Plastic Materials for Solar Energy Applications

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Business Areas of Evonik

Chemicals

- Focus: specialty chemicals
- A global leader
- 2007 sales: €10.8 billion
- Leading market positions in over 80% of sales
- Market-driven R&D and modern innovation management
- Over 100 production facilities in some 30 countries

Energy

- Focus: hard coal-fired power plants and renewable energies
- A technology leader in planning, building and operating power plants
- 2007 sales: €2.8 billion
- Grid-independent power producer with around 9,500 MW installed global capacity
- Strong position in the fields of biomass and geothermal energy in Germany

Real Estate

- Focus: residential property
- One of the largest private residential property companies in Germany
- Manages about 60,000 own residential units plus a 50% stake in THS with more than 75,000 units
- 2006 sales: €0.4 billion
- Active property owner with strong regional focus

Business Unit
Performance Polymers

Show Evonik's vertical integration

monomer – polymer (PLEXIGLAS and PA) -
sheet - coatings and structures - lamination

Evonik global capabilities

- acrylic plants in USA, Germany, Austria, China, Russia to support world-wide needs
- optical design
- sophisticated laboratories and testing capabilities
- polymer, sheet, structured sheet, coatings, lamination, co-extrusion, etc.

Issue for Competitive Solar Energy Production

Costs ↓ $\frac{€}{Wp}$

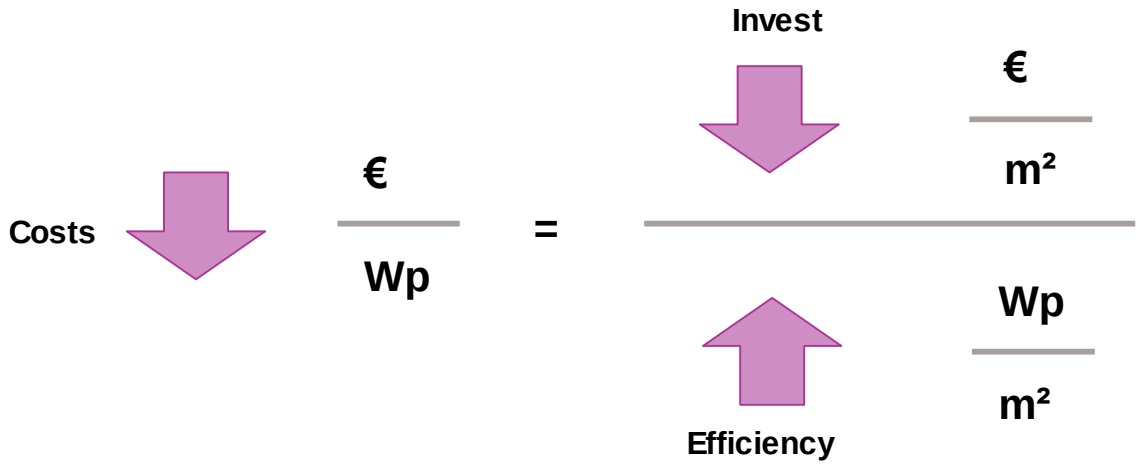
Source: MCI team, PH-FF

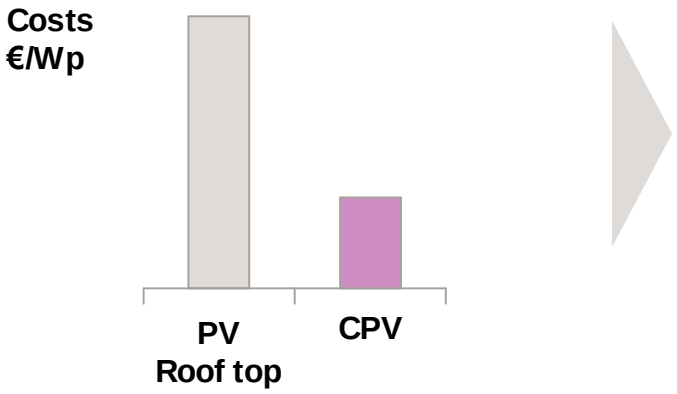
Issue for Competitive Solar Energy Production

$$\text{Costs} \downarrow \quad \frac{€}{Wp} \quad = \quad \frac{\text{Invest} \downarrow \; \frac{€}{m^2}}{\text{Efficiency} \uparrow \; \frac{Wp}{m^2}}$$

Source: MCI team, PH-FF

Issue for Competitive Solar Energy Production



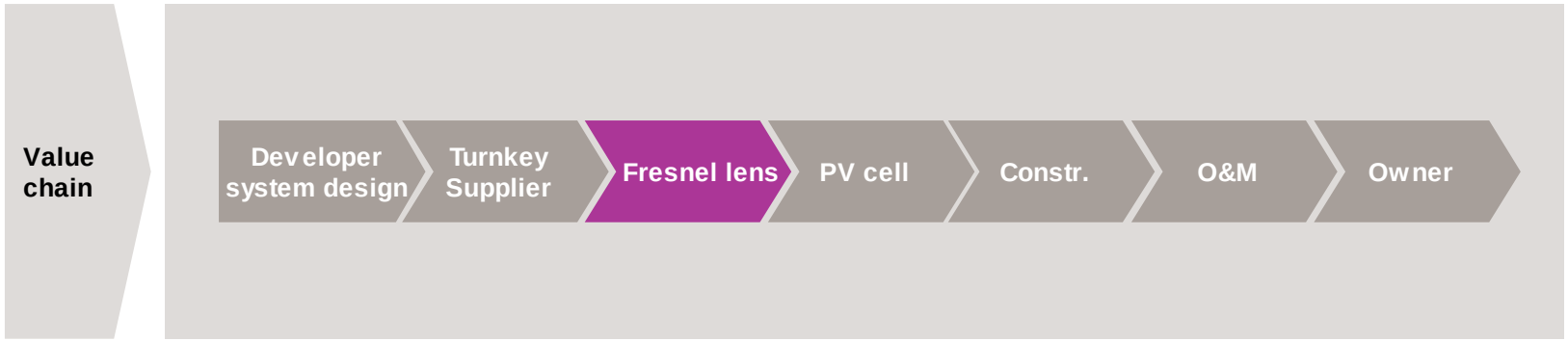


Forcast
for CPV
Grid parity in 2012

Source: MCI team, PH-FF

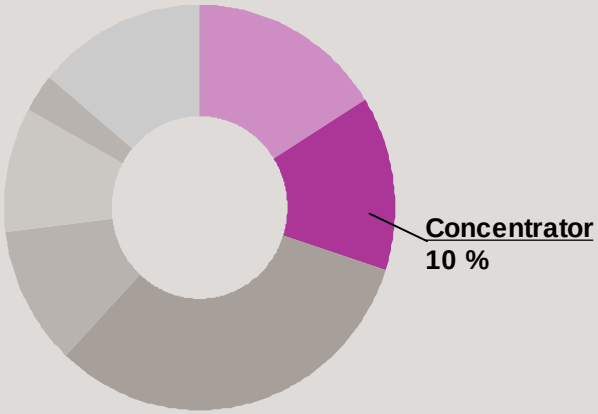
„Concentrating Photovoltaics employs inexpensive *optic elements* to concentrate sun light on a much smaller but highly efficient *solar cell*“ (CPV today)

CPV is Performance Driven



CPV is Performance Driven

Cost break down

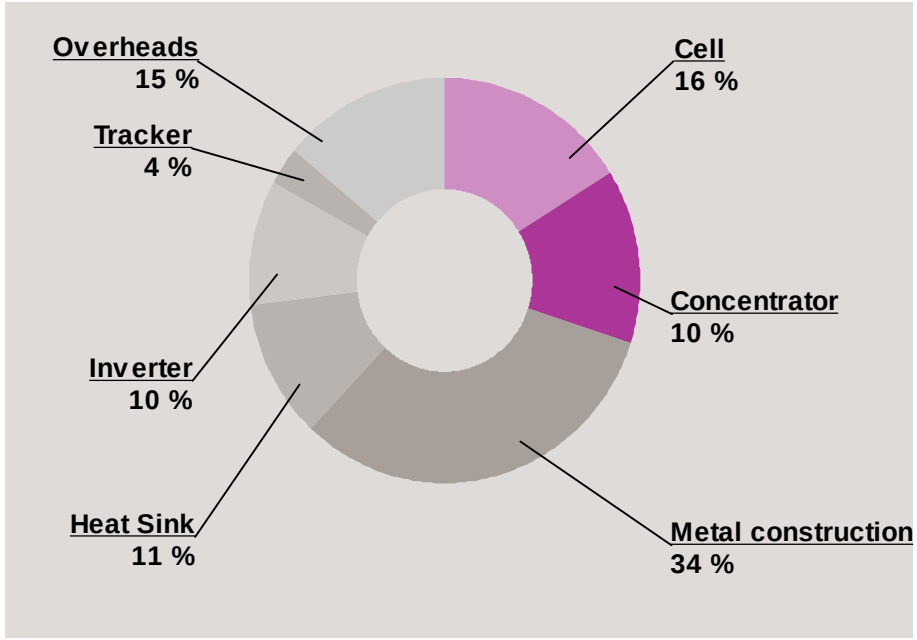


Value chain

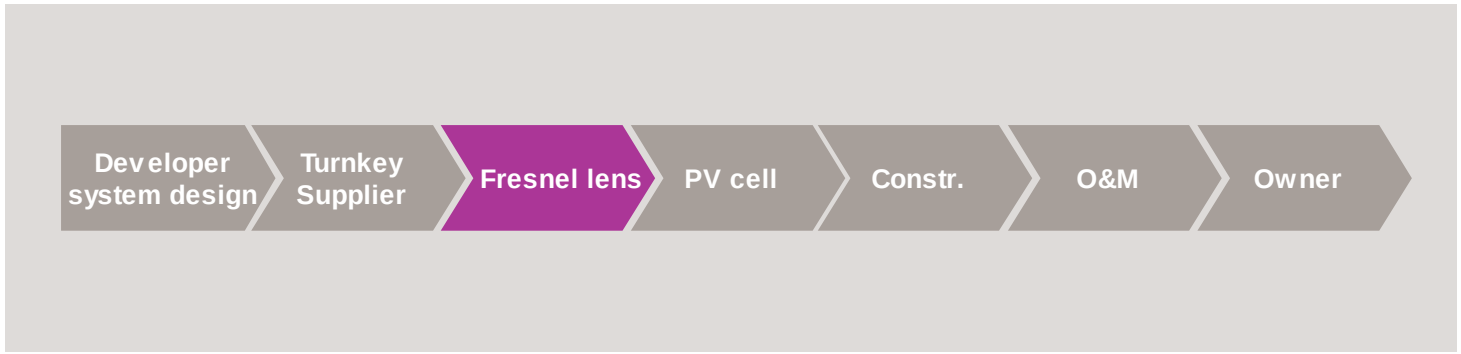
Developer system design → Turnkey Supplier → **Fresnel lens** → PV cell → Constr. → O&M → Owner

CPV is Performance Driven

Cost break down



Value chain

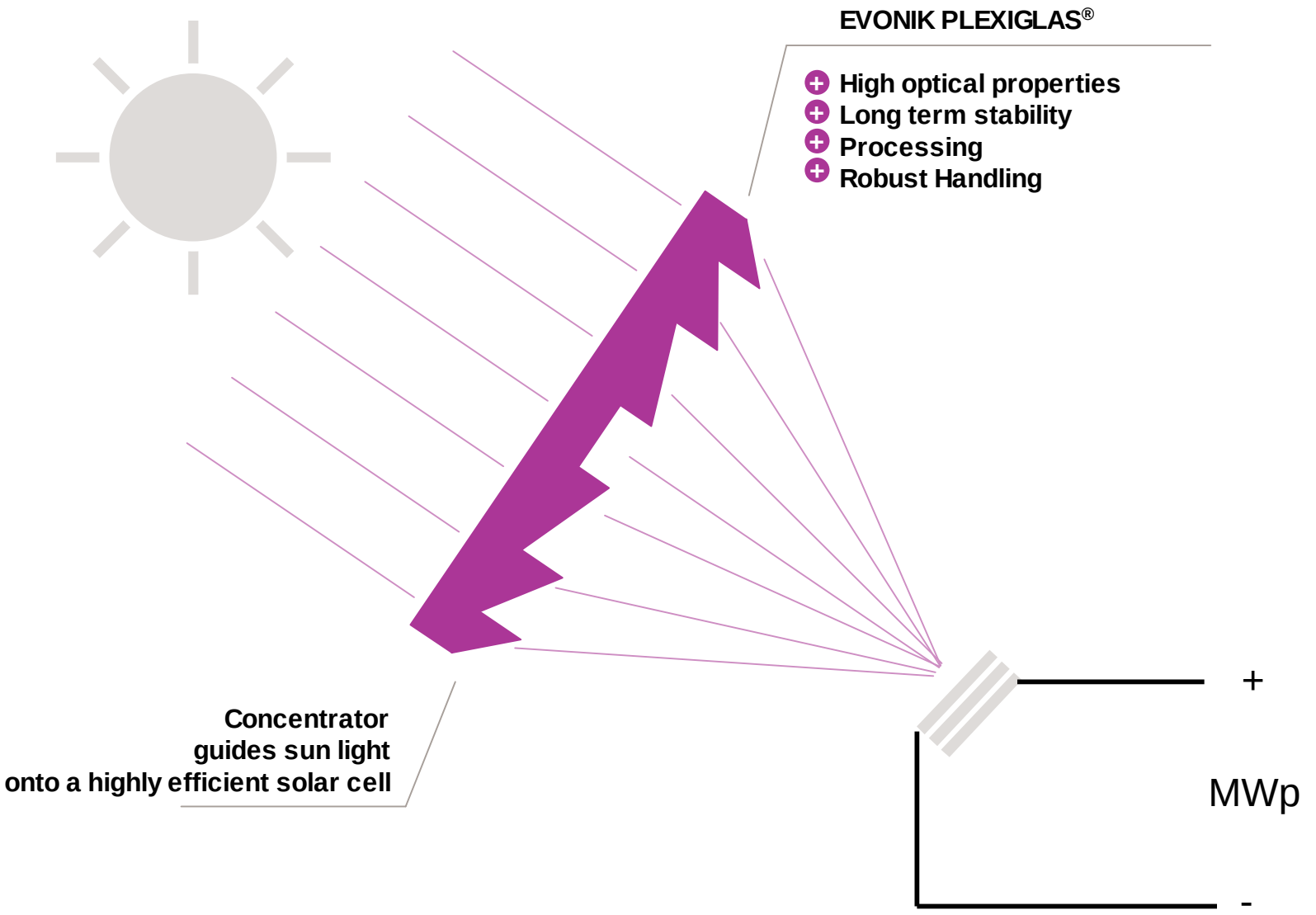


Comparison of Transparent Plastics

Property	Testmethod	Unit	PMMA	PC	PS	SAN	PVC
Light transmission (3mm)	DIN 5036	[%]	92	88	89	89	83
Light transmission after 10 years weathering		[%]	90	hazy	hazy	hazy	72
Weatherability			Very good	medium	poor	poor	medium
Scratch resistance			Very good	poor	medium	medium	poor
Fuel resistance			good	good	poor	poor	good
Density	DIN 53479	[g/cm³]	1,19	1,2	1,05	1,08	1,40
Vicat-Softening Temperature	DIN 53460	[°C]	113 *	150 *	90 *	100 *	80 *
Long term Temperature		[°C]	100 *	130 *	75 *	85 *	65 *
E-Modulus	DIN 53457	[N/mm²]	3300	2200	3100	3500	2500
Tensile stress	DIN 53455	[N/mm²]	72	65	50	75	55
Tensile strain	DIN 53455	[%]	4-6	> 80	3-5	5	20
Impact resistance unnotched	DIN 53453	[kJ/m²]	15	no Break	15	15	30
Impact resistance notched	DIN 53453	[kJ/m²]	2	35	2	3	3
Burning behaviour (3 mm)	DIN 4102		B 2	B 1	B 2	B 2	B 1
Ball Indent hardness H961/30	DIN 53456		185	130	150	160	120

* depending on Type

The Lens Determins the Performance of the Total System

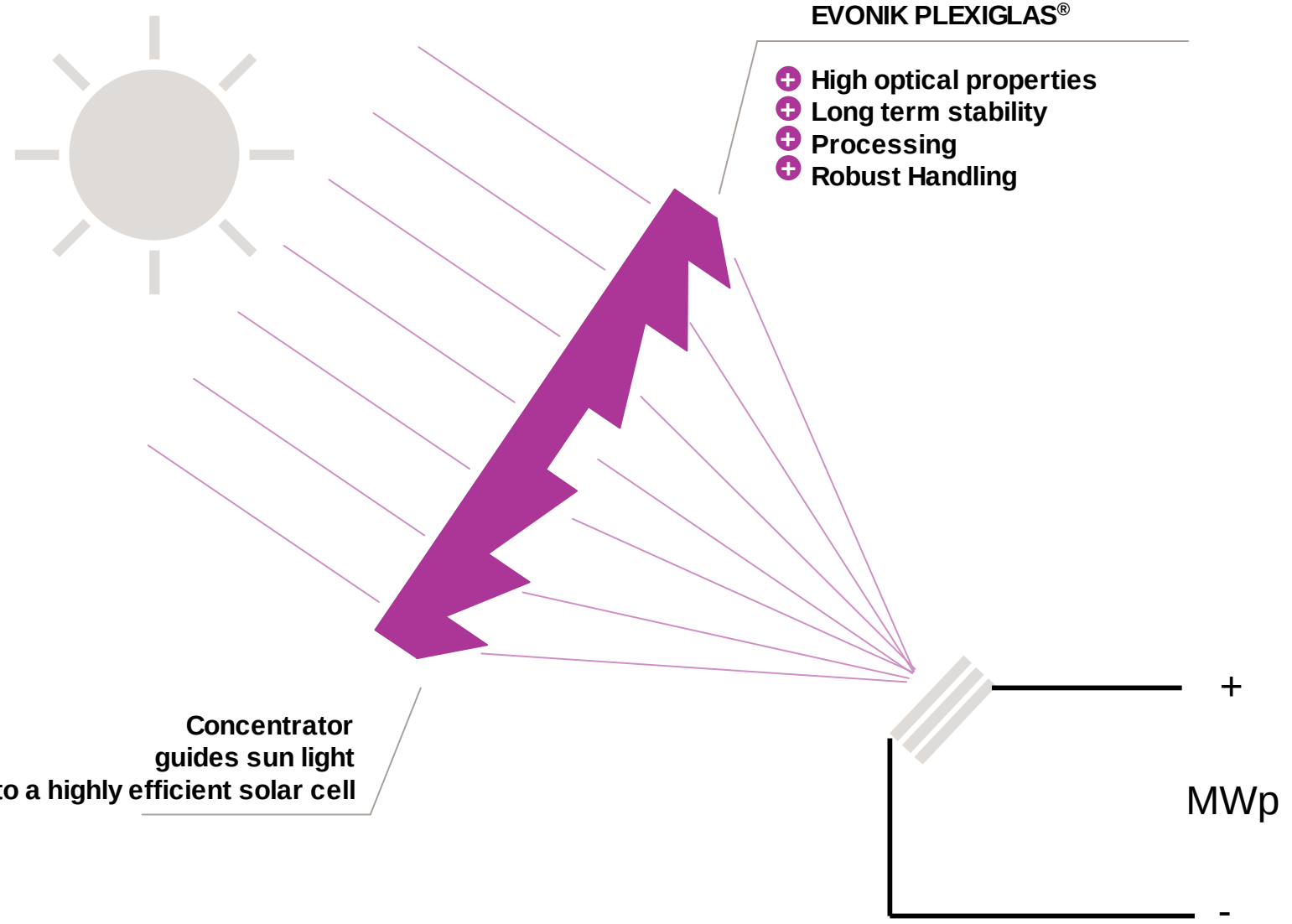


The Lens Determins the Performance of the Total System

Optics

EVONIK PLEXIGLAS®

- **High optical properties**
- **Long term stability**
- **Processing**
- **Robust Handling**

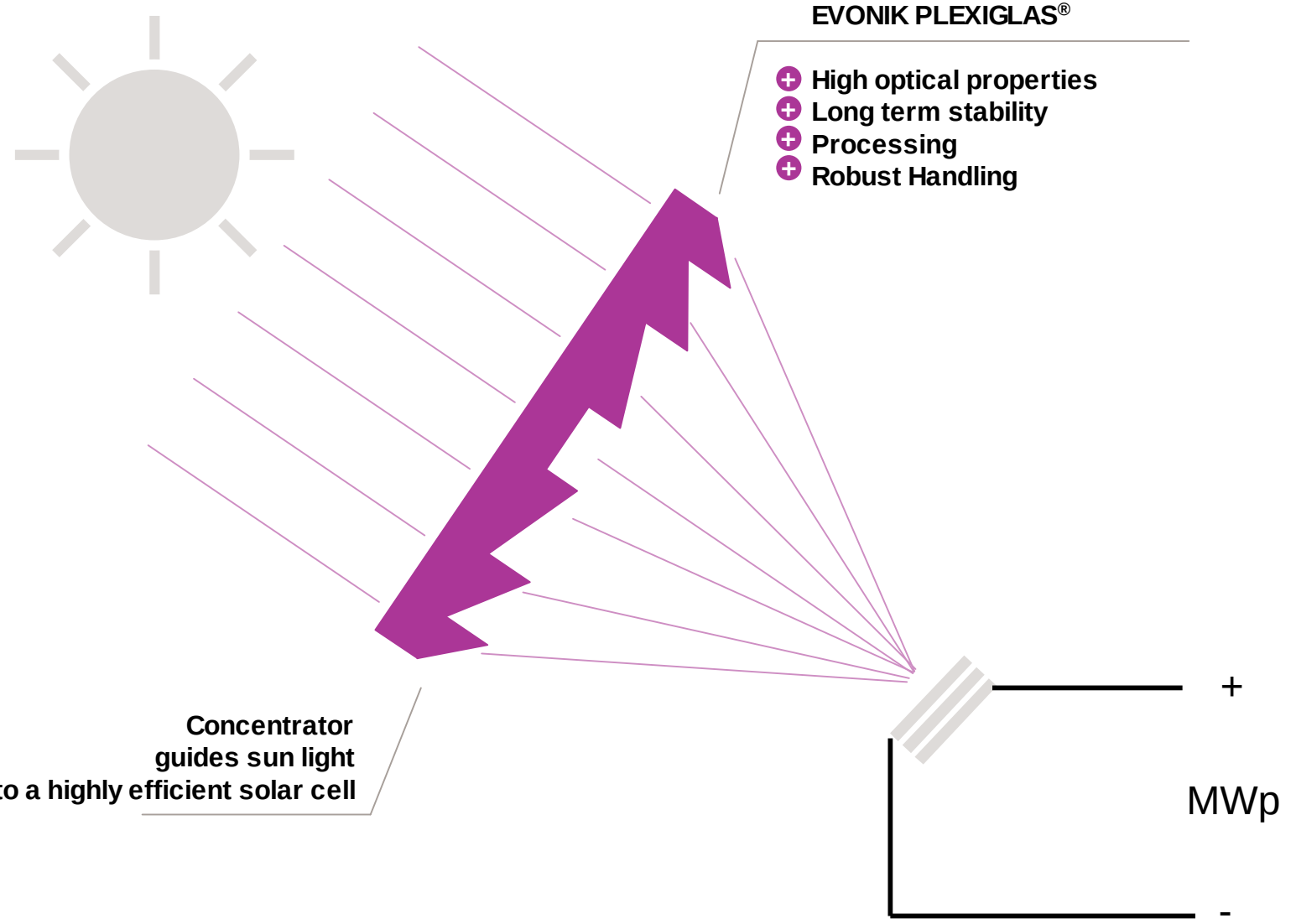


Concentrator guides sun light onto a highly efficient solar cell

The Lens Determins the Performance of the Total System

Optics

Long term stability

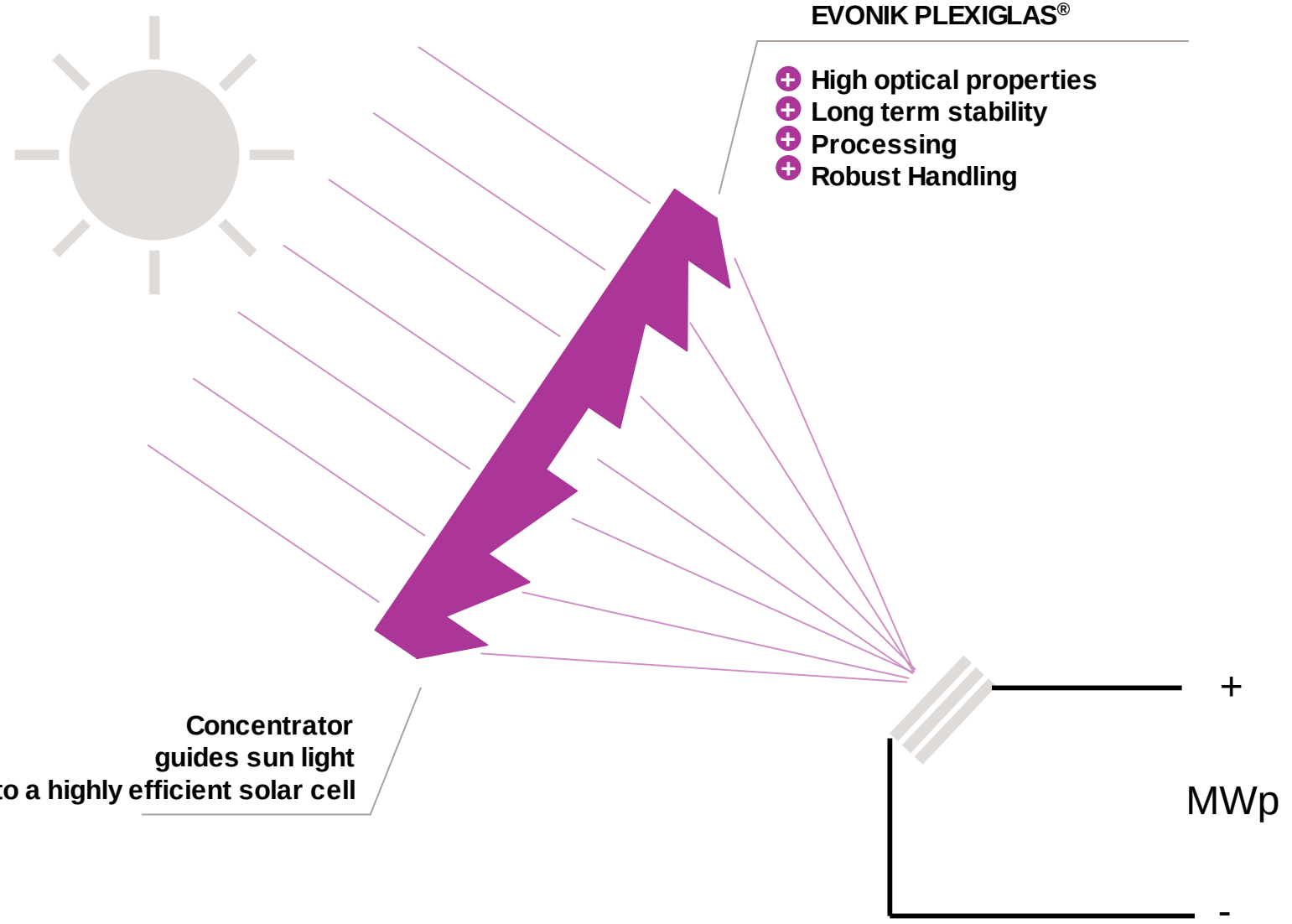


The Lens Determins the Performance of the Total System

Optics

Long term stability

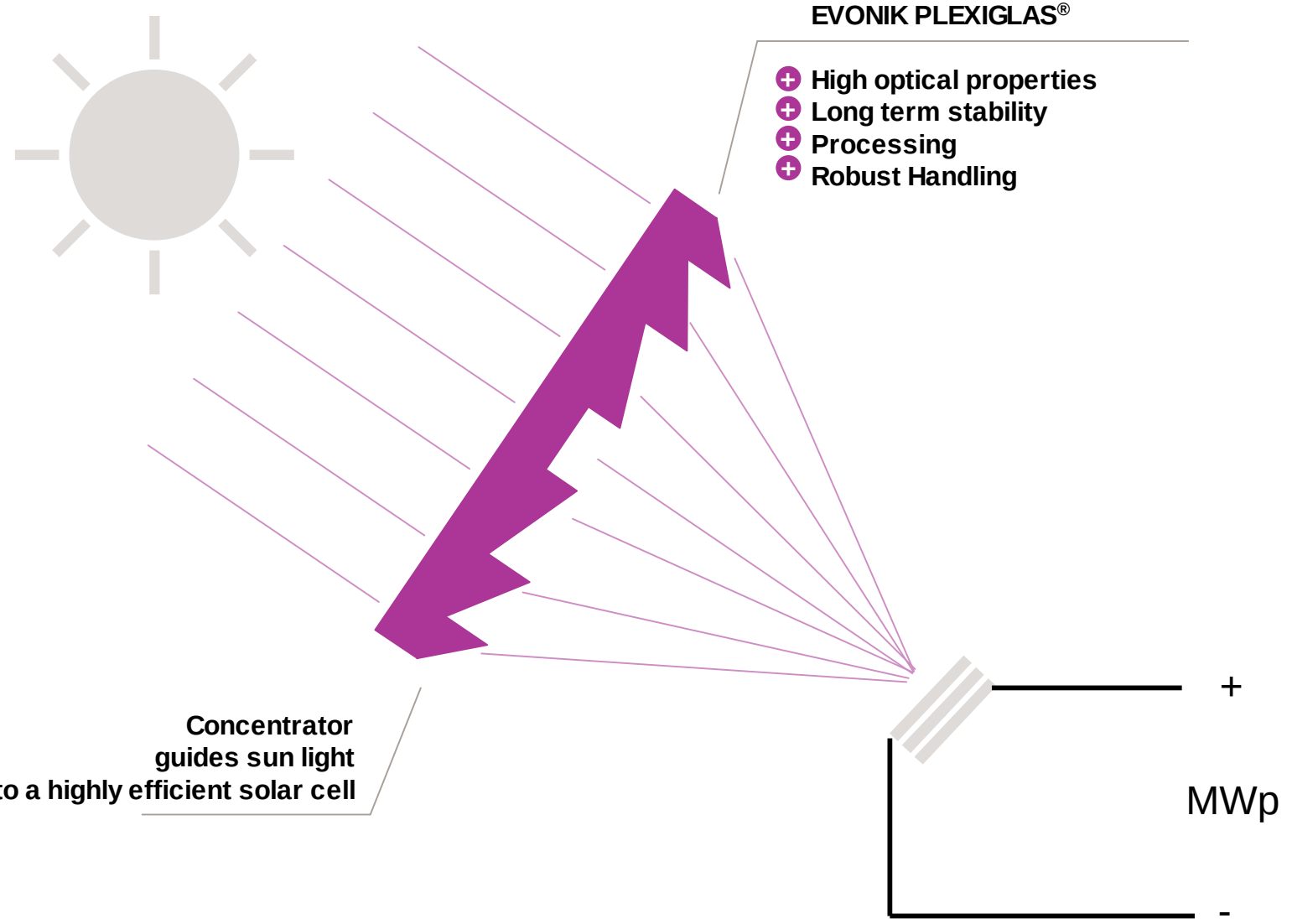
Processing



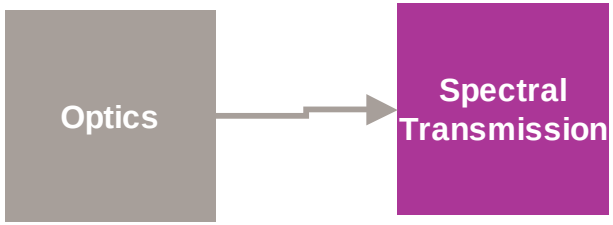
The Lens Determins the Performance of the Total System

EVONIK INDUSTRIES

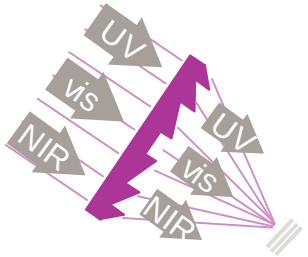
- Optics
- Long term stability
- Processing
- Robust Handling



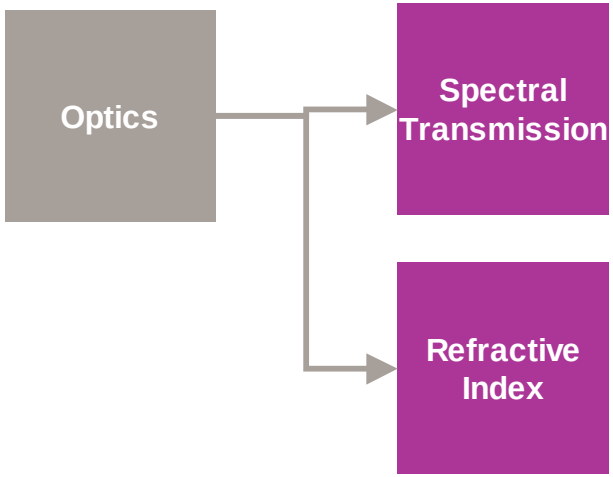
Optical Challenges for the Lens



Maximum transmission of all spectral regions where the solar cell is active. UV, vis, NIR

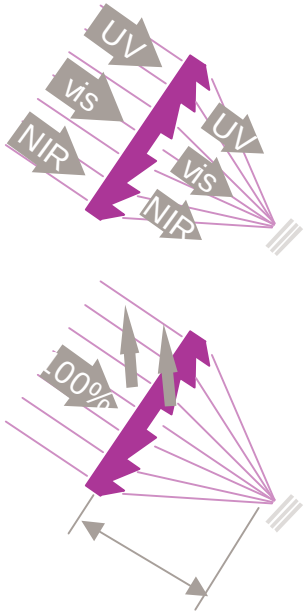


Optical Challenges for the Lens



Maximum transmission of all spectral regions where the solar cell is active. UV, vis, NIR

Refractive Index RI: Determines the focal length and the losses due to fresnel reflection. (lower RI; minor losses)



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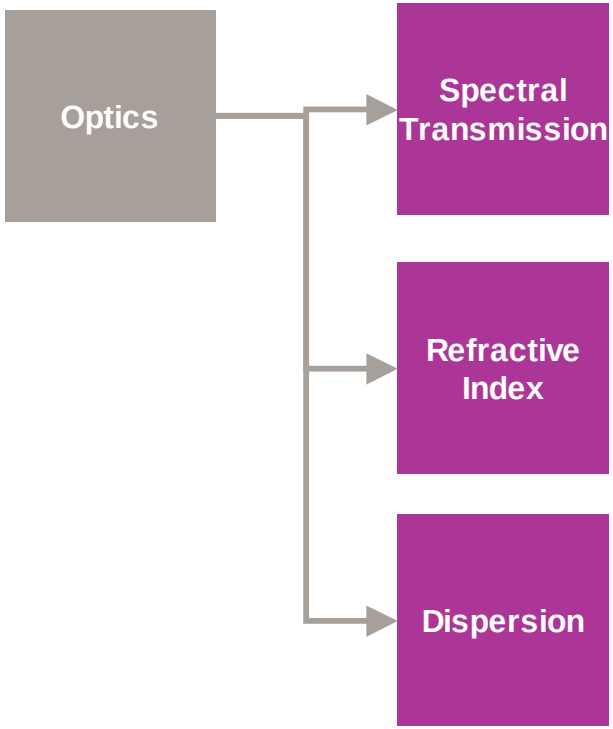
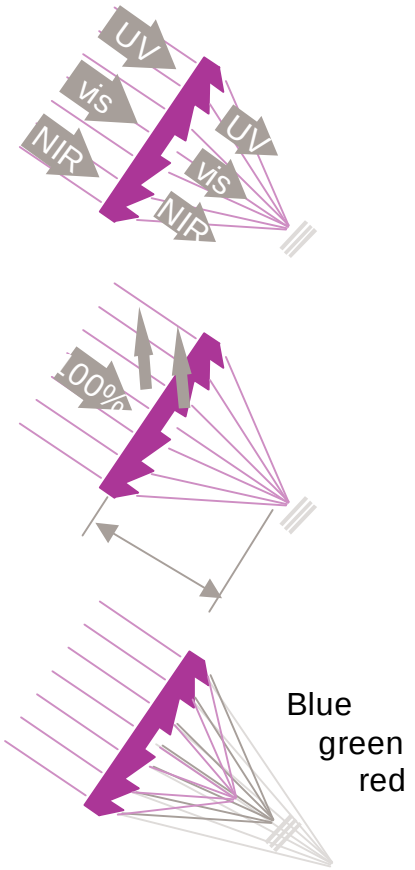


Maximum transmission of all spectral regions where the solar cell is active. UV, vis, NIR

Refractive Index RI: Determines the focal length and the losses due to fresnel reflection. (lower RI; minor losses)

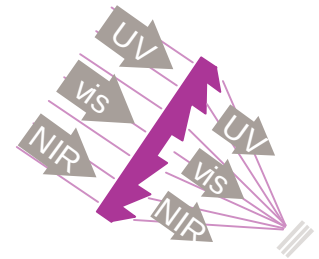
High Abbe-Number: one focus
Low Abbe-Number: blue, yellow, red have different focal length

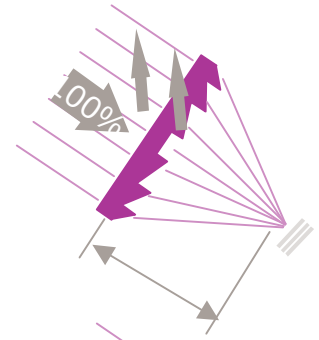


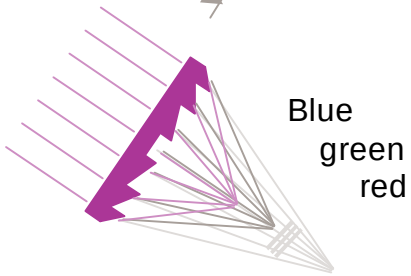
Optical Challenges for the Lens

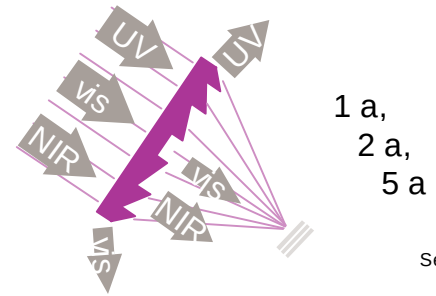
Optics

- **Spectral Transmission**
  Maximum transmission of all spectral regions where the solar cell is active. UV, vis, NIR
- **Refractive Index**
  Refractive Index RI: Determines the focal length and the losses due to fresnel reflection. (lower RI; minor losses)
- **Dispersion**
  High Abbe-Number: one focus
  Low Abbe-Number: blue, yellow, red have different focal length
- **Non Yellowing**
  Degradation of some polymers increases the yellowness. UV-protection of some polymers reduces spectral transmission!



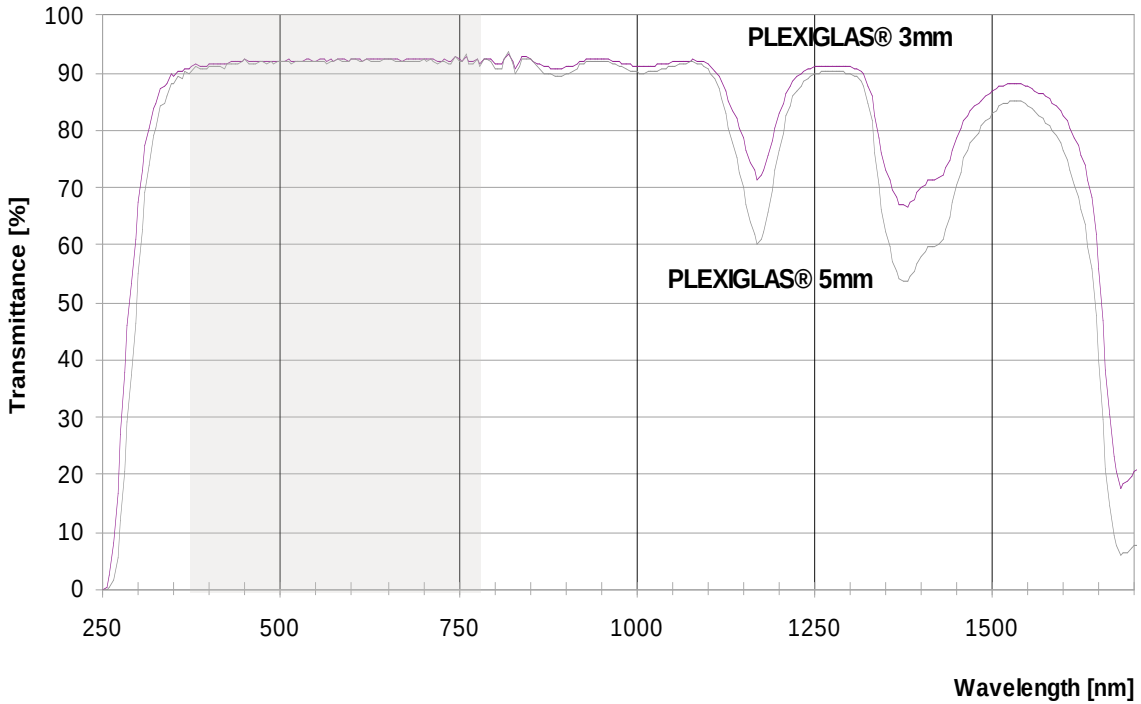






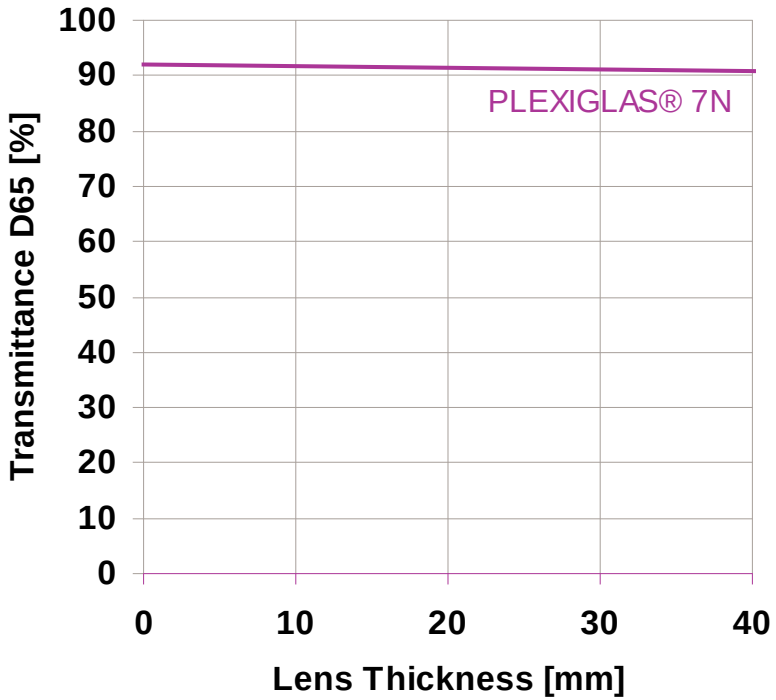
Transmission Determines How Much Energy Gets Through the Lens

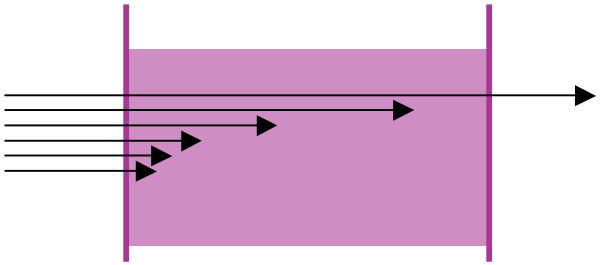
Optics



Optical Damping

Optics



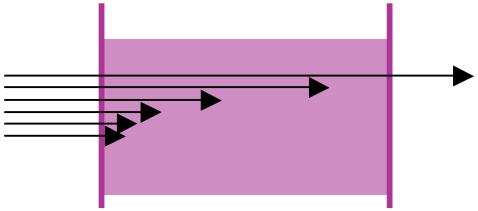


Optical Properties of PMMA

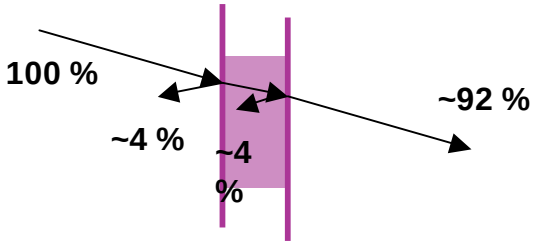
Optics

Refractiv-index n_{D20}	
Abbe-number	
Light Transmission	
Angel of total reflection	
Optical Absorption [dB/ km]	

Optical Absorption



Fresnel reflections

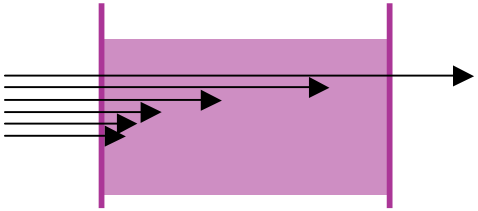


Optical Properties of PMMA

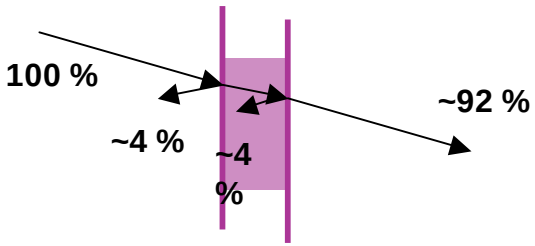
Optics

	PMMA*
Refractiv-index n_{D20}	1,49
Abbe-number	60
Light Transmission	92%
Angel of total reflection	42°
Optical Absorption [dB/ km]	70-100

Optical Absorption



Fresnel reflections



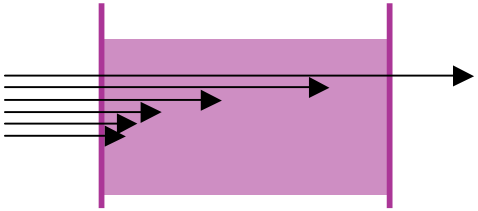
*Due to ist‘s properties, PMMA is often called organic glass

Optical Properties of PMMA

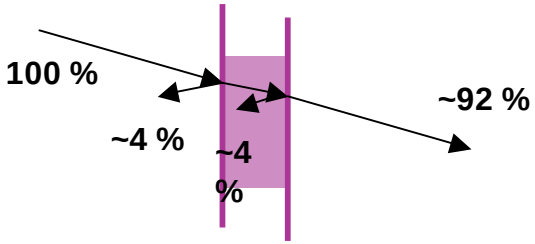
Optics

	PMMA*	Polycarbonat	Glass
Refractiv-index n_{D20}	1,49	1,59	1,53
Abbe-number	60	30	60
Light Transmission	92%	87%	91%
Angel of total reflection	42°	39°	41°
Optical Absorption [dB/ km]	70-100	700	0,2

Optical Absorption



Fresnel reflections



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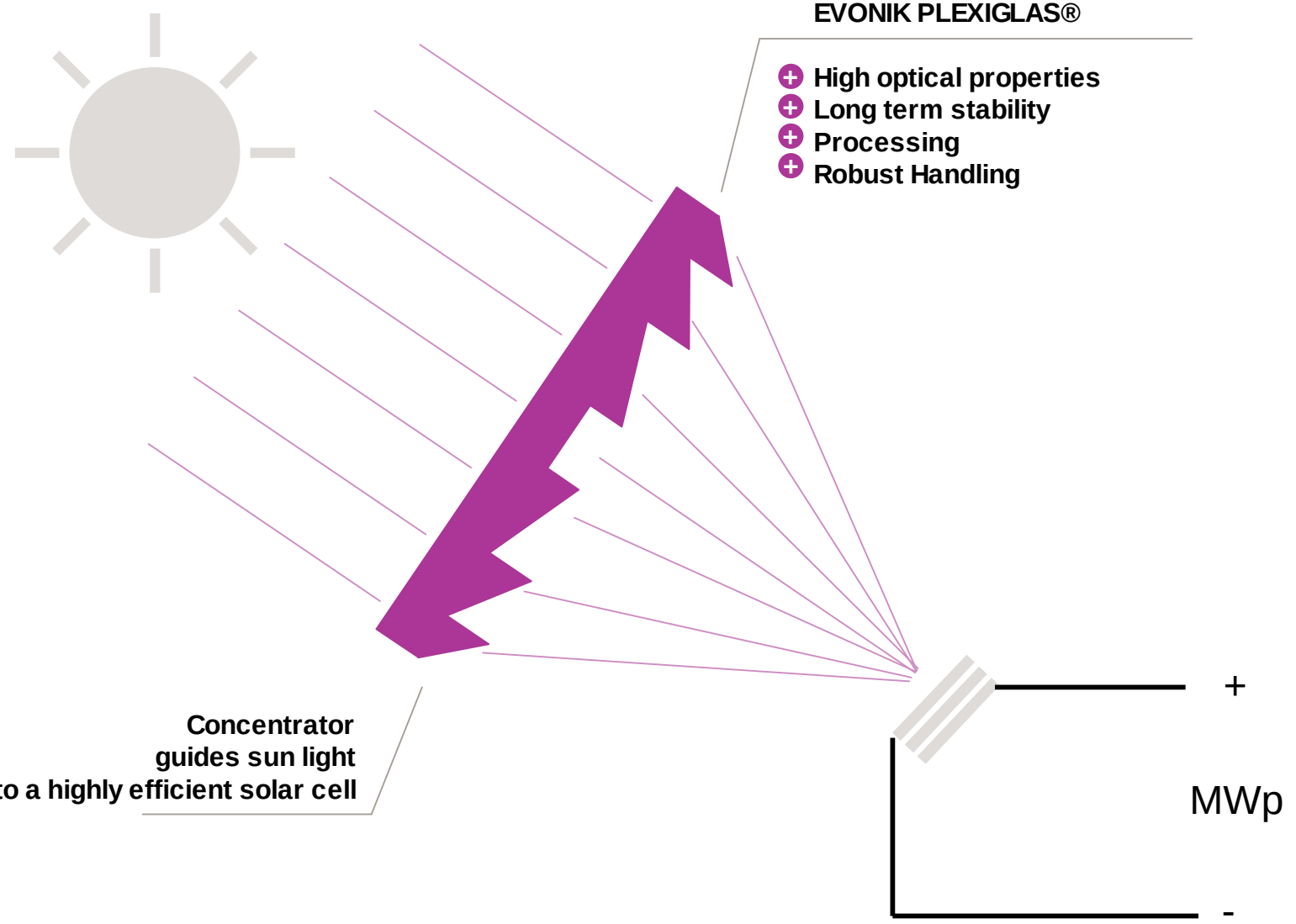
The Lens Determins the Performance of the Total System

Optics

Long term stability

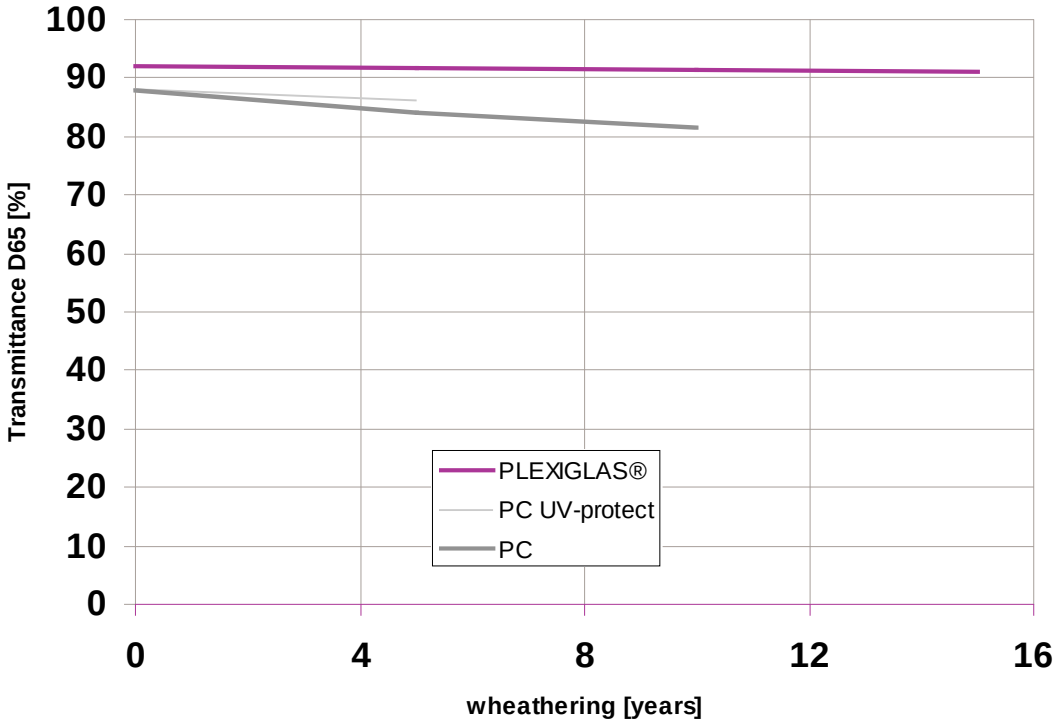
Processing

Robust Handling



Stability of Transmission

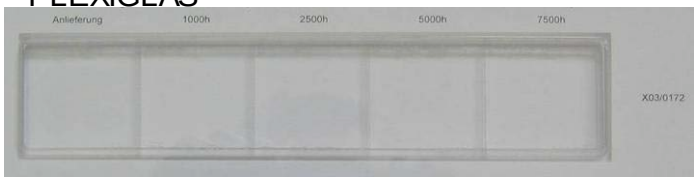
Long term stability



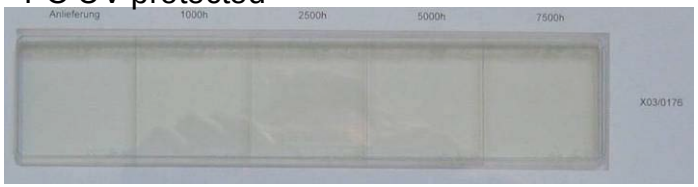
Yellowing

Long term stability

PLEXIGLAS®



PC UV-protected



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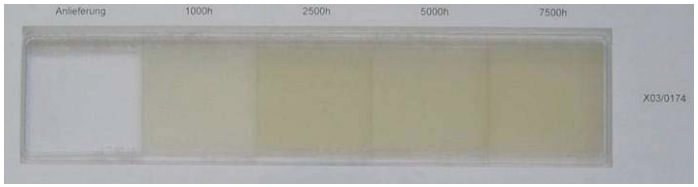
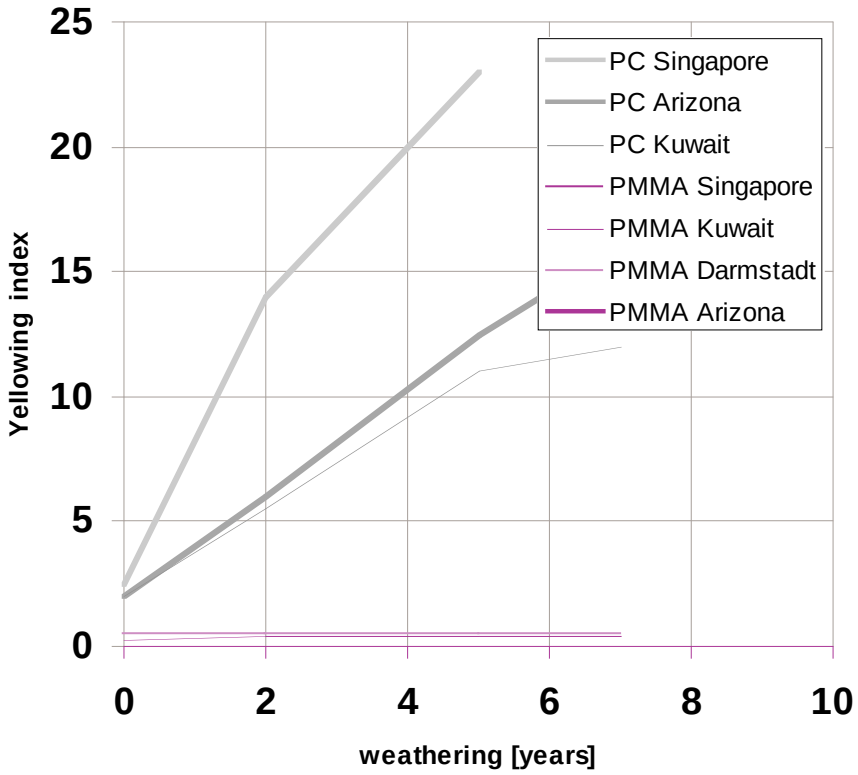


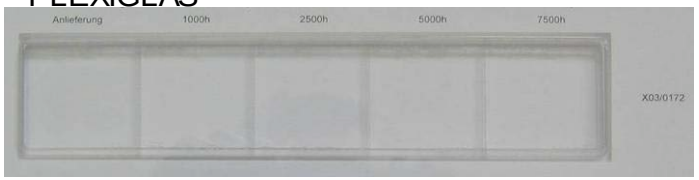
- **PMMA is UV-stable**
- **PC need UV-protection that reduces the spectral transmission**

Yellowing

Long term stability



PLEXIGLAS®



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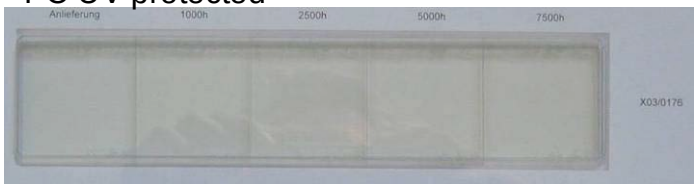
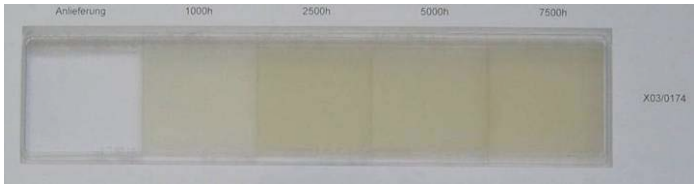


PC



- **PMMA is UV-stable**
- **PC need UV-protection that reduces the spectral transmission**

Evonik Acrylic in Solar Applications

For more than 15 years, Entech Solar's *SunLine*® (left photo) and *SolarRow*® (right photo) CPV arrays have used lenses protected by ACRYLITE® acrylic sheet produced by Evonik Cyro LLC.

Entech Solar's lenses produced with 3M's Fresnel film and laminated to Evonik Cyro's ACRYLITE® acrylic sheet

Evonik Acrylic in Solar Applications

AMONIX's concentrator design protected by ACRYLITE® acrylic sheet produced by Evonik Cyro LLC and currently in service > 10 years

concentrator lens produced with 3M's Fresnel film and laminated to Evonik Cyro's ACRYLITE® acrylic sheet

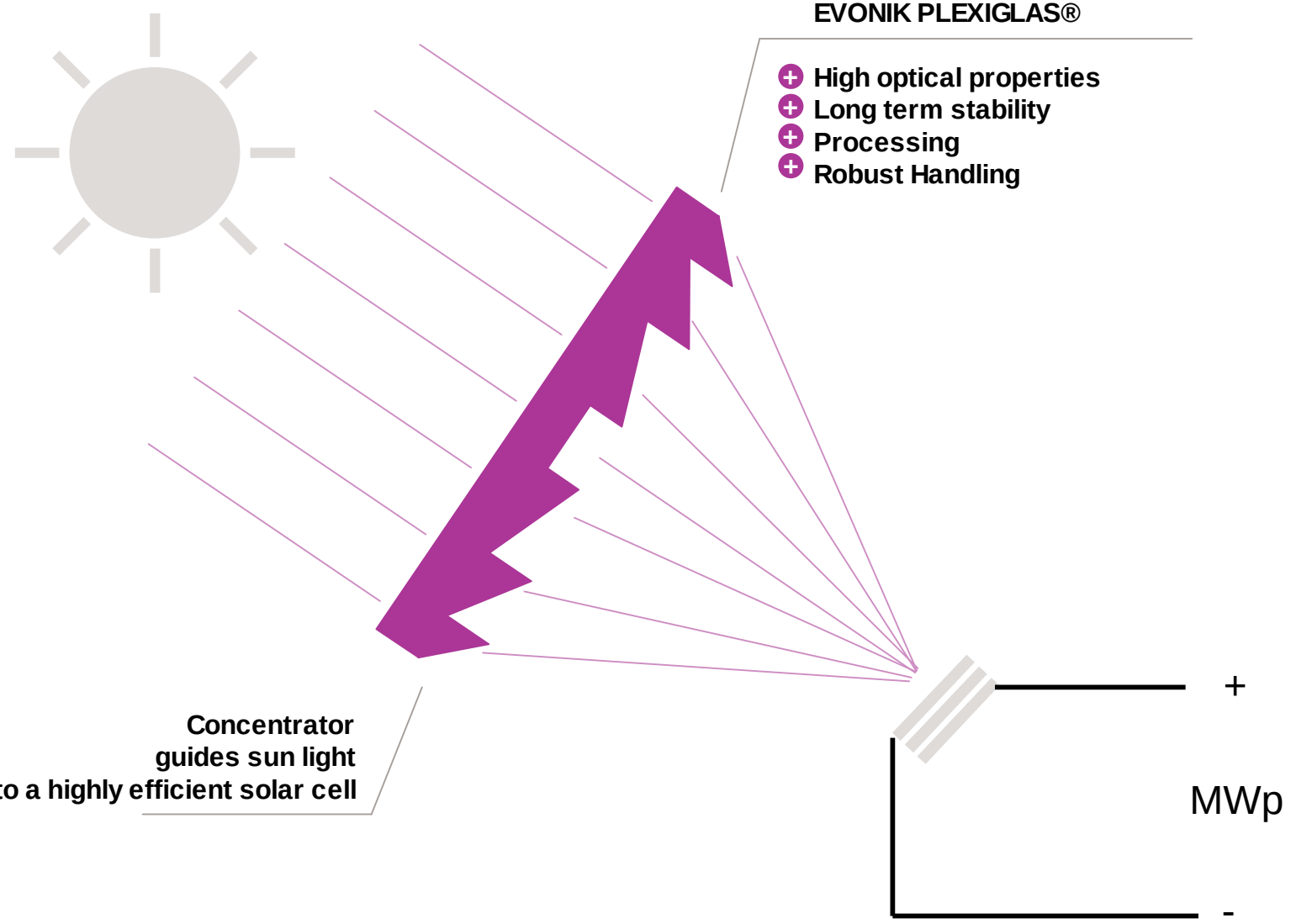
The Lens Determins the Performance of the Total System

Optics

Long term stability

Processing

Robust Handling

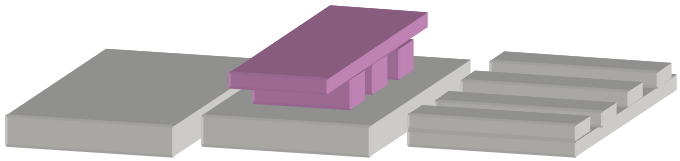


Lens Panel Technologies for Thermoplastics I

Technology

Hot Embossing (batch process)

Process



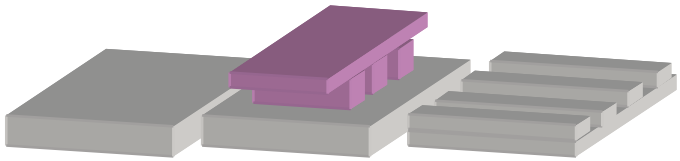
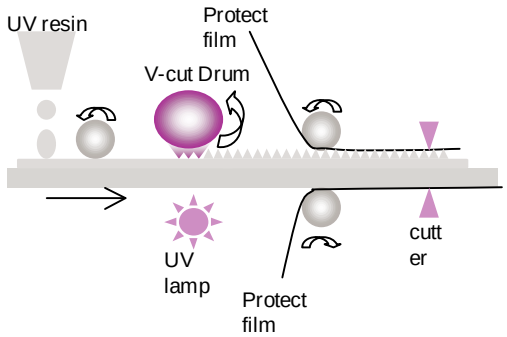
Material

PLEXIGLAS® extruded and cast sheets

Processing

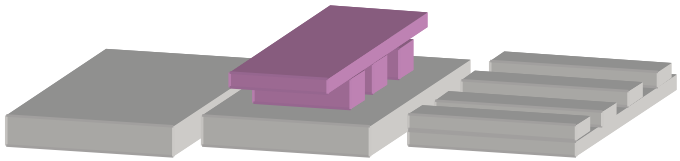
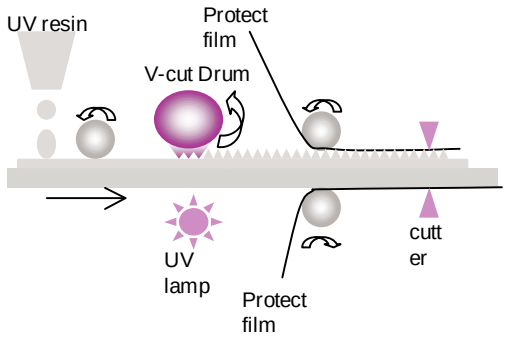
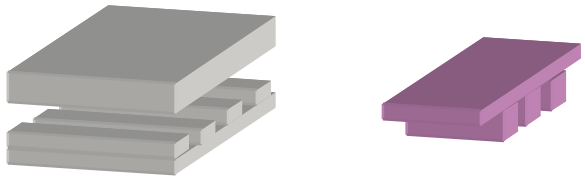
Lens Panel Technologies for Thermoplastics I

Processing

Technology	Process	Material
Hot Embossing (batch process)		**PLEXIGLAS® extruded and cast sheets**
Textured roll embossing		**PLEXIGLAS® Sheets as substrate** **PLEXIGLAS® wheatherable films embossing films**

Lens Panel Technologies for Thermoplastics I

Processing

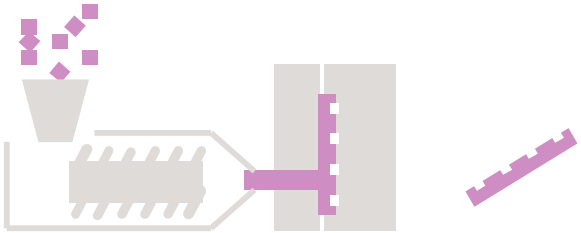
Technology	Process	Material
Hot Embossing (batch process)		**PLEXIGLAS® extruded and cast sheets**
Textured roll embossing		**PLEXIGLAS® Sheets as substrate** **PLEXIGLAS® wheatherable films embossing films**
Direkt cast		**EVONIK MMA**

Lens Panel Technologies for Thermoplastics II

Technology

Injection (Compression) Molding

Process



Material

PLEXIGLAS® Molding Compounds

Processing

Lens Panel Technologies for Thermoplastics II

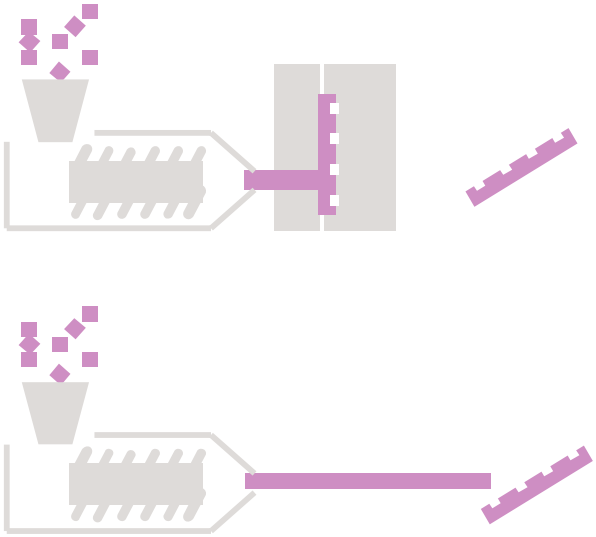
Processing

Technology

Injection (Compression) Molding

Profile Extrusion

Process

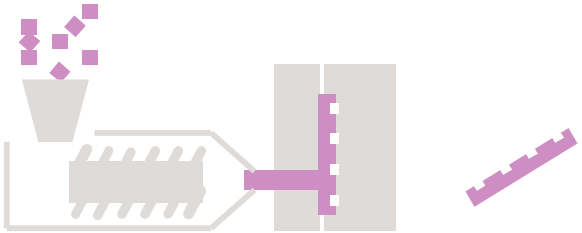
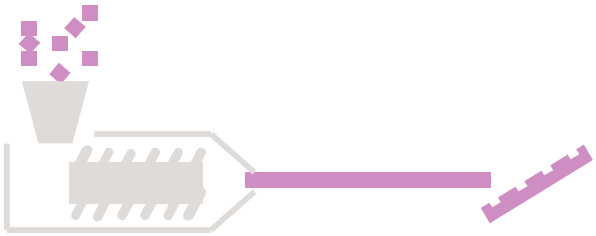
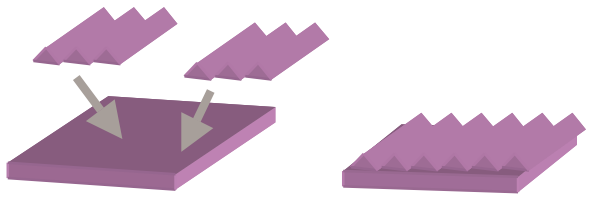


Material

PLEXIGLAS® Molding Compounds

PLEXIGLAS® Molding Compounds

Lens Panel Technologies for Thermoplastics II

	Technology	Process	Material
Processing	Injection (Compression) Molding		**PLEXIGLAS® Molding Compounds**
	Profile Extrusion		**PLEXIGLAS® Molding Compounds**
	Lamination and Glueing Structured Films		**PLEXIGLAS® extruded and cast sheets**

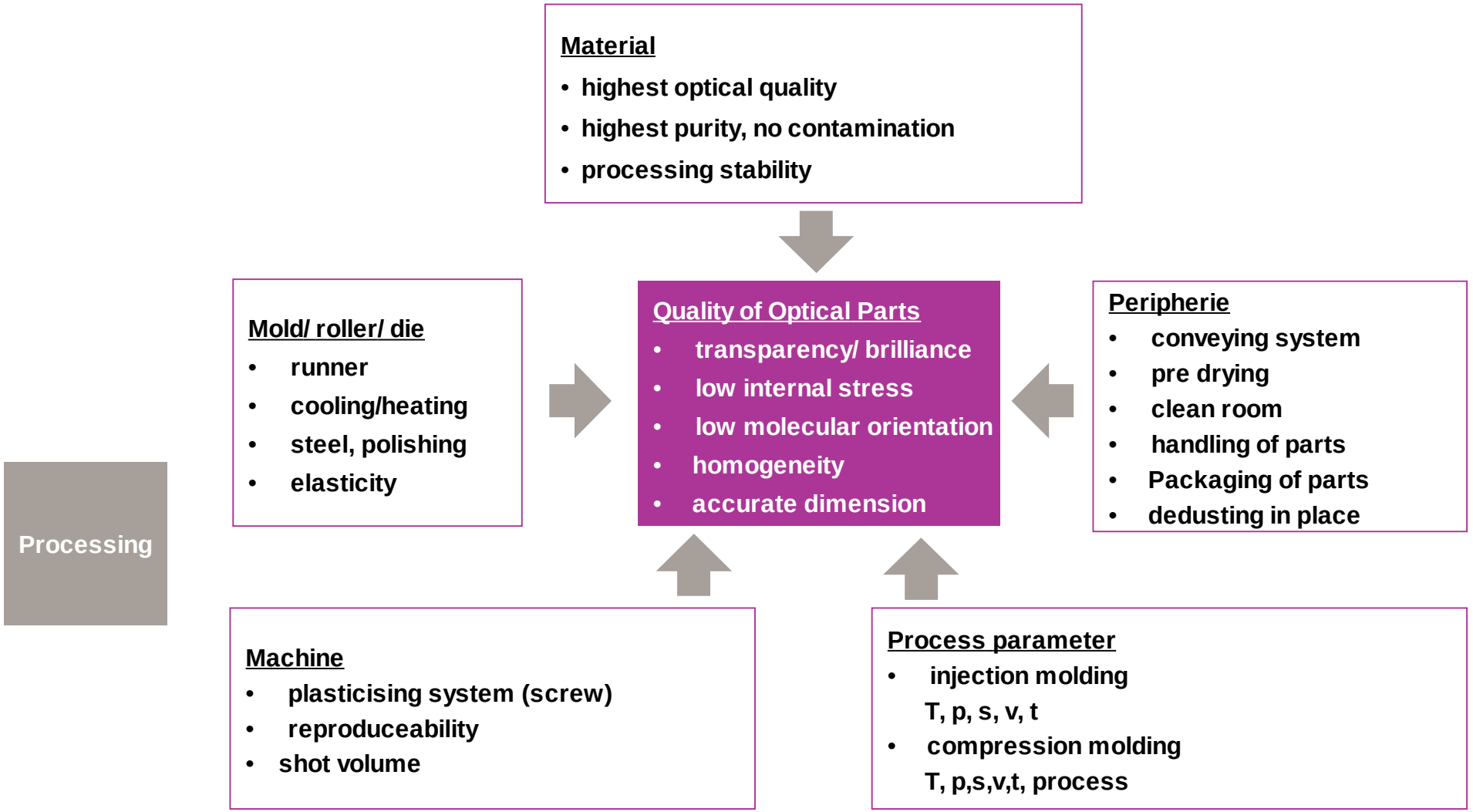
PLEXIGLAS® Molding Compounds
Key Factors for High Optical Quality

Processing

Quality of Optical Parts

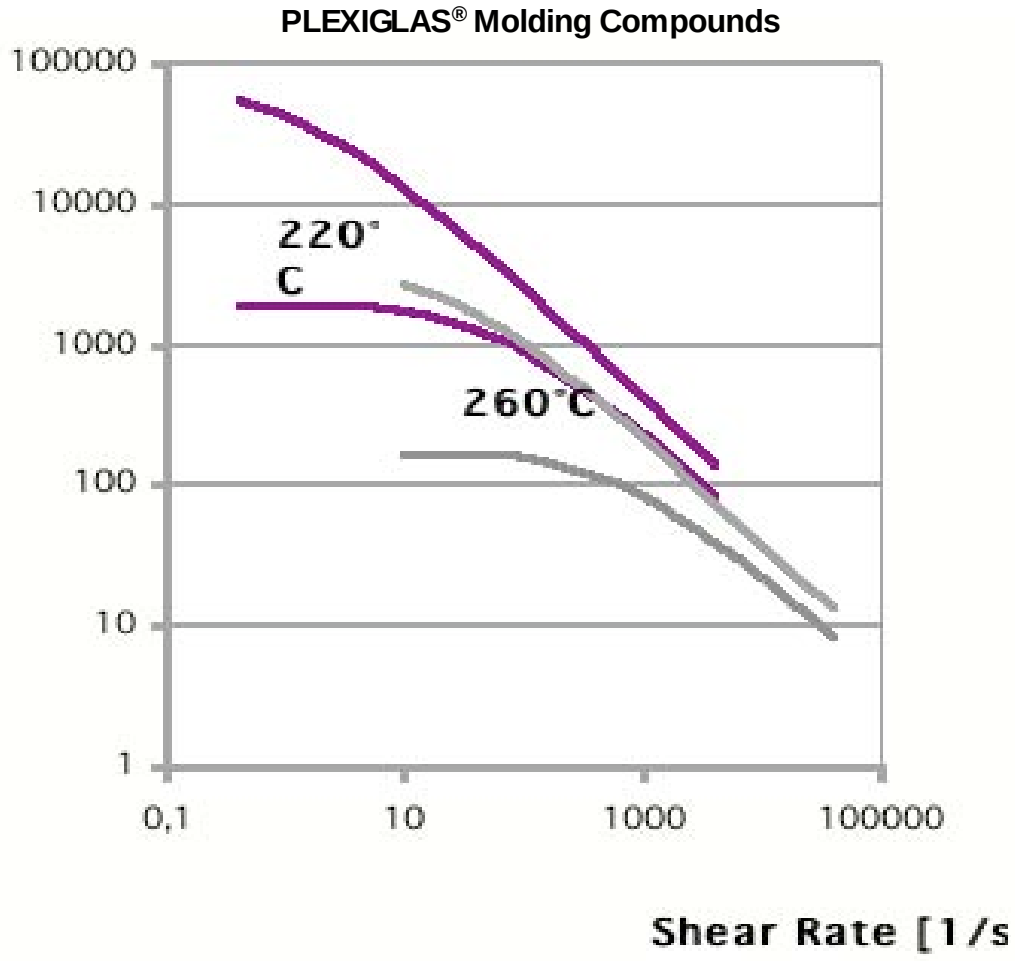
- transparency/ brilliance
- low internal stress
- low molecular orientation
- homogeneity
- accurate dimension

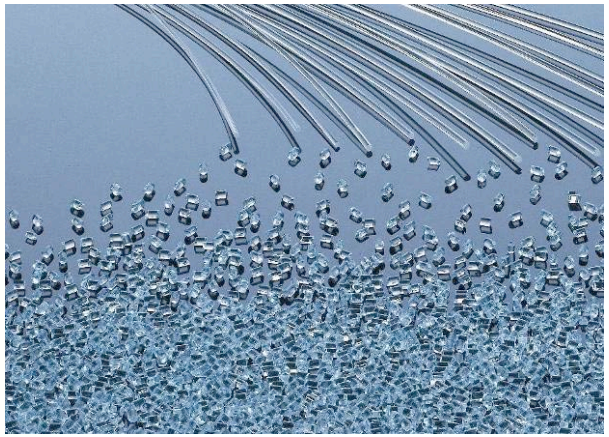
PLEXIGLAS® Molding Compounds
Key Factors for High Optical Quality



Range of Rheology

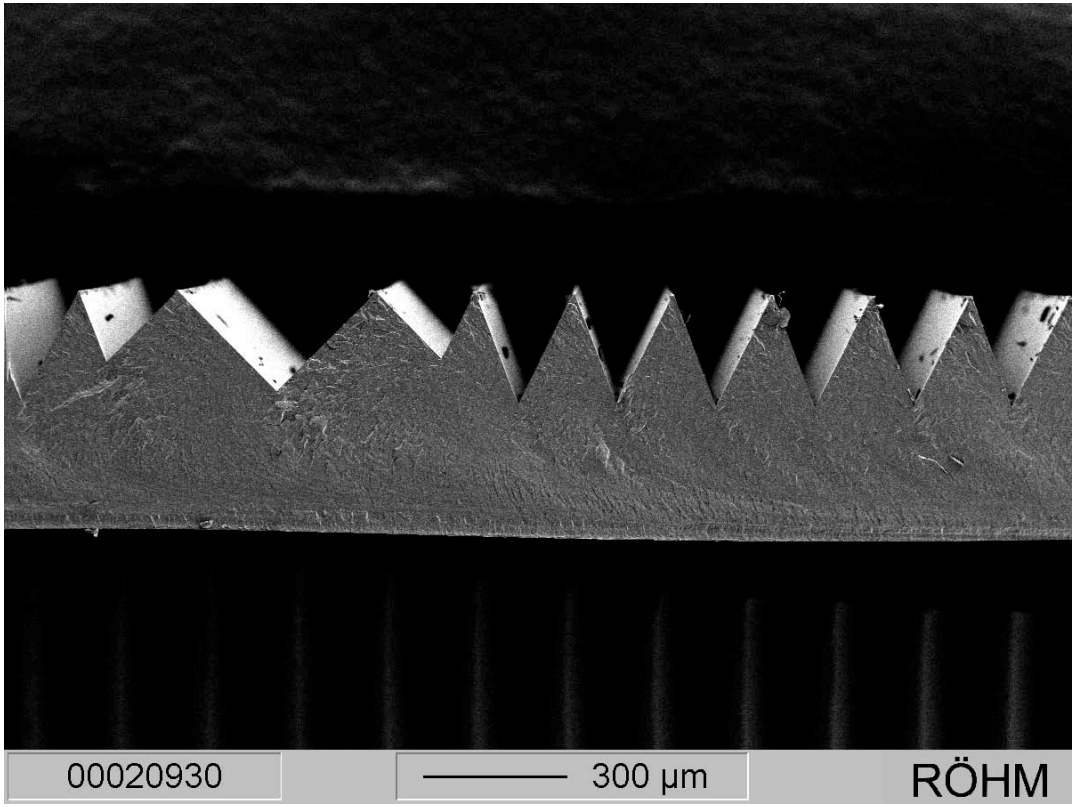
Processing





Reproduction of Functional Structures

Processing



Reproduction of Functional Structures

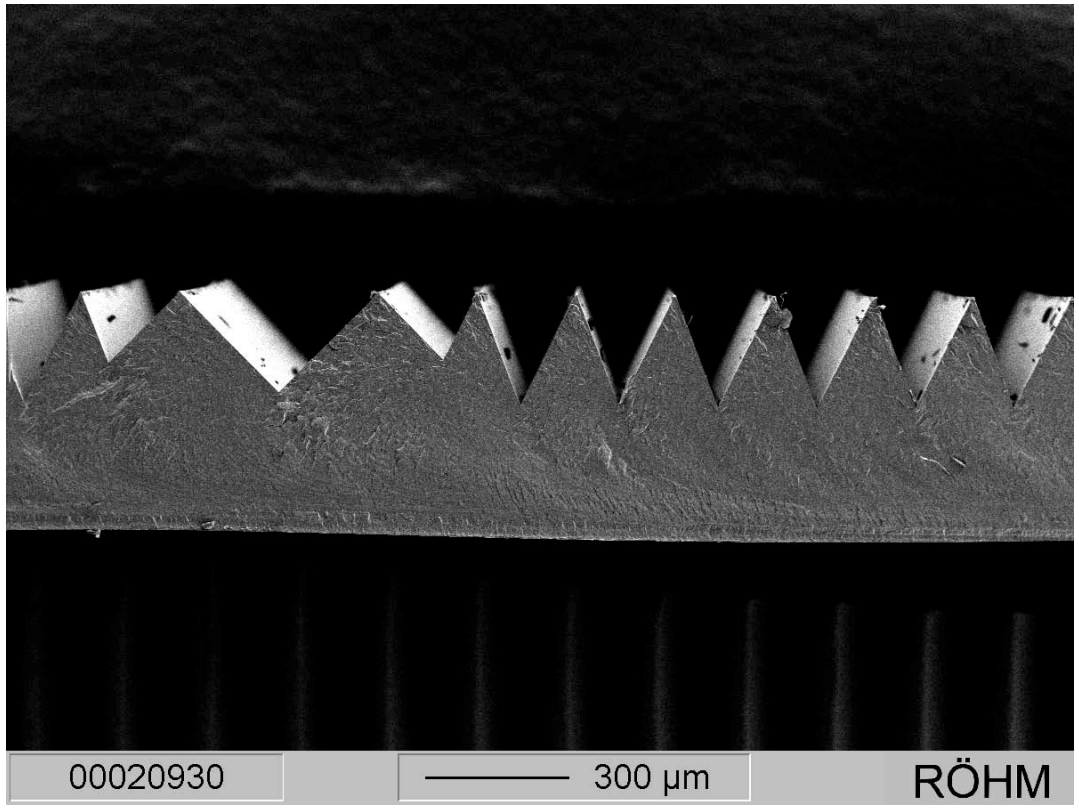
Processing

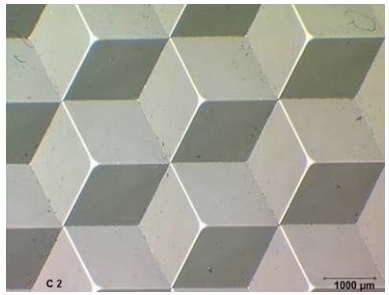
Makro structures: > 1mm
Application examples:
Retro reflecting structures,
Fresnel structures

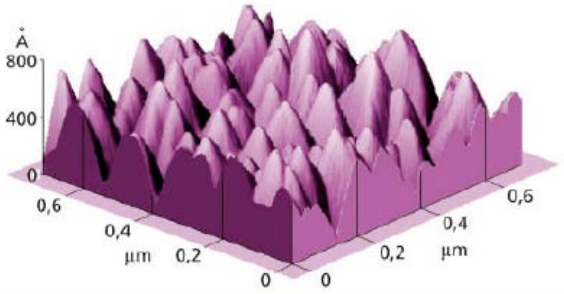
Mikro structures: > 1µm < 1mm
possible Applications:
self cleaning effect (Lotus Effect),
surface structures with light guide function

Nano struktures: < 1 µm
possible Applications :
Eliminating reflections on surfaces („Antireflex“)
eg. On Display (Moth-eye effect)

Due to it‘s excellent reproduction properties any structure is possible – demolding angle of 2° is recommended







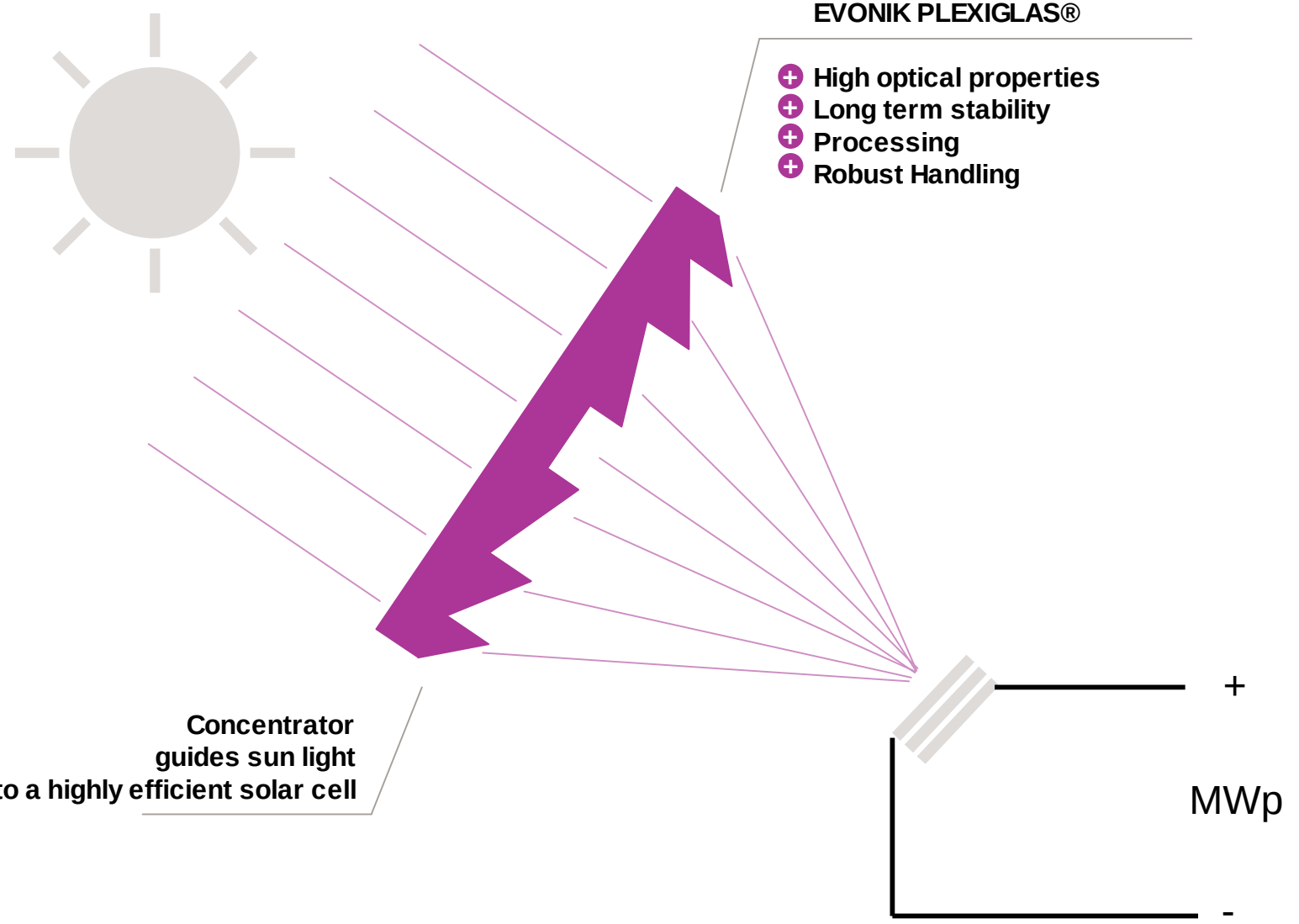
The Lens Determins the Performance of the Total System

Optics

Long term stability

Processing

Robust Handling



Basic Datas of PMMA

Density	g/cm^3	1.19
Glass transition temperatur	°C	85 - 115
Stress at break	N/mm^2	70 - 80
Strain at break	%	3.5 – 6.5
Tensile modulus	MPa (1 mm/min)	1800 - 3200
Charpy SZ	kJ/m^2	20 - 80
Vicat Temp.	°C	94 - 112

Robust Handling

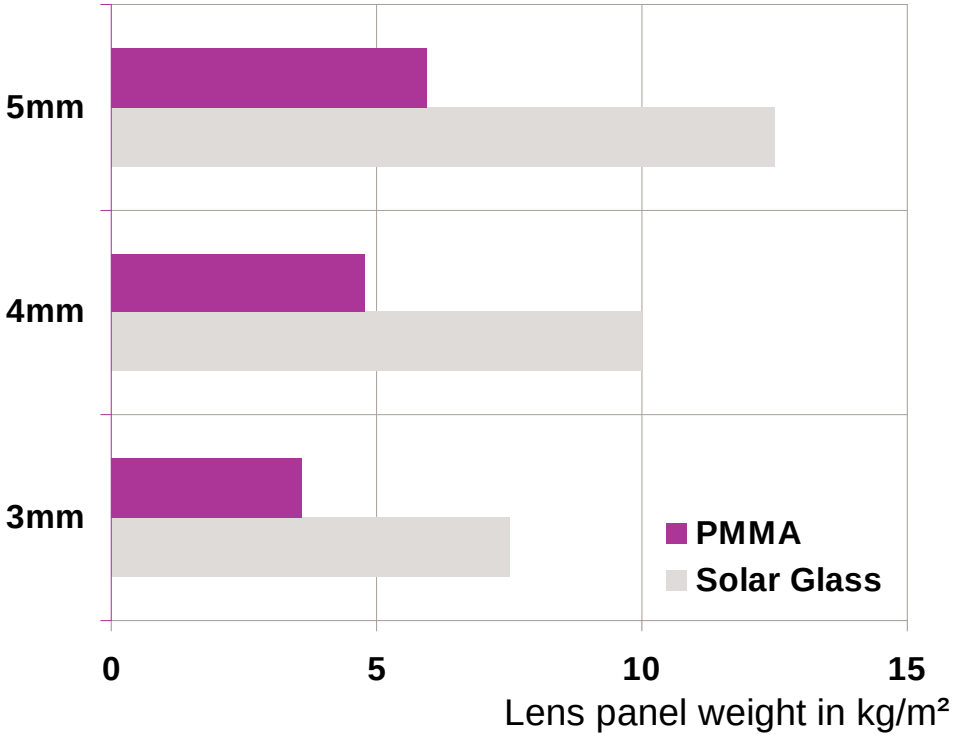
Enhanced Properties

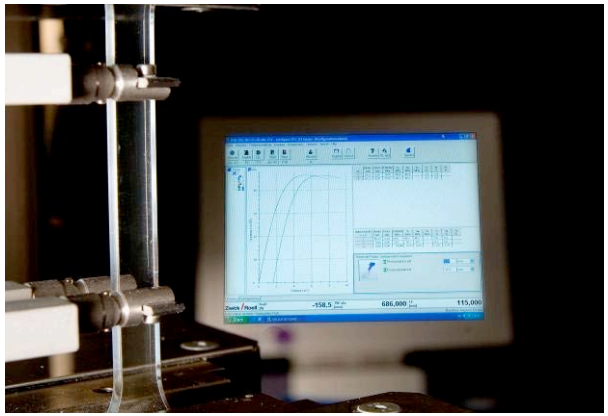
- No erosion – closed-cell Surface
- High gloss
- Easy to clean
- No yellowing
- Polishable surface
- Heat resistance
- Easy to process

Resistance

- Water
- Sweat
- Ink
- leach
- Weak acids

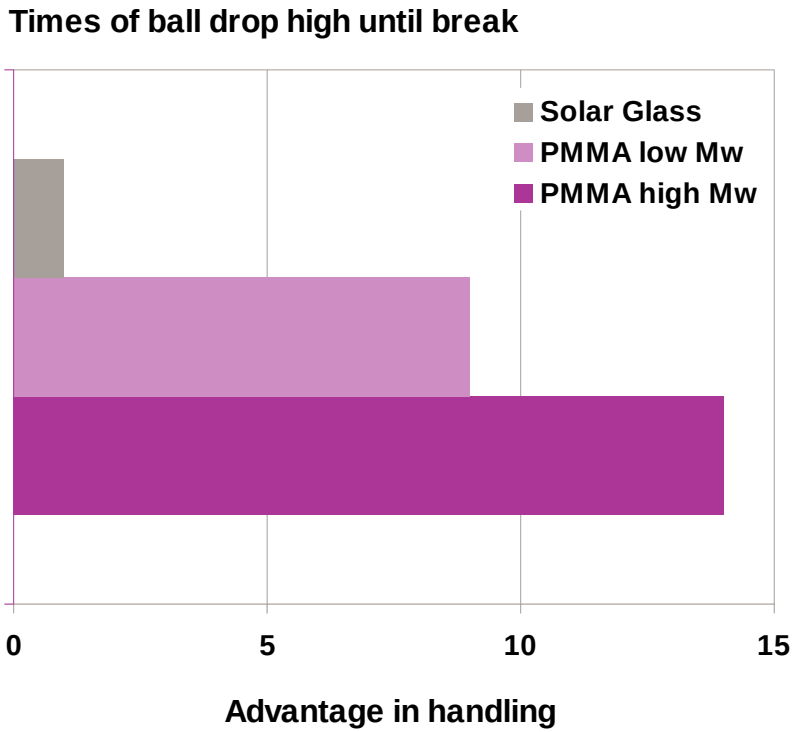
Make Your Construction Light

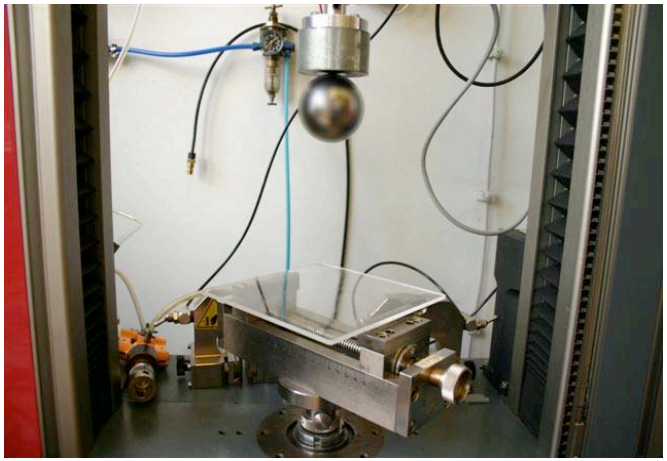




Robust Handling

PMMA Lens - Not Easy to Damage





Conditiones:

23 °C; 50% rel. humidity

Samples:

4mm white glass for PV application

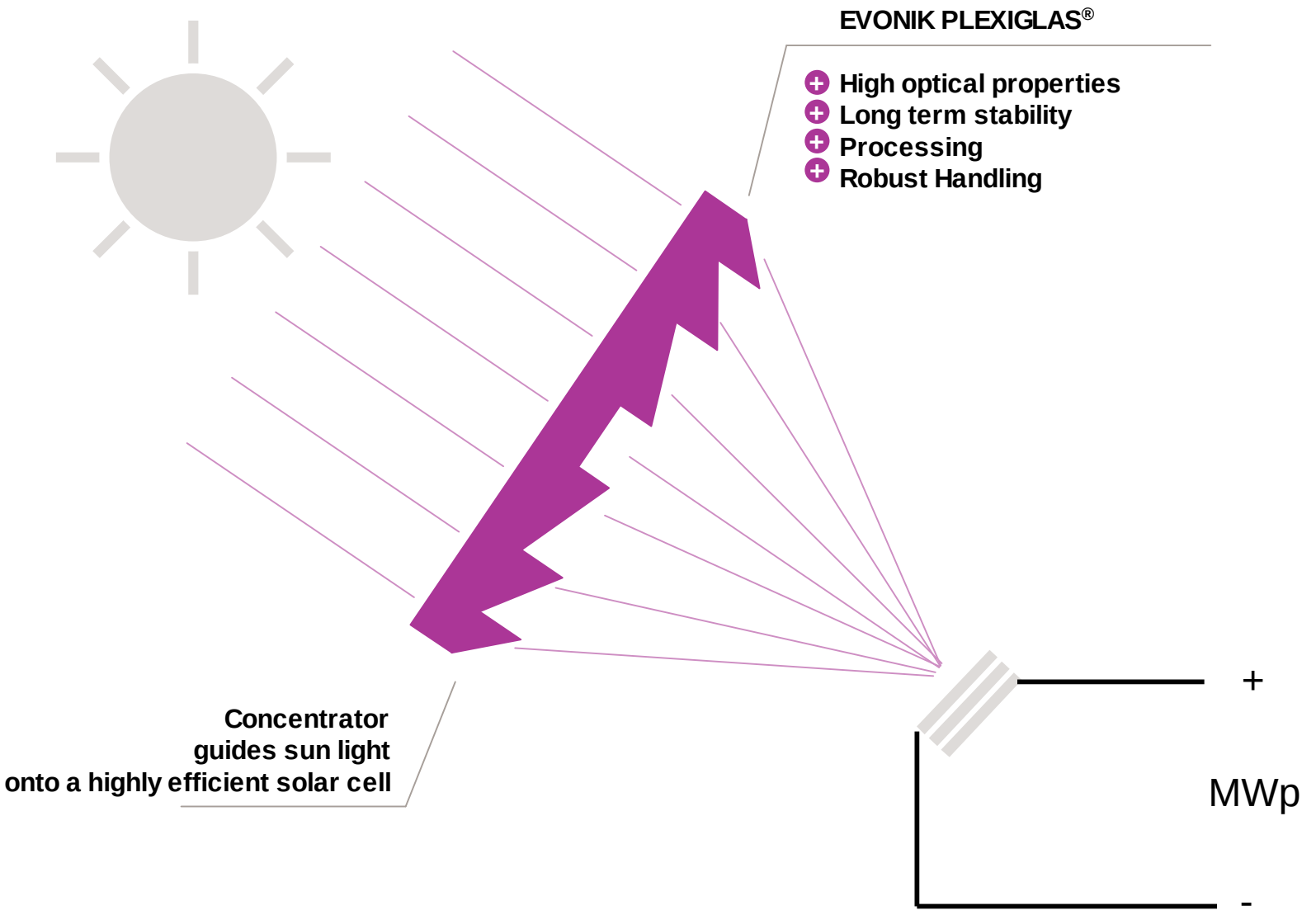
4mm extruded PLEXIGLAS® 8N

4mm extruded PLEXIGLAS® 8H

Ball: Steel D=60mm

Robust Handling

The Lens Determins the Performance of the Total System

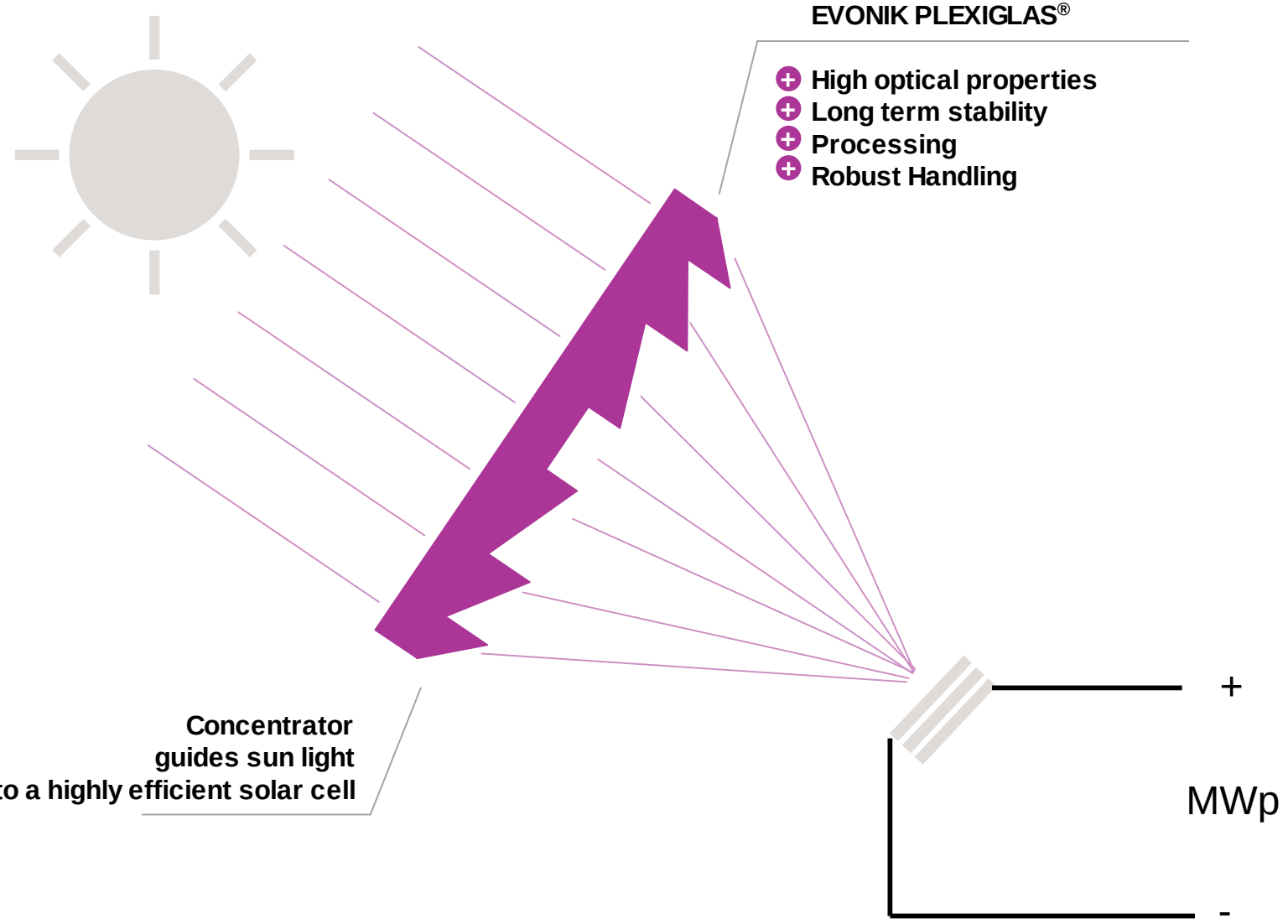


The Lens Determins the Performance of the Total System

Optics

EVONIK PLEXIGLAS®

- **High optical properties**
- **Long term stability**
- **Processing**
- **Robust Handling**

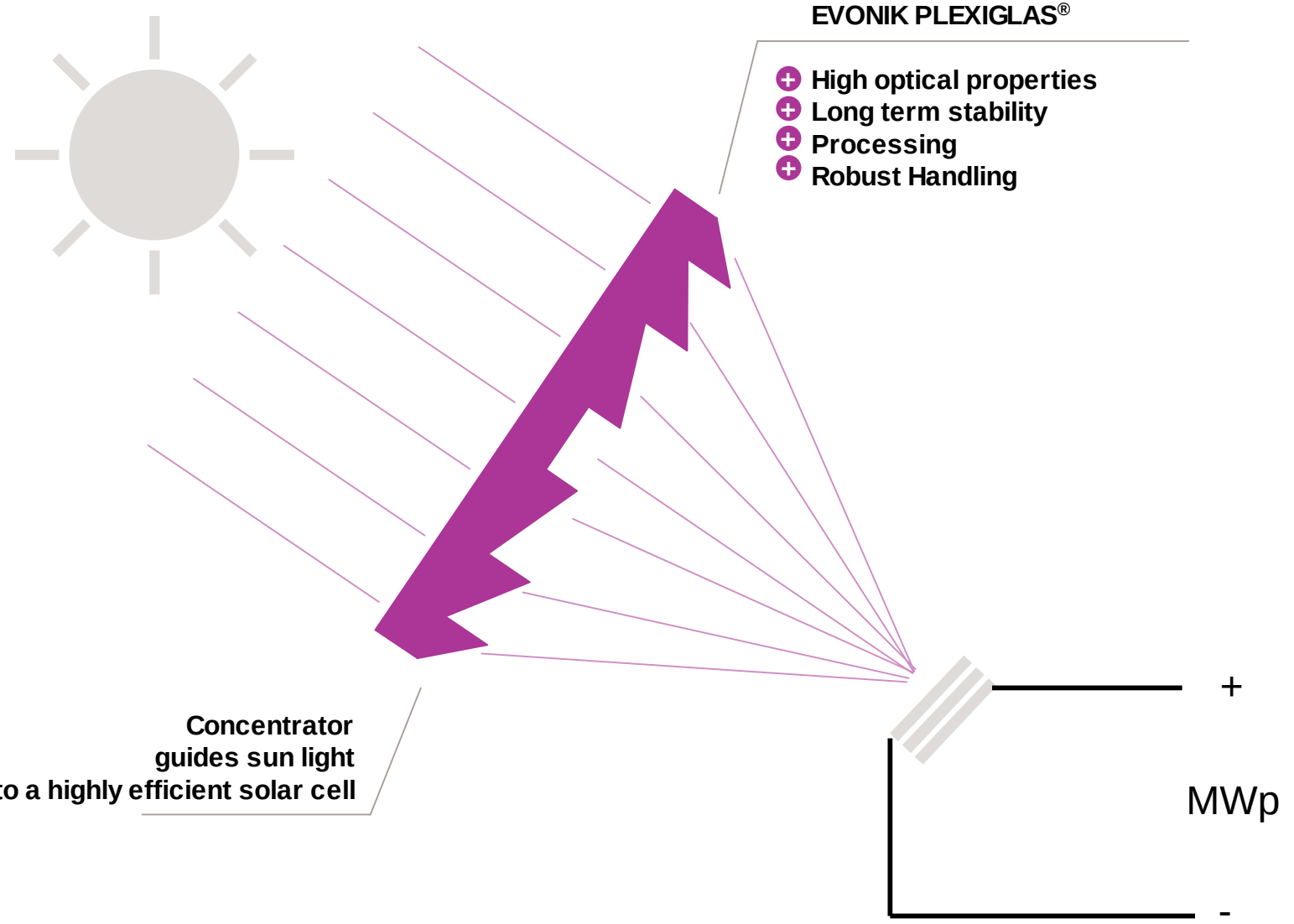


Concentrator guides sun light onto a highly efficient solar cell

The Lens Determins the Performance of the Total System

Optics

Long term stability

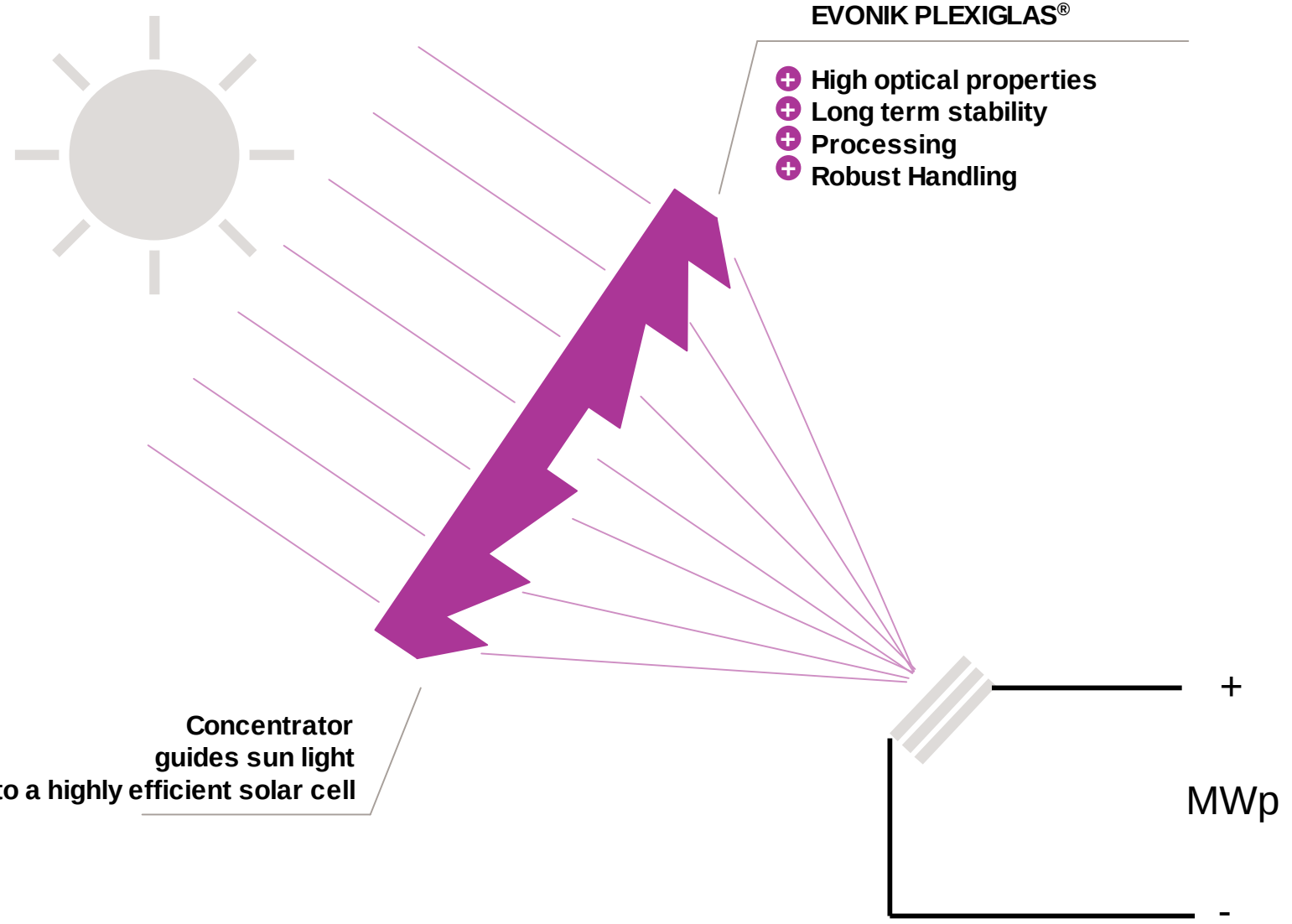


The Lens Determins the Performance of the Total System

Optics

Long term stability

Processing



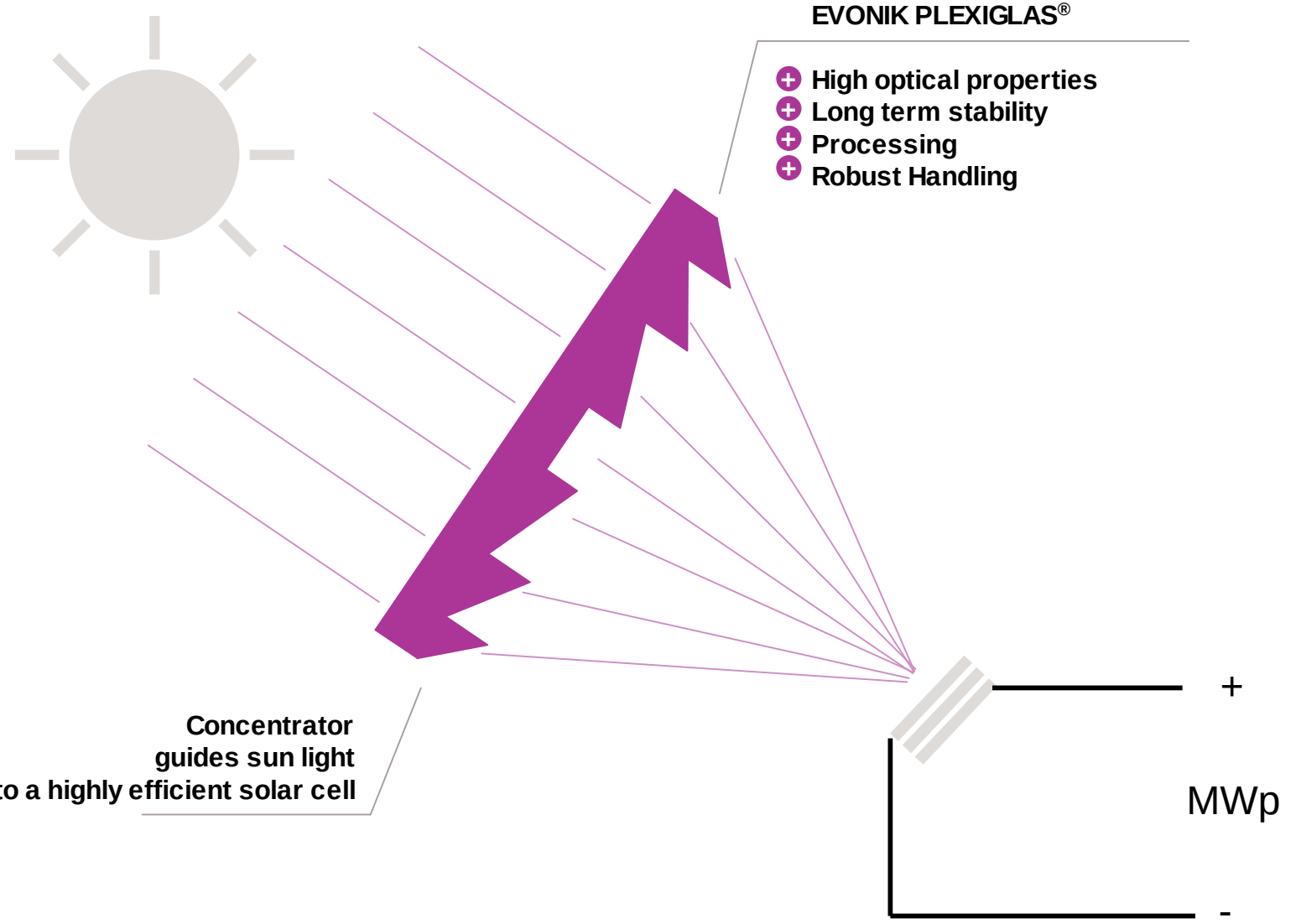
The Lens Determins the Performance of the Total System

Optics

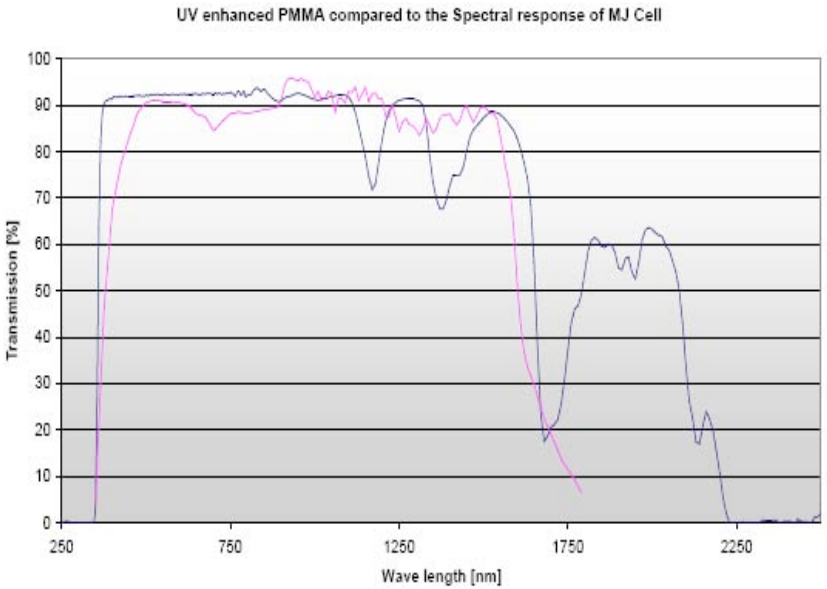
Long term stability

Processing

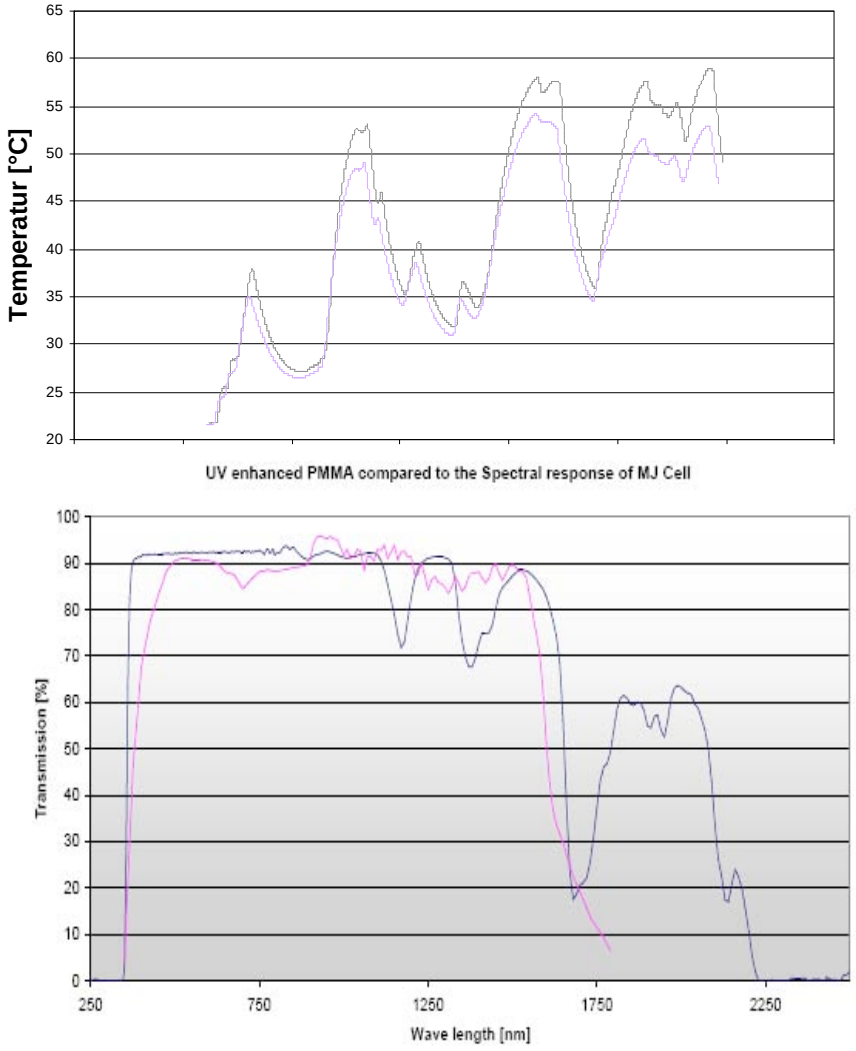
Robust Handling



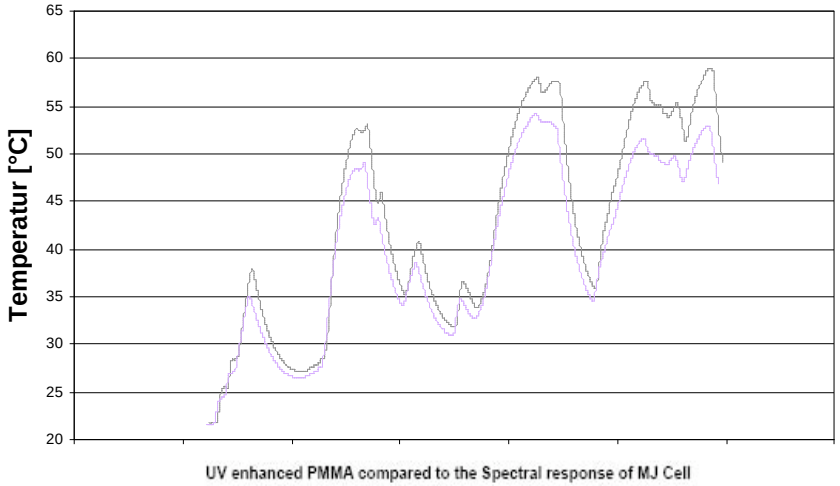
Outlook
PLEXIGLAS® UV- enhanced

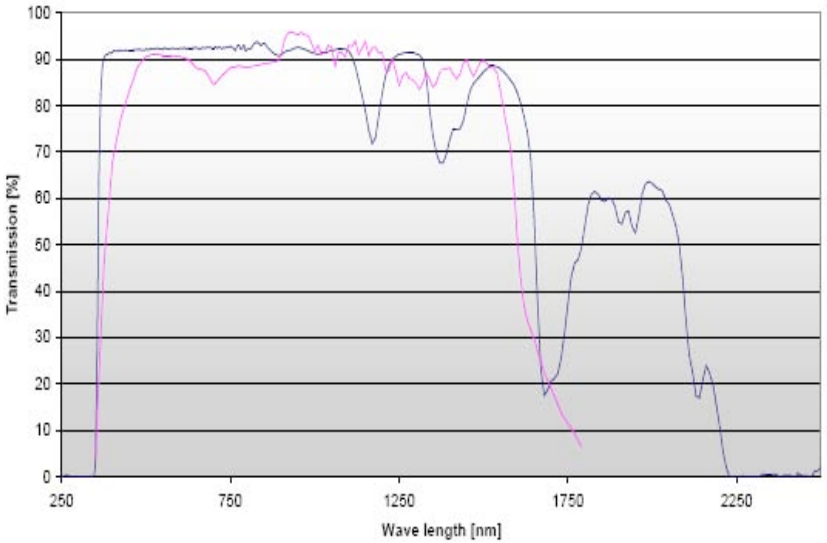


Outlook
PLEXIGLAS® UV- enhanced

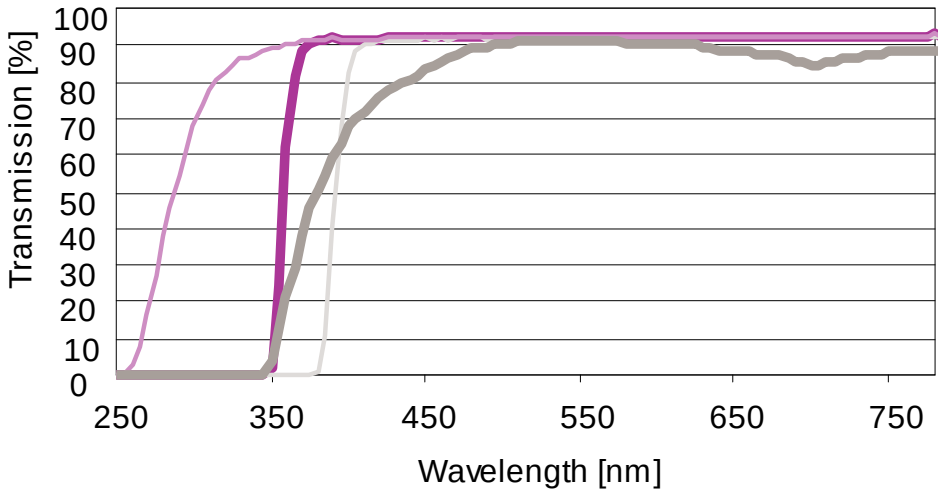


Outlook
PLEXIGLAS® UV- enhanced





UV-enhanced PLEXIGLAS®
„naked PMMA“
Spektral resonse of a MJ cell



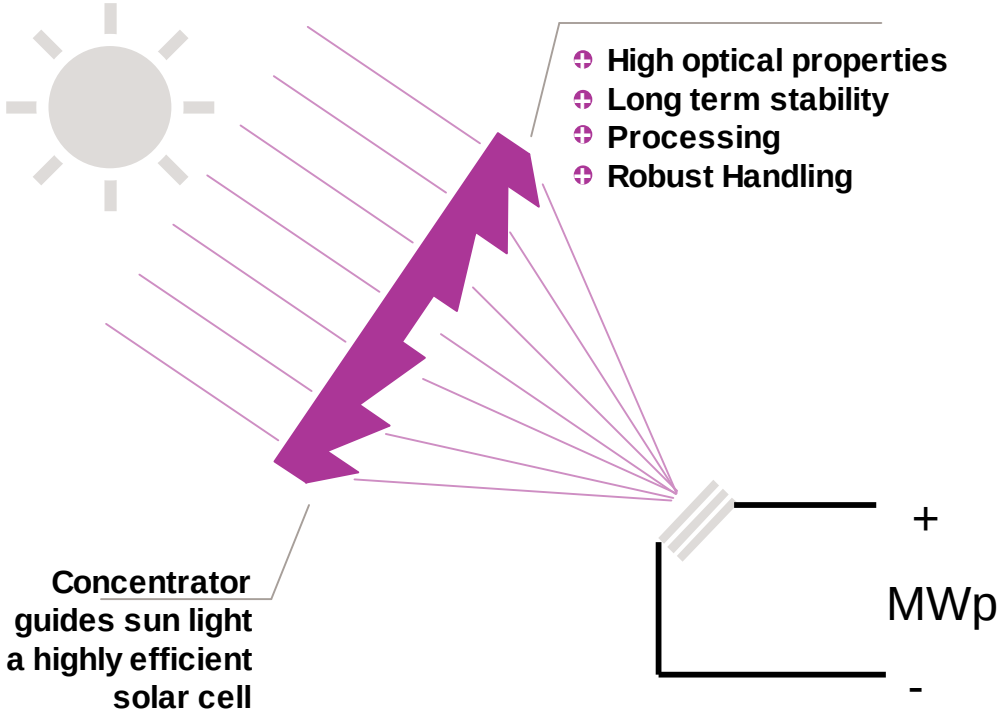
Advantages

- **Optimized UV- protection for the MJ cell**
- **Reduced thermal load on the cell by cutting irradiance which can not be converted**
- **Prolonging life cycle of the cell**
- **Prolonging the life time of MJ cells by cutting the unconvertible UV rays**
- **Increased module efficiency**

CPV Performance with PMMA Lenses

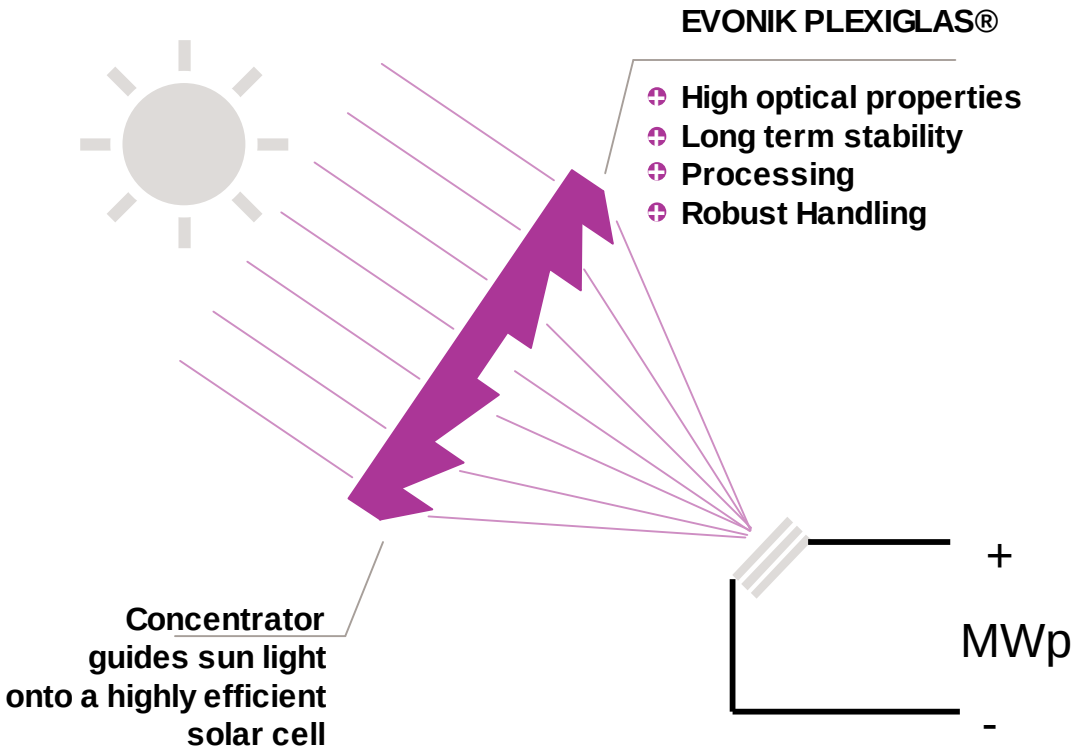
EVONIK PLEXIGLAS®

- **High optical properties**
- **Long term stability**
- **Processing**
- **Robust Handling**



Concentrator guides sun light onto a highly efficient solar cell

CPV Performance with PMMA Lenses



- There are different options and technologies to design lenses.
- ACRYLITE® and PLEXIGLAS® molding compounds and sheets are a well proven plastics solution
- Understanding market needs
- Increasing reliability by setting standards and passing the requirements
- Being a partner to bring this Industry forward
- Get in contact with us


EVONIK
INDUSTRIES