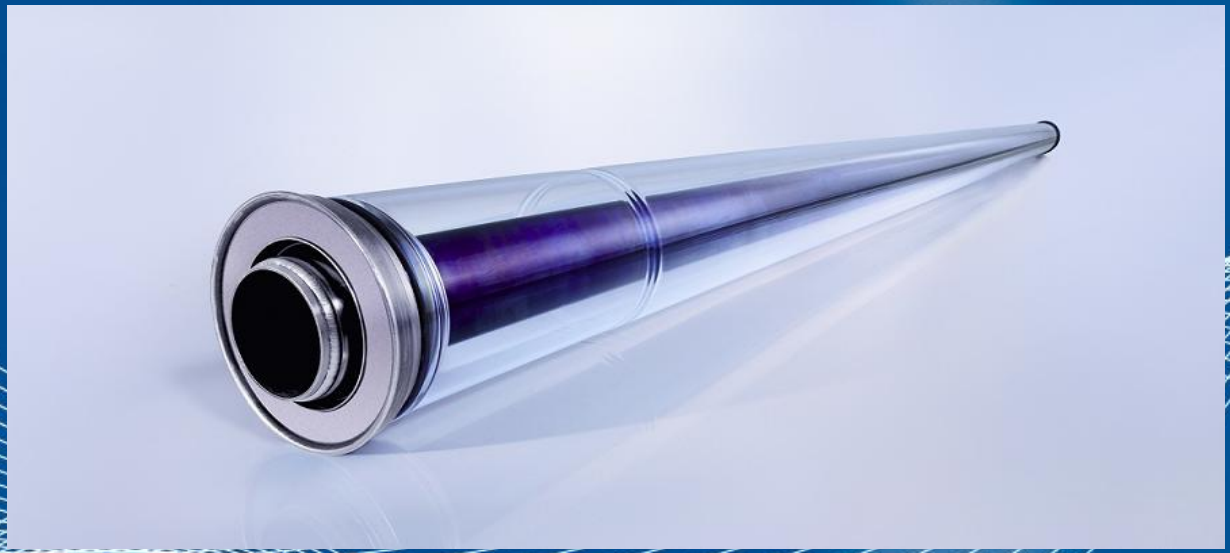
SCHOTT Solar CSP GmbH

SETTING THE BENCHMARK IN RECEIVER TECHNOLOGY



Christoph Fark, Managing Director SCHOTT Solar CSP GmbH

SCHOTT AG

A globally diversified international high-tech manufacturing group

Home Appliances

- Home Tech
- Flat Glass
- Solar

Precision Materials

- Pharmaceutical Systems
- Electronic Packaging

Optical Industries

- Advanced Materials
- Lighting and Imaging

- International technology company, founded 1884 in Jena (Germany), Owner Carl-Zeiss-Foundation
- 2.26 billion Euros sales in 2008/09; 74% exported
- Approx. 17,400 employees worldwide

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High quality components for solar power plants and photovoltaics

SCHOTT Solar AG

Solar power plants (CSP*)

- Solar receiver

Photovoltaics (PV**)

- Crystalline silicon module

- Thin film module

* *CSP: Concentrated Solar Power*
** *PV: Photovoltaics*

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Milestones

1983
- Start of receiver **glass supply** for CSP power plants by SCHOTT

2002
- Start of **receiver development** for CSP plants at SCHOTT

2005
- First order for 64 MW power plant Nevada Solar One (USA)
- Delivery of prototypes for molten salt test loops

2006
- Start of automated **receiver production in Germany** (Mitterteich)

2007
- Start of commercial operation of Nevada Solar One

2008
- Start of **production lines 2 and 3 in Spain** (Aznalcollar)
- Delivery of prototypes for direct steam test loops

2009
- Start of commercial operation of Andasol 1 in Spain
- Start of receiver **production lines 4 and 5 in the US** (Albuquerque, NM)
- New SCHOTT Solar® receiver generation with **improved optical characteristics**

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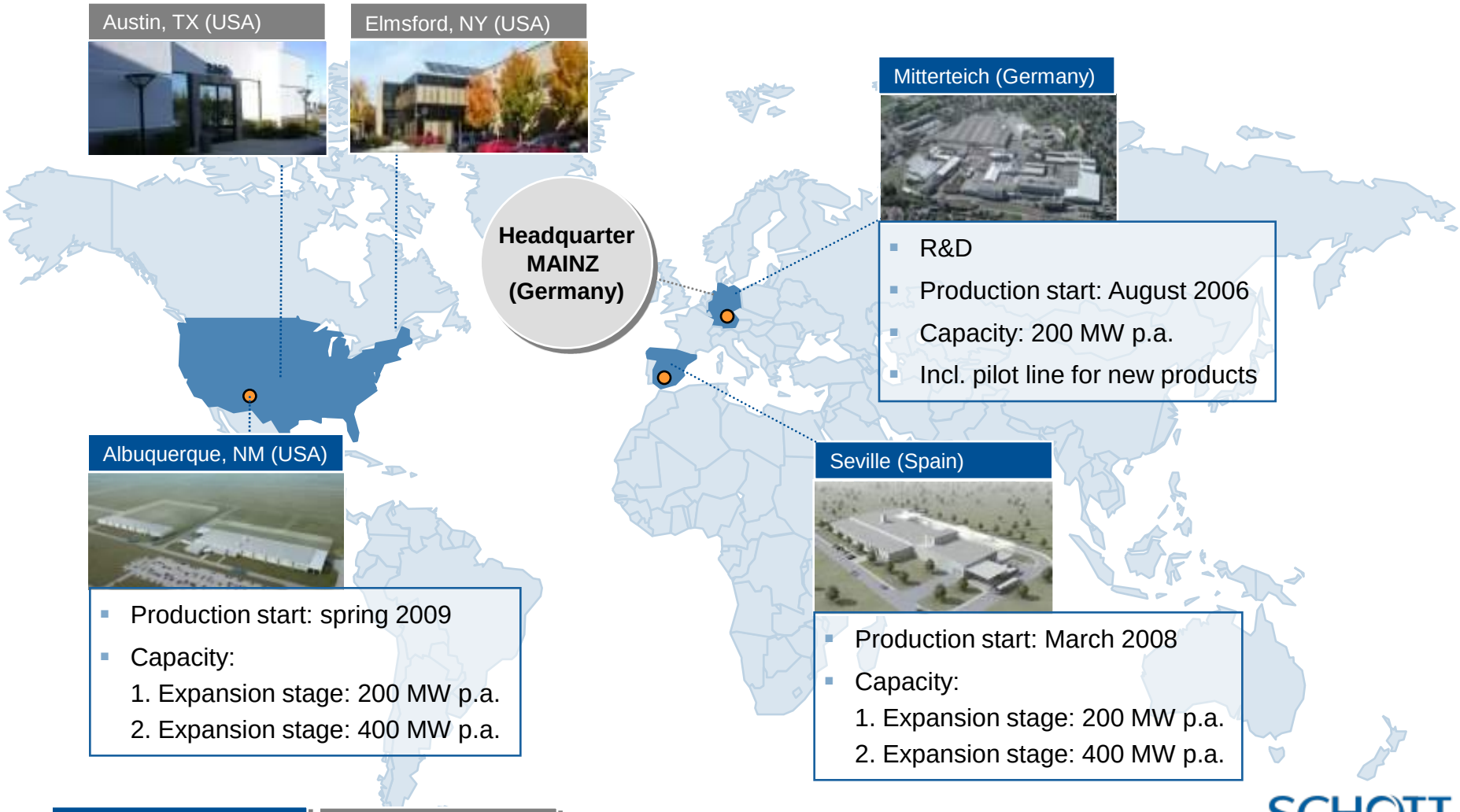
Production and sales locations



- R&D
- Production start: August 2006
- Capacity: 200 MW p.a.
- Incl. pilot line for new products

- Production start: spring 2009
- Capacity:
  1. Expansion stage: 200 MW p.a.
  2. Expansion stage: 400 MW p.a.

- Production start: March 2008
- Capacity:
  1. Expansion stage: 200 MW p.a.
  2. Expansion stage: 400 MW p.a.

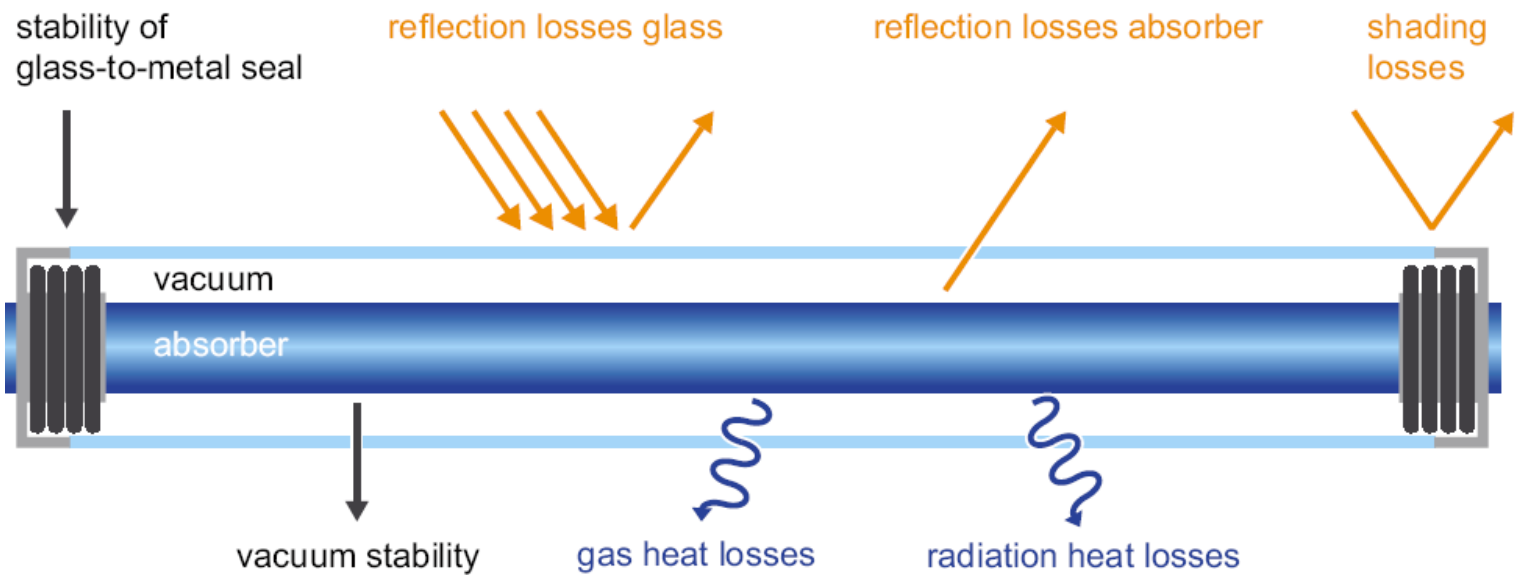
The Receiver

Core component of parabolic trough power plants

During operation receivers are mechanically and thermally stressed.

The quality of the receiver therefore has a decisive influence on the efficiency of the solar field.

The most important issues are:



Quality requirements for CSP receivers

For power plant projects a very long life span is required to

- Match the business plans which are based on long pay back periods
- Keep maintenance costs low during operation

During operation receivers are mechanically and thermally stressed

Most important issues are:

- Durability of glass-to-metal seal
- Stability of vacuum (e.g. low hydrogen permeation)
- Durability of absorber coating
- Abrasion resistance of anti reflective glass coating

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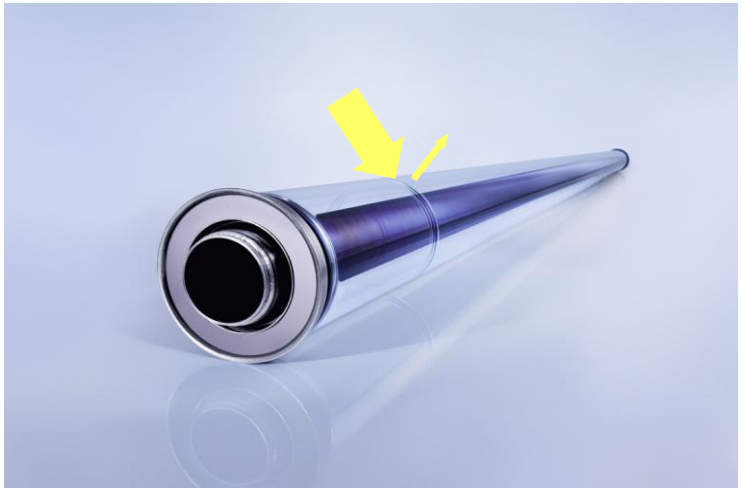
Quality requirements – anti-reflective coatings

1	High quality glass with anti-reflective coatings
2	Glass-to-metal seal & receiver endings
3	Lifetime of vacuum
4	New absorber coating



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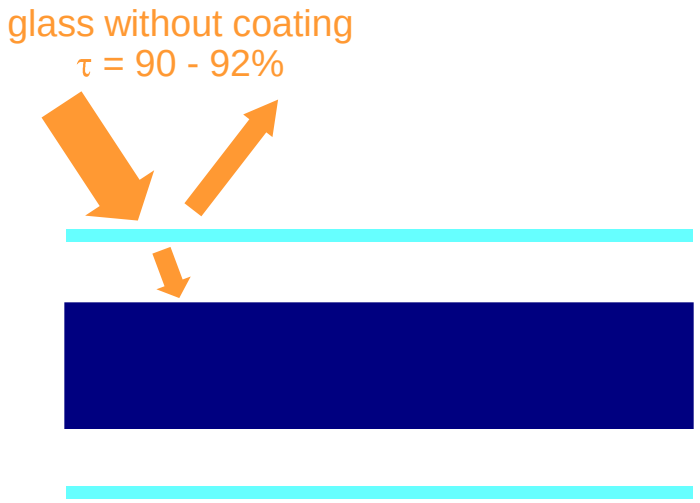
Anti-reflective coatings – Main challenges

- Typical transmittance values for borosilicate glass: 90 – 92%
- Adhesion of AR-coating to borosilicate glass
- Long-term stability of the coating
- Higher transmittance can be achieved through anti-reflective (AR) coatings



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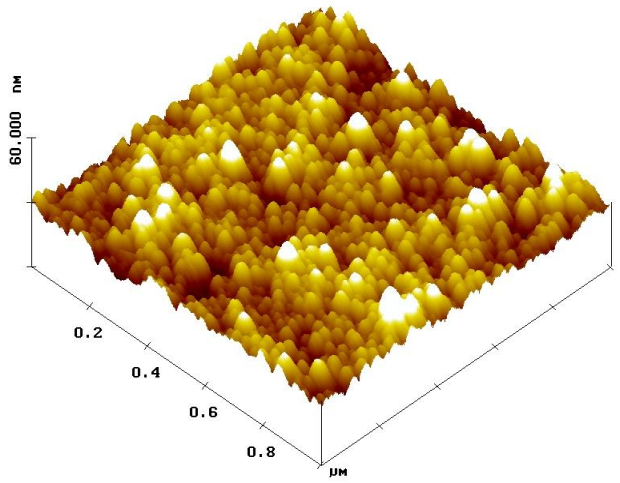
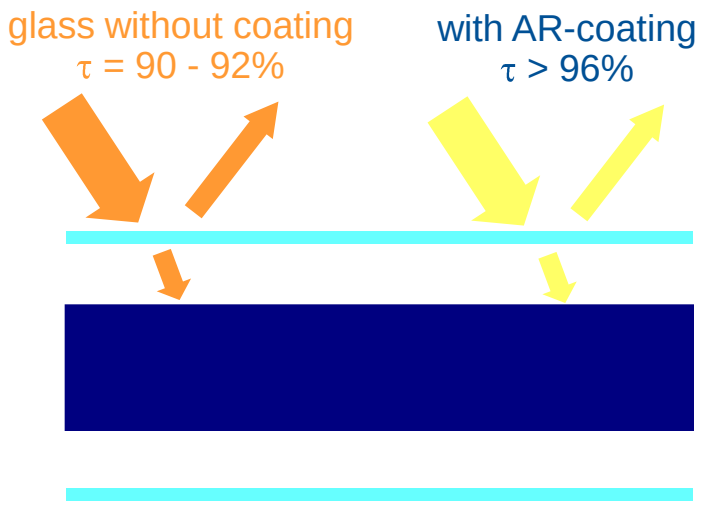
Anti-reflective coatings – USP and IP SCHOTT CSP

- Sol-Gel coating based on alcoholic dilutions with SiO2 nano particles
- Patented production process by SCHOTT Solar

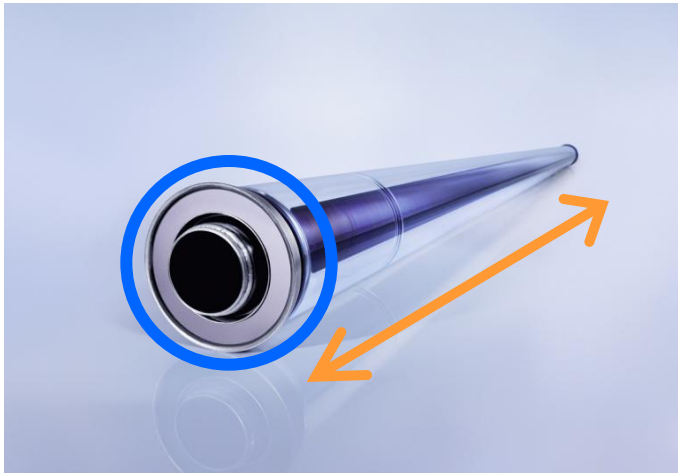




Composition of the AR-layer with
- **Maximum glass adhesion and long-term abrasion resistance**
- **Transmittance values up to 97%**

Quality requirements – Glass-to-metal seal & receiver endings

1	High quality glass with anti-reflective coatings
2	**Glass-to-metal seal & receiver endings**
3	Lifetime of vacuum
4	New absorber coating



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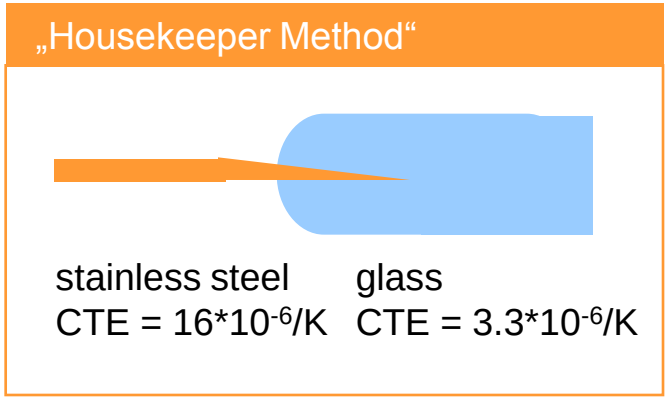
Glass-to-metal seal – Main challenges

- insulation with vacuum between glass and steel tube

  ➔ minimization of heat conduction losses

- durability of vacuum depends on mechanical strength and temperature resistance of glass-to-metal seal

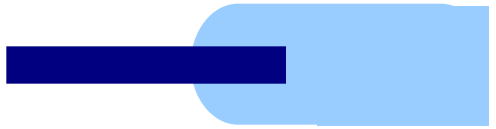
- **glass and steel have different coefficients of thermal expansion**



Glass-to-metal seal – USP and IP SCHOTT CSP

- new approach with matching coefficients of thermal expansion ➔ sealing with low stress
- automated production process
- automated proof test (100%)
- patented material combination

SCHOTT Approach



Matching coefficent of thermal expansion of glass and metal

Minimization of defects during power plant operation
Stress at 400 C six times lower than with housekeeper method

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Receiver endings – Main challenges

- Essential to compensate different thermal expansion of steel and glass
- Design affects active absorber area
- Competitive products position the bellows on the outside

  ➔ reduces active aperture area significantly

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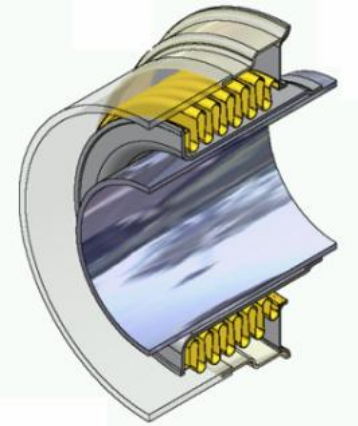
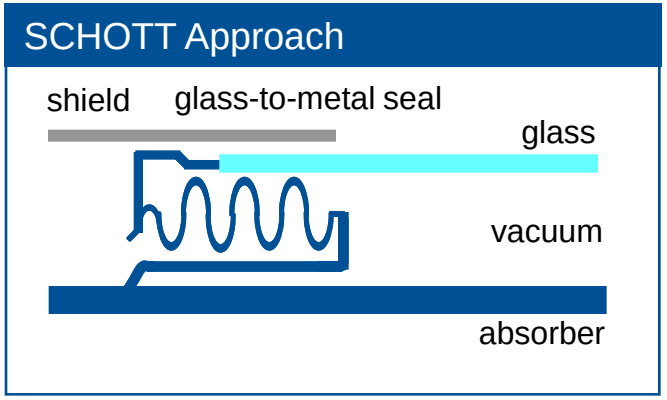
Receiver endings – USP and IP SCHOTT CSP

- Bellows positioned on the inside
- Glass-to-metal-seal is protected against radiation
- Bellows are compressed during operation ➔ further reduction of shading
- Patented design





Active aperture area of the receiver

- More than 96% of the total area
- At least 2% more than the competition

Quality requirements – Lifetime of vacuum

1	High quality glass with anti-reflective coatings
2	Glass-to-metal seal & receiver endings
3	Lifetime of vacuum
4	New absorber coating

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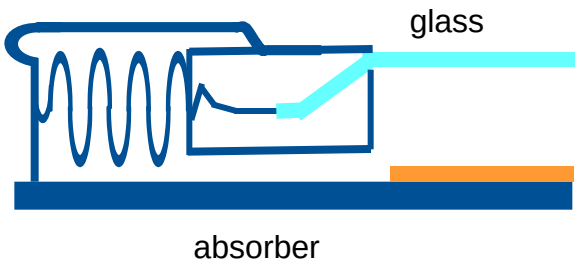
Lifetime of vacuum – Main challenges

- Heat transfer oil decomposes during operation, hydrogen is generated
- Hydrogen permeation leads to vacuum loss and increased heat loss (factor 2-3)
- Getter material absorbs hydrogen to maintain vacuum, but capacity is limited
- Permeation rate depends on oil quality, temperature, steel properties, etc.

Competition



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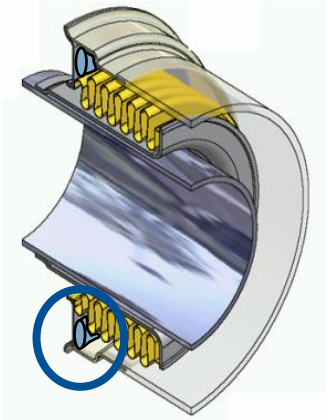
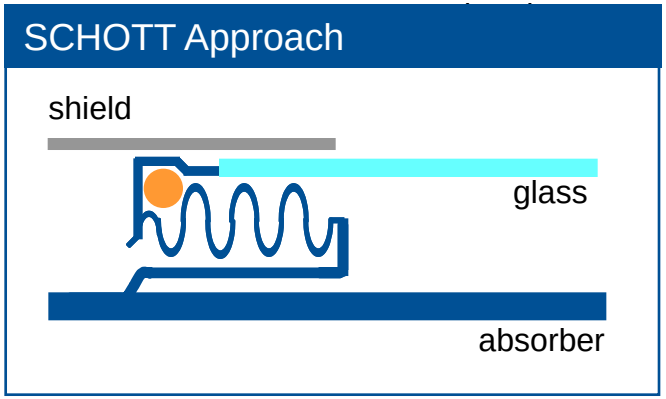
Lifetime of vacuum – USP and IP SCHOTT CSP

- Getter material integrated in the bellows (coolest position of the receiver)
- Increases long-term vacuum stability/ receiver lifetime up to 30% compared to the competition
- Patented design





Quality requirements – New absorber coating

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2	Glass-to-metal seal
3	Lifetime of vacuum
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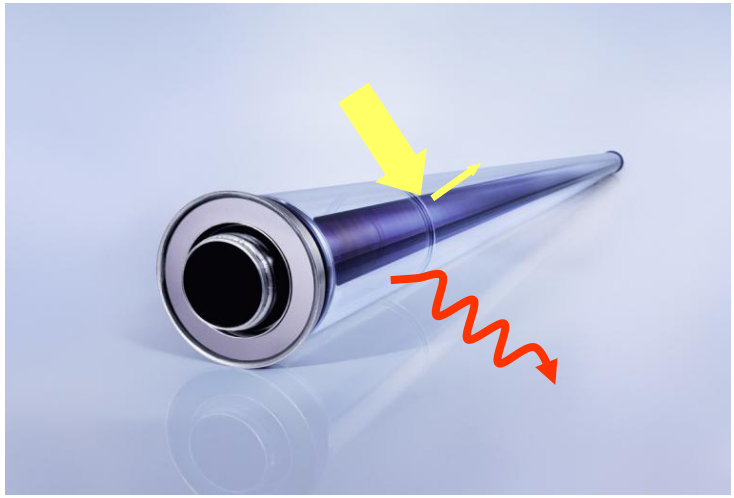

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New absorber coating – Main challenges

- Optical properties of absorber coating are crucial for overall performance of solar field
- Coatings have to be stable at high temperatures

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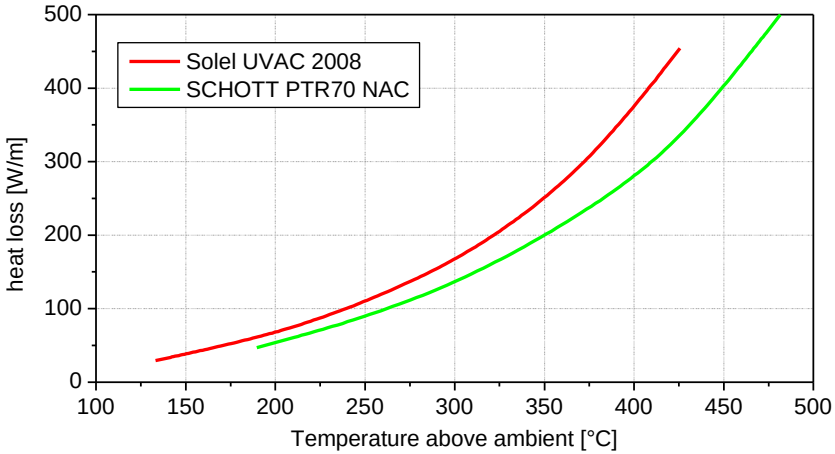
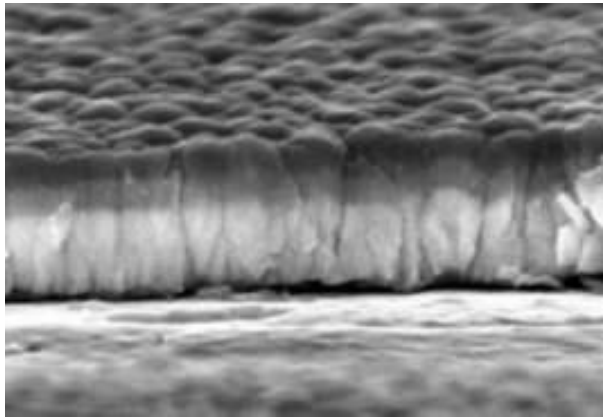
New absorber coating – USP and IP SCHOTT CSP

- New coating – introduced Sept. 2009
- Polished low-carbon steel as substrate material and multilayer cermet coating
- NREL1 test: competitor‘s receiver shows 25% higher heat losses





Thermal emittance values below 10%
Solar absorptance ≥ 95% at 400 C
Value of receiver increased by at least 12%
Reduction of LEC by 2-3%

1 NREL: National Renewable Energy Lab, Golden, Colorado, USA

Parabolic trough – the second generation

Reference projects

Nevada Solar One, USA

- First parabolic power plant after SEGS I – IX
- Capacity: 64MW$_{el}$
- Construction start: February 2006
- Start of operation: June 2007

Andasol 1, Spain

- First European parabolic power plant
- Capacity: 50MWel (+ thermal storage: 7.5 hrs)
- Construction start: July 2006
- Start of operation: December 2008

Since then, numerous other parabolic trough plants have been built or are currently under construction in the US, Spain, Northern Africa and the Middle East, with more than 80 projects in Spain alone.

SCHOTT PTR®70 Receiver

- >> 500.000 already delivered to power plants around the globe
- Distance equivalent to the distance between Bangalore and Delhi

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With a broad R&D pipeline, SCHOTT Solar is actively shaping the future of parabolic trough technology

Examples

➔ **larger receiver diameter and length for larger solar collector designs**

- SCHOTT PTR®80 Receivers
- SCHOTT PTR®90 Receivers

➔ **receiver suitable for alternative heat transfer fluids and higher working temperatures**

- SCHOTT Receivers for Molten Salt
- SCHOTT Receivers for Direct Steam

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Thank you for your attention