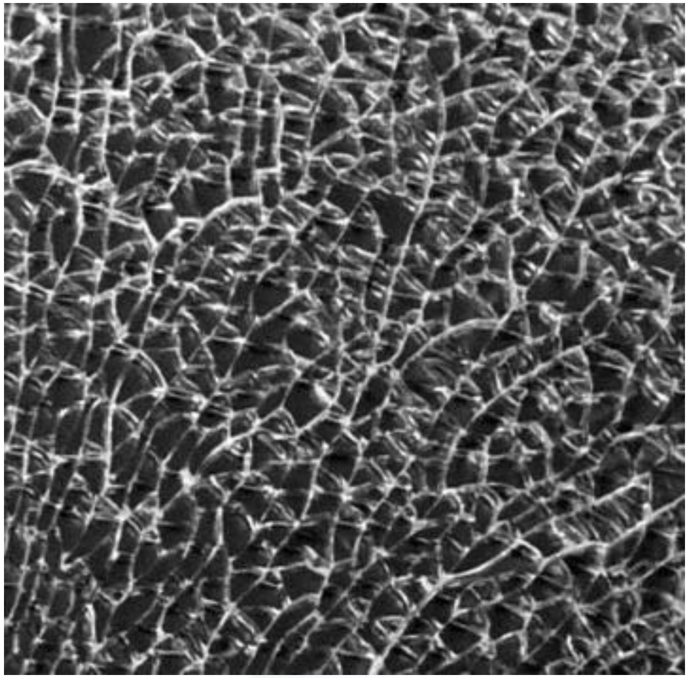
Structure failures



Inclusions

Common glass faults. (Photos: T. Hofmann).

A common treatment to increase the stability of glass is thermal hardening: By heating beyond the softening point (>590 °C) and subsequent rapid cooling by means of cold air (quenching) a "residual stress state" is generated: The surface of the glass pane cools down faster than the inner parts. While the glass surface has solidified already, the inner bulk is still contracting. The surface of the resulting glass product is under compressive stress; its inner parts are under tensile stress. Glass produced in that way is referred to as "thermally toughened safety glass."



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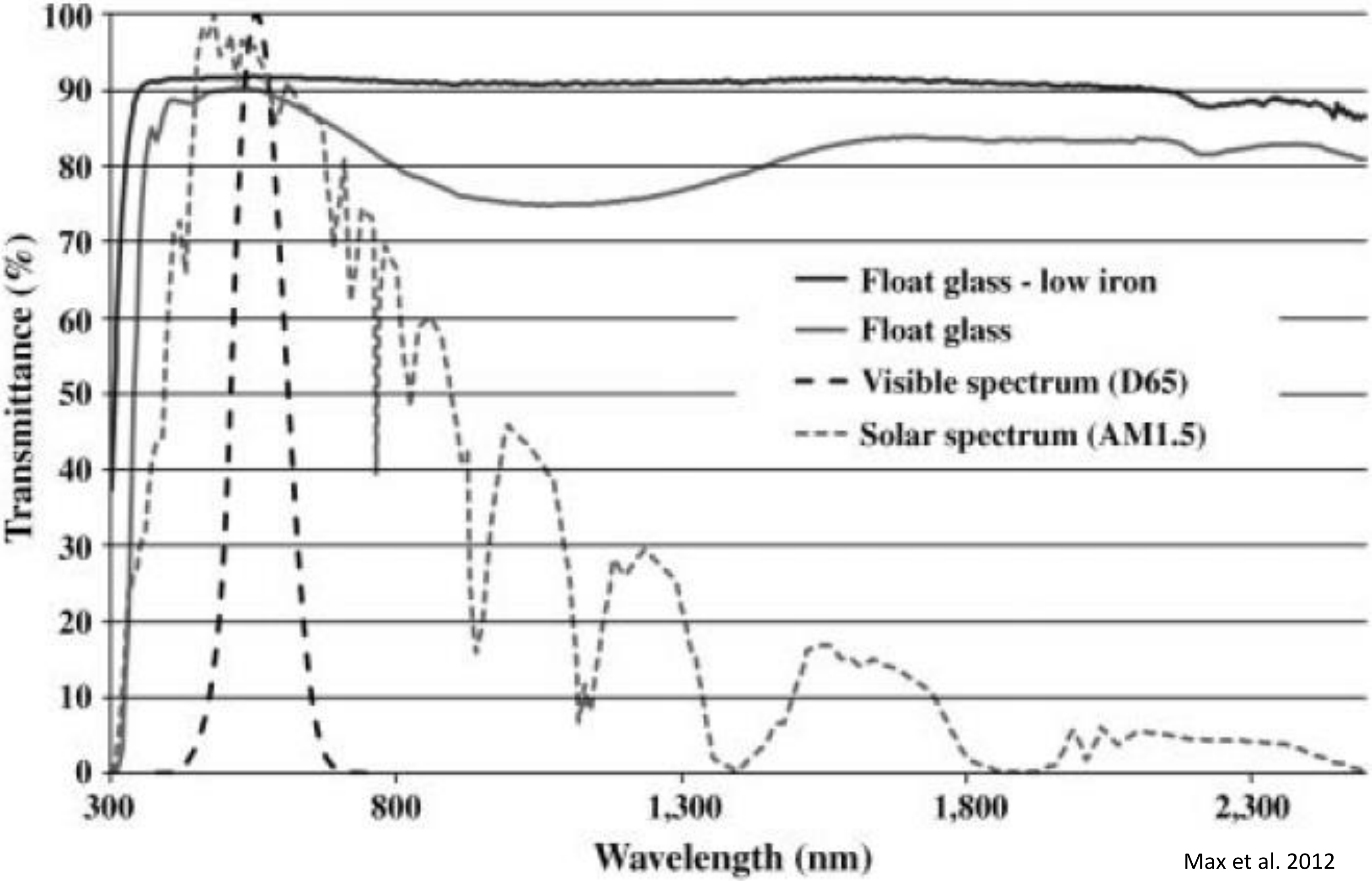
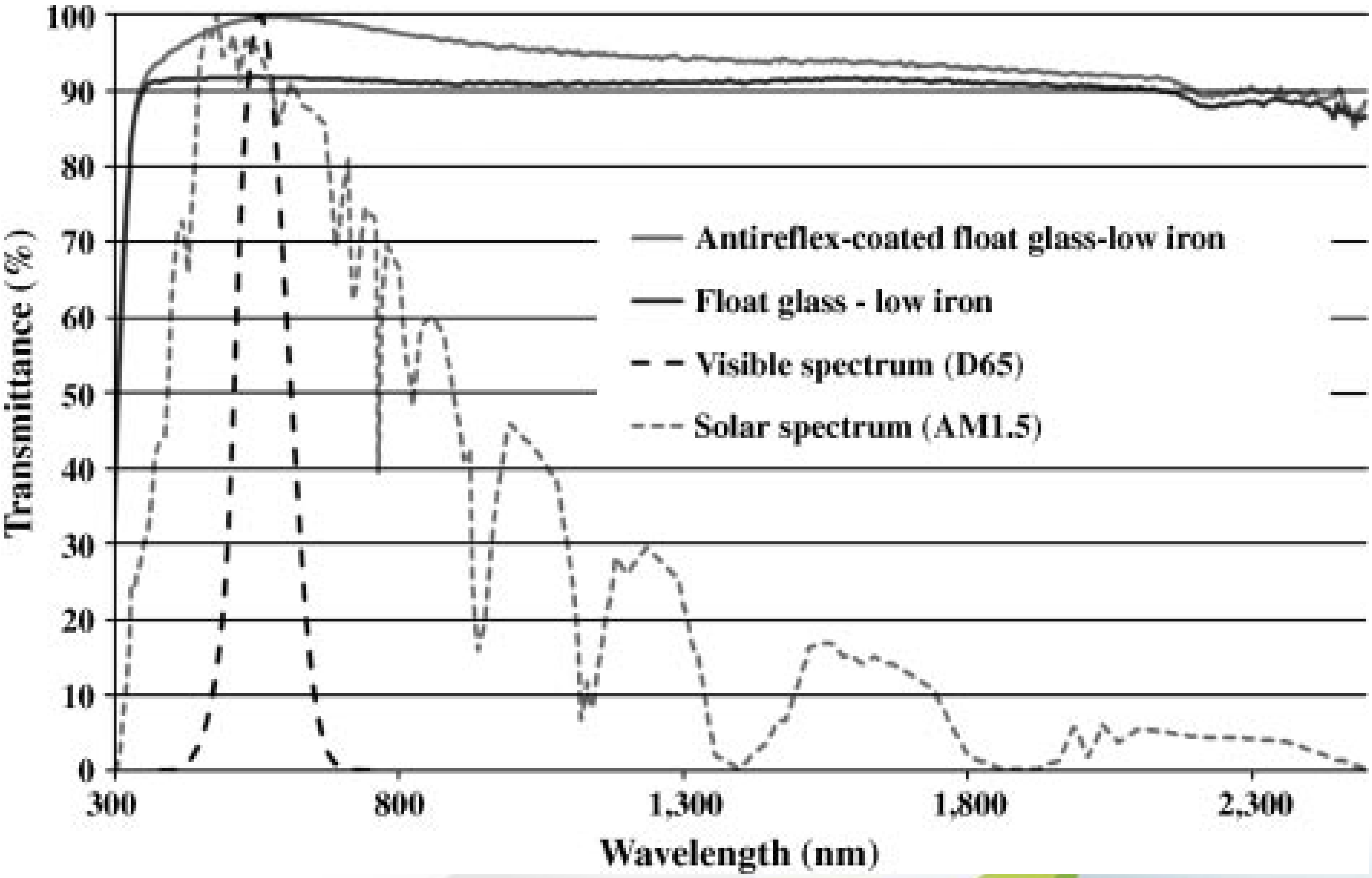
UV-transmission of glass depends on the Iron- (Fe-) content: Standard-Floatglas: ca. 0,3 % Fe / low Iron Floatglas: < 0,01% Fe



Max et al. 2012

And might be further increased by anti-reflection coatings



Perpendicular transmittance (%) of different glass types in different spectral ranges.

	Spectral range (nm)						
	Vis	Vis, dif	PAR	UV	UV-A	UV-B	TSR
Glass type	380–780	380–780	400–700	280–400	315–400	280–315	300–2,500
Float glass	89.8	–	89.1	70.2	72.1	3.5	84.7
Float glass, low iron	91.7	0.3	91.6	88.1	88.4	63.7	91.1
Micro-structured glass, low iron	91.7	2.3	91.8	87.8	88.1	60.1	91.6
Patterned glass, low iron	91.9	68.7	91.6	86.3	86.7	58.2	91.6

further important Characteristics of Glass:
density: ca. 2,5 g cm^{-3}
service life: theoretically unlimited
Aging: none
Decrease of Light Transmittance: none
Condensation behaviour: Film wise
Not inflammable

Through anti-reflexion (AR-) coatings, light transmission of low iron glasses are increased to nearly 99 %
Low-Emissivity (low-E) coatings reduce the transmissivity for long-wave (thermal radiation) and thus increase insulation capacity

Price:
Standard-float glass: ca. 5 € m^{-2}
low iron float glass AR-coated (“solar glass”): ca. 15,5 € m^{-2}

Other **rigid materials** used as greenhouse covers

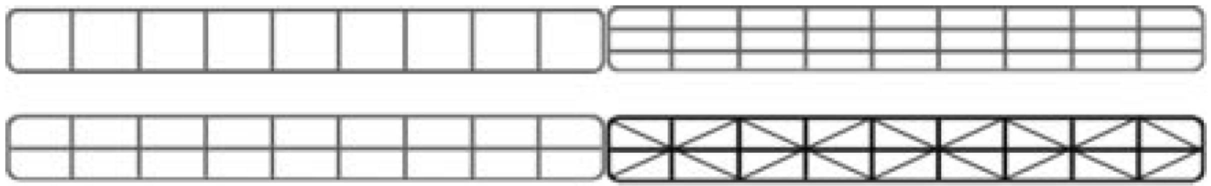
The use of rigid plastic sheets to cover greenhouses is much less Wide-spread then glass of plastic film

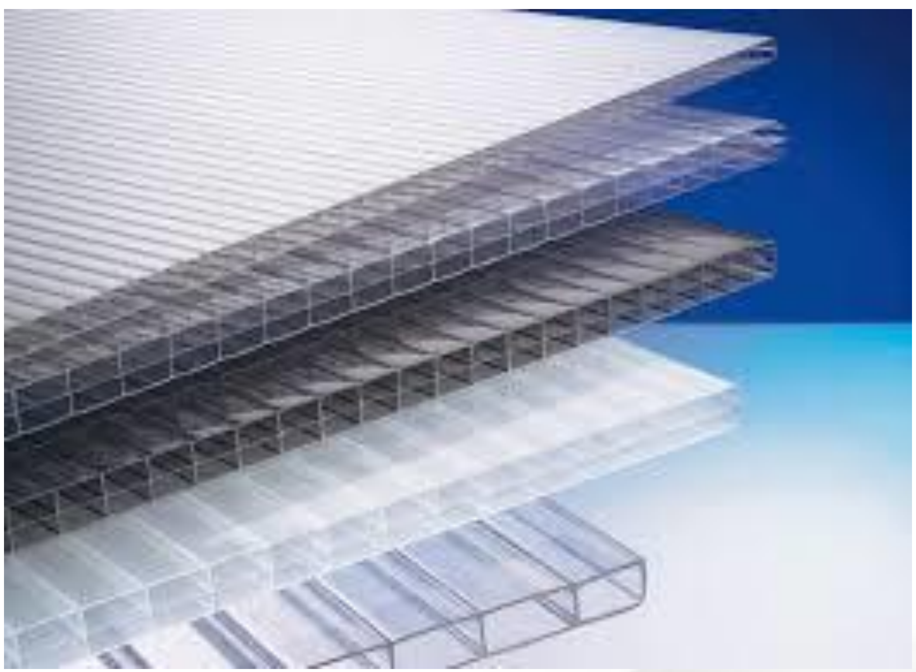
The most common basic materials used for rigid plastic greenhouse glazing elements are

- **Poly(methyl methacrylate) (PMMA)**
- **Polycarbonates (PC)**
- **Polyvinyl chloride (PVC)**
- **and (glass) fibre reinforced plastics ([G]RP, FRP)**

(rarely also PE (Polyethylene) and PP (polypropylene) can be found)

most commonly rigid plastic greenhouse glazing elements are deployed as corrugated sheets or as sheets with a double-, triple-, or multilayer cross-section, referred to as twin- (multiple-) wall sheets or cellular sheets





Poly(methyl methacrylate) (PMMA)

commonly referred to as acrylic glass, Plexiglas, or Perspex
synthetic, thermoplastic material with a visual appearance resembling that of glass
(thermoplastics are plastics that can be reversibly remelted and remolded in a certain temperature range).PMMA

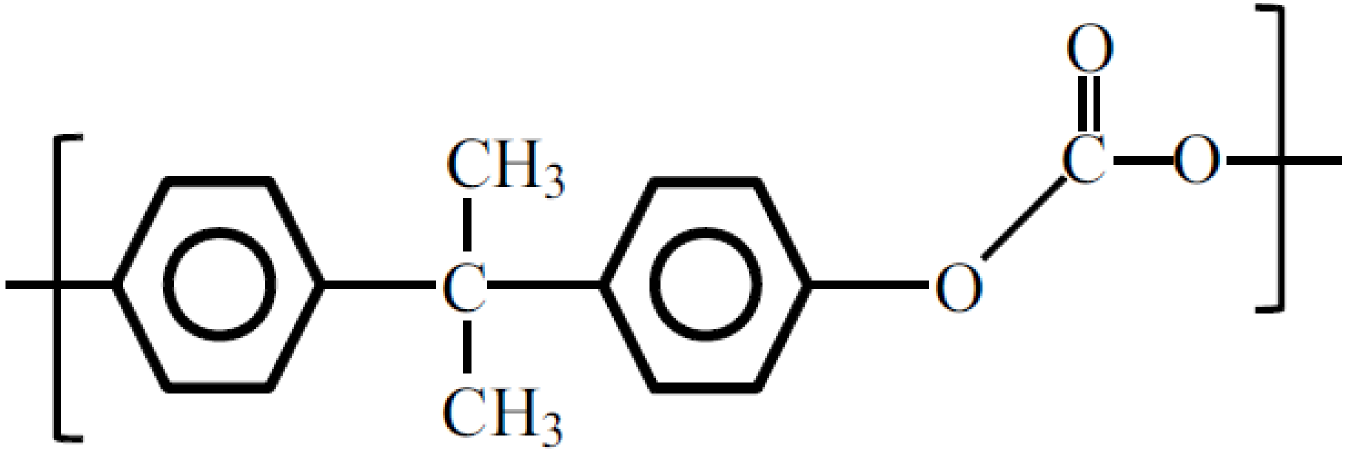
molecular formula: [$C_5H_8O_2$]n)

formed by polymerization of the monomeric methyl methacrylate.

Polycarbonates (PC)

group of synthetic thermoplastic polymers that belong to the polyester family

Generally PCs are linear polyesters of carboxylic acids and bivalent alcohols



Poly vinyl chloride (PVC)

primarily amorphous (crystallinity around 5%) thermoplastic material, produced by radical or ionic polymerization of the monomeric vinyl chloride (H_2C-CHCl)

molecular formula C_2H_3Cl

Glass fiber reinforced plastics (GRP, FRP, commonly sometimes referred to as fiber glass) are fiber-plastic-composites consisting of a plastic component and glass fibers. For greenhouse covering purposes, the most commonly used basic materials are thermosetting plastics
(also known as thermosets or duroplastics), for example, polyester resins or epoxy resins.

A major disadvantage of rigid plastic sheets is the shorter service life as compared to glass
Main reason for the degradation of polymers are Reductions in molecular sizes and formation of functional groups such as carbonyls and hydroperoxides within the molecules
The scission of entanglements and tie chain molecules in semicrystalline polymers leads to drastic reductions in molecular sizes and subsequent reorganization into crystalline phases, thus an increase of crystallinity
These changes produce unwanted effects like brittleness, yellowing, surface deterioration, and decreasing light transmittance and are thus responsible for the reduction in service life entailing the necessity to replace plastic covers after a certain time. Temperature extremes and their duration can also weaken plastic materials.

Material/wall thickness	Configuration	UV (280–400 nm)	PAR (400–700 nm)	U-value ($W\,m^{-2}\,K^{-1}$)
PMMA				
3 mm	Single-wall, corrugated	1–90	90	6.6
16 mm	Twin-wall	1–83	82	2.5–2.8
16 mm	Twin-wall, 'Alltop'[z]	83	91	2.5
16 mm	3-Wall	1–70	76	2.4
32 mm	4-Wall	4	76	1.6
PVC				
1 mm	Single-wall, corrugated	0	90	6.8
6 mm[y]	Twin-wall	0	75–80	4.2–5.0
PC				
1 mm	Single-wall, corrugated	<3	90	6.8
6 mm[2]	Twin-wall	<3	82	3.6
6 mm	4-wall	<3	68	3.2
10 mm	Twin-wall	<3	73	3.2
10 mm	4-Wall	<3	68	2.5
16 mm	3-Wall	<3	70	2.4
16 mm	X-structured[x]	<3	60–70	1.8
32 mm	5-Wall	<3	60	1.4
GRP				
1 mm	Single-wall, corrugated	0–10	86	6.8
20 mm	Twin-wall	<3	74	2.4
50 mm	Twin-wall	<3	74	2.0
PE				
5 mm	Twin-wall	<3	70–75	4.0