Anforderungen an die Analytik für die Prozesskontrolle bei der Herstellung von Dünnschichtsolarzellen aus industrieller Sicht

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SULFURCELL

Sulfurcell's history: Passion for CIS since 1991

1991 RESEARCH **2003** PILOT PRODUCTION **2008** MASS PRODUCTION


HMI lab


Sulfurcell's pilot plant


CIS technology


Sulfurcell's products in application

1991 – 2001	Hahn-Meitner-Institut Berlin takes lead in thin-film technology based on Copper-Indium-Sulfide (CIS)
2000 – 2002	Nikolaus Meyer starts planning & capital acquisition for a pilot production of CIS-type PV-modules
April 2003	Launch of HMI spin-off Sulfurcell (EUR 16m financing closed)
July 2004	Plant begins operation
July 2005	Scale-up of CIS technology completed (5 x 5 ⇒ 125 x 65 cm²), prototype presented to public
Dec 2005	Market entry
Dec 2006	Innovation award from the governments of Berlin & Brandenburg
2005 – 2008	Continuous improvement of key performance indicators up to a running rate of 2.5 MW/a / 80 % yield
Jul 2008	75 MW expansion started (EUR 85m of equity raised)

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Sulfurcell's 75 MW production facility CIS-Line

Dimension

- 16.000 m² production
- 3.000 m² offices

BIPV

- 700 facade-integrated modules
- PV test field + 0.5 MW PV power plant on roof

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Sulfurcell in numbers

SULFURCELL SOLARTECHNIK GMBH

- Location: Berlin, Germany
- Site: 1.600 m² pilot plant (in operation),
  21.000 m² production (under construction)
- Staff: 165 (Aug08)
- Revenues: EUR 4m (2008)
- Management: Dr. Nikolaus Meyer (CEO)
  Dr. Rüdiger Stroh (COO)


Rüdiger Stroh, Nikolaus Meyer

SHAREHOLDERS

- Private Equity type investors, a.o.:
  - Intel Capital (Santa Clara)
  - Climate Change Capital (London)
  - BEU (Vattenfall, Gaz de France) (Berlin, Paris)
  - Ventegis Capital (Berlin)
  - Demeter (Paris)
  - Zouk (London)
  - AIG (Zürich)
  - Bankinvest (Kopenhagen)
  - Engelbert Giesen (Berlin)
  - Masdar (New York)
- Helmholtz Zentrum Berlin (Hahn-Meitner-Institut)
- Management

Sulfurcell serves the market with high-quality products with a focus on building integrated photovoltaics (BIPV)

SULFURCELL'S PRODUCT PORTFOLIO

Framed modules

- Max. mechanical load (4800 kPa/m²)
- Applicable as cladding element

Frameless modules

- Optimized for minimum costs
- Excellent self-cleaning

Modules for roof integration

- Aesthetic excellence
- Replacing roof tile (rainproof)

QUALITY

All products passed accelerated life-time tests (IEC 61646) and are certified by German TÜV

CONTRACTED WHOLESALER

IBC SOLAR

krannich Solar

energiebau solarstromsysteme gmbh

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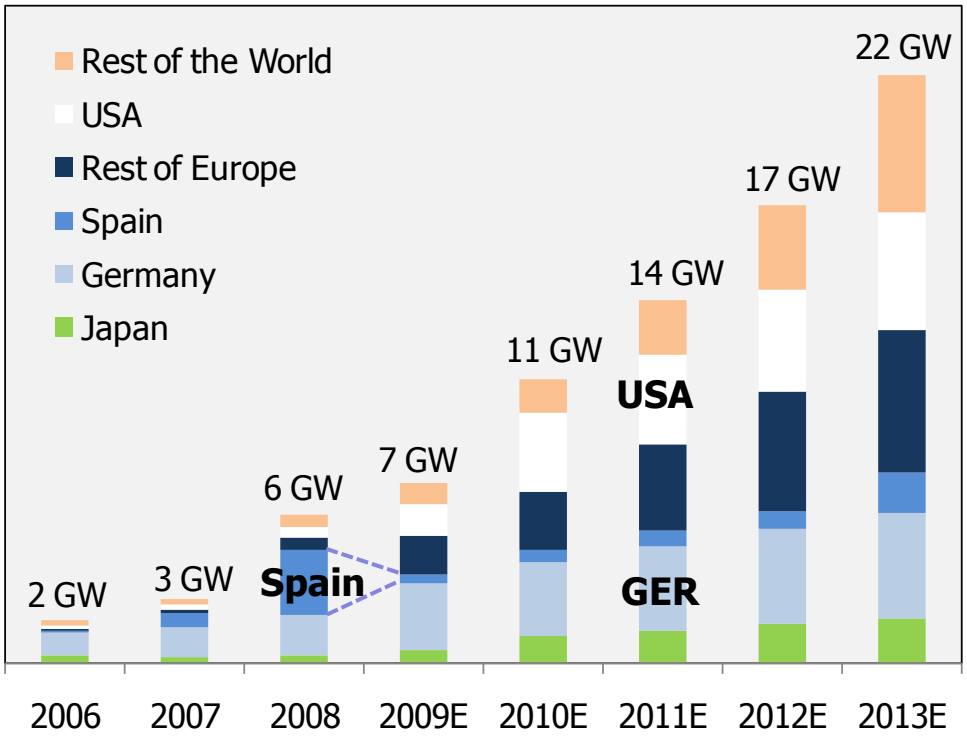
Market growth continues after prices felt 30 – 50 %

Market development

- 2009: Collapse of the Spanish market and impact from the global economic crisis shifted market into a oversupply situation
  - ⇒ Large manufacturer suffer from over-capacity
  - ⇒ 30 % price drop
- German incentive program and low system prices allow high margins on PV investments and attract international equity and debt investors
  - ⇒ German market vital and globally dominating since June 09
- Long-term perspective for the PV market encouraging due to fast growth of US and Mediterranean markets

Annual installations of PV modules

Source: 2009 Forecast of the European PV Industry Association (Police-driven scenario)



Thin-film solar modules based on materials from the CIS/CIGS-family: Highest efficiency potential and features predestined for solar architecture

WAFER

Crystalline Silicon (poly-Si)

- Inherently high manufacturing costs
  - Substantial need of high-purity silicon
  - Longish production process
- Unattractive for solar architecture

THIN-FILM

CIS-materials (CIS/CIGS)

- Only thin-film technique equalling efficiency potential of poly-crystalline Silicon (20 %)
- Modification of material composition give room for continuous improvement
- Attractive outward appearance

THIN-FILM

Cadmium Telluride (CdTe)

- Today lowest manufacturing costs due to economy-of-scale (First Solar 08: > 250 MW)
- Concerns on certain markets regarding environmental and health impact

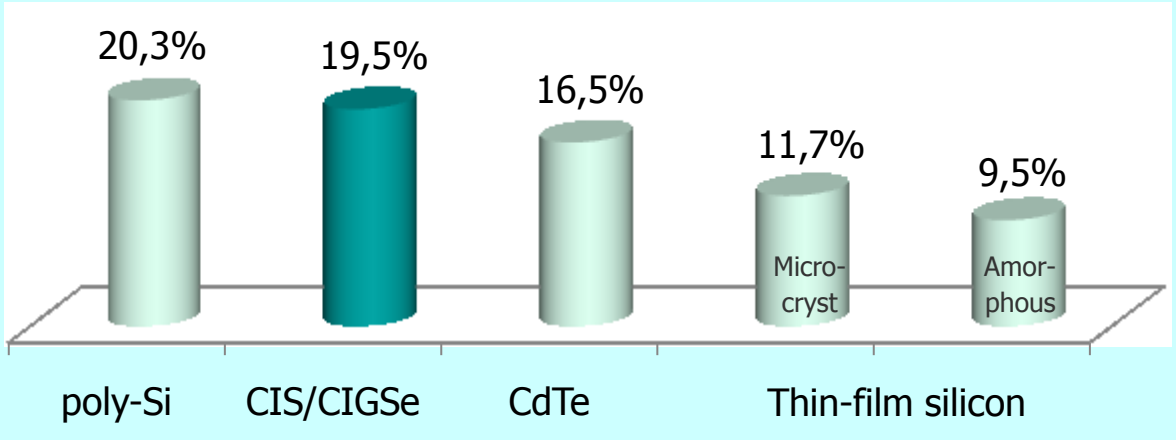
THIN-FILM

Thin-film silicon

- Today's commercial products exhibit 6 – 8% efficiency in spite of 20 years of optimization
- High capex per MW
- 10 – 20 % efficiency degradation during first year of operation

Maximum efficiencies achieved on laboratory cells

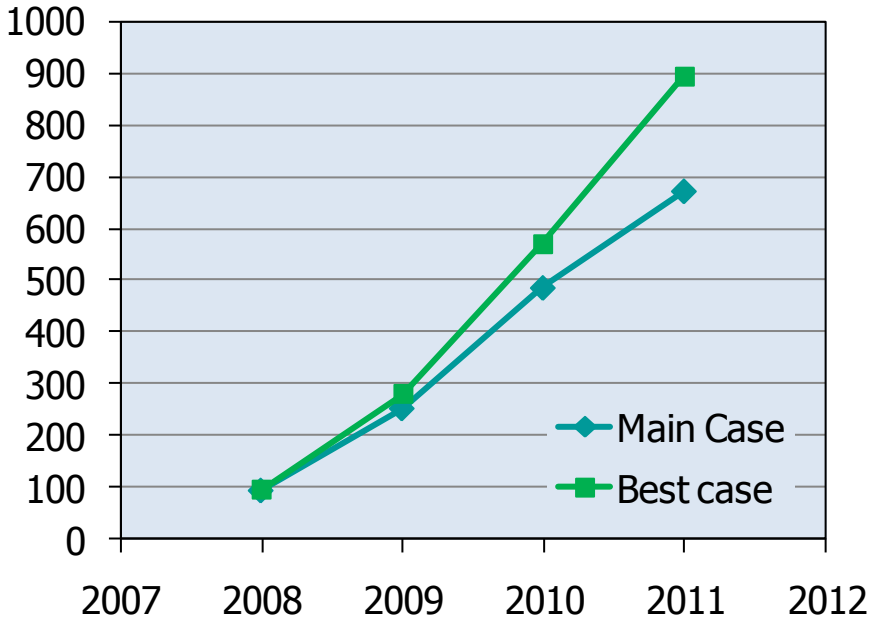
Source: Solar efficiency tables, Progress in PV, Vol. 15, 425-430 (2007)



Production volume CIS-based

- More than twenty companies in the world started industrial manufacturing of CIS-type PV modules
- Production volume will rise to more than 500 MW by 2011
- Cost position depends on
  1. Module efficiency (today: 7 – 11%)
  2. Yield (today: 30 – 90%)
  3. Capex costs (uptime) (today: 0.30 – 0.60 €/W*)
- Cost perspective for a mature high volume production of 11% modules (> 75 MW/a): 0.5 – 0.7 €/W

Annual production volume CIS (MW)



Source: LBBW 2009

* Annual depreciations + capital costs = 20% of capex (€ 1.5 – 3m per MW)

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Broad variety of industrial manufacturing methods for CIS/CIGSe

	CIS/CIGSe manufacturing (process/technique)		**Substrate**	**Module assembling** (serial connection)
Würth (GER)	**1 step**	**Coevaporation**	**Glass**	**Integrated**
Solibro (GER)				
Solyndra (US)			**Glass tubes**	
Global (US)		**Coevaporation (role-to-role)**	**Metallic foil**	**Post cell processing**
Solarion (GER)			**Polymer foil**	
Avancis (GER)	**2 step**	**Sputtering + Annealing**	**Glass**	**Integrated (patterning)**
Centrotherm (GER)				
Honda (JN)				
Johanna (GER)				
Showa Shell (JN)				
Sulfurcell (GER)				
Odersun (GER)		**Sputtering + Annealing (role-to-role)**	**Metallic foil**	**Post cell processing**
Nanosolar (US)		**Spraying + Annealing (role-to-role)**		

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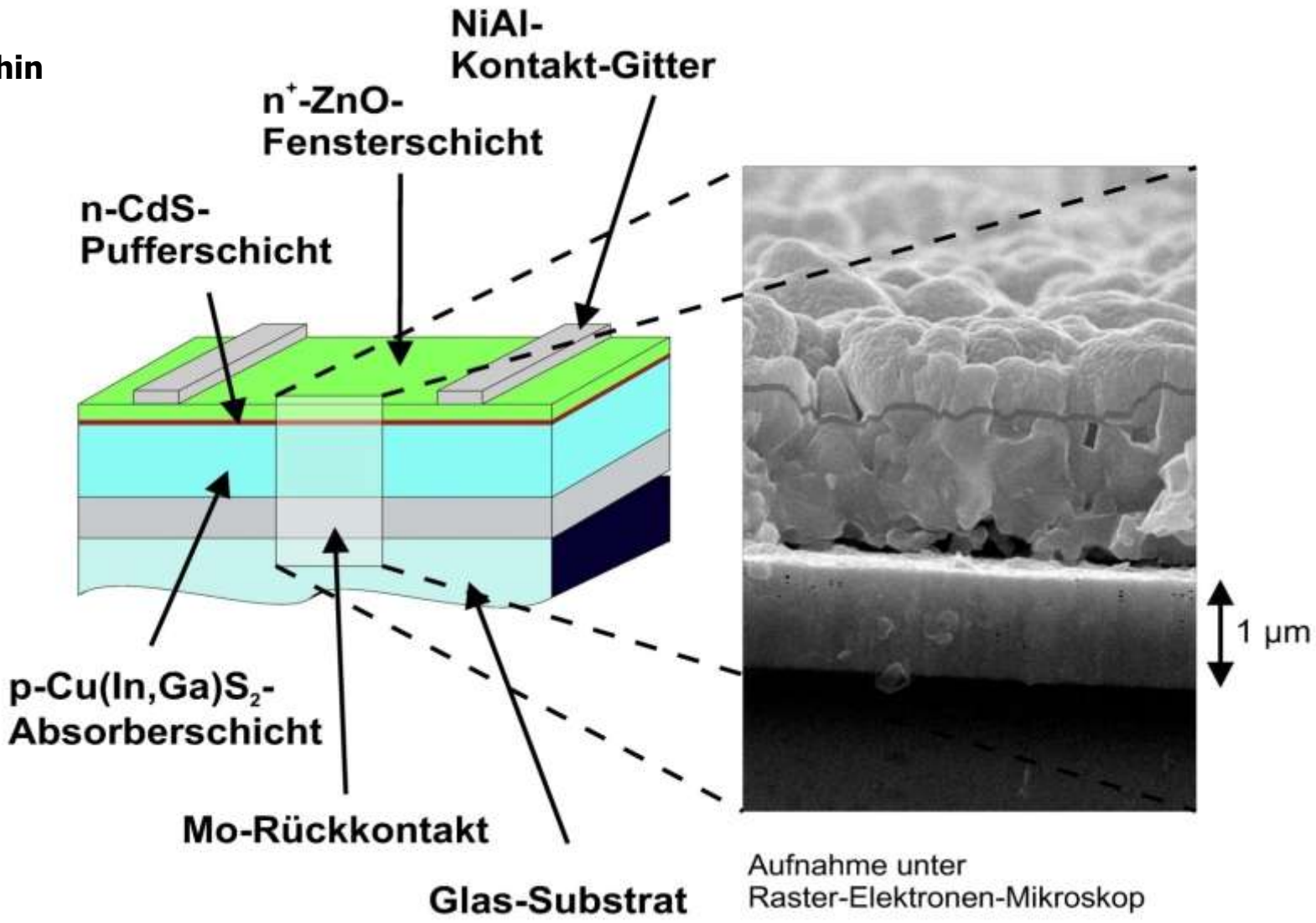
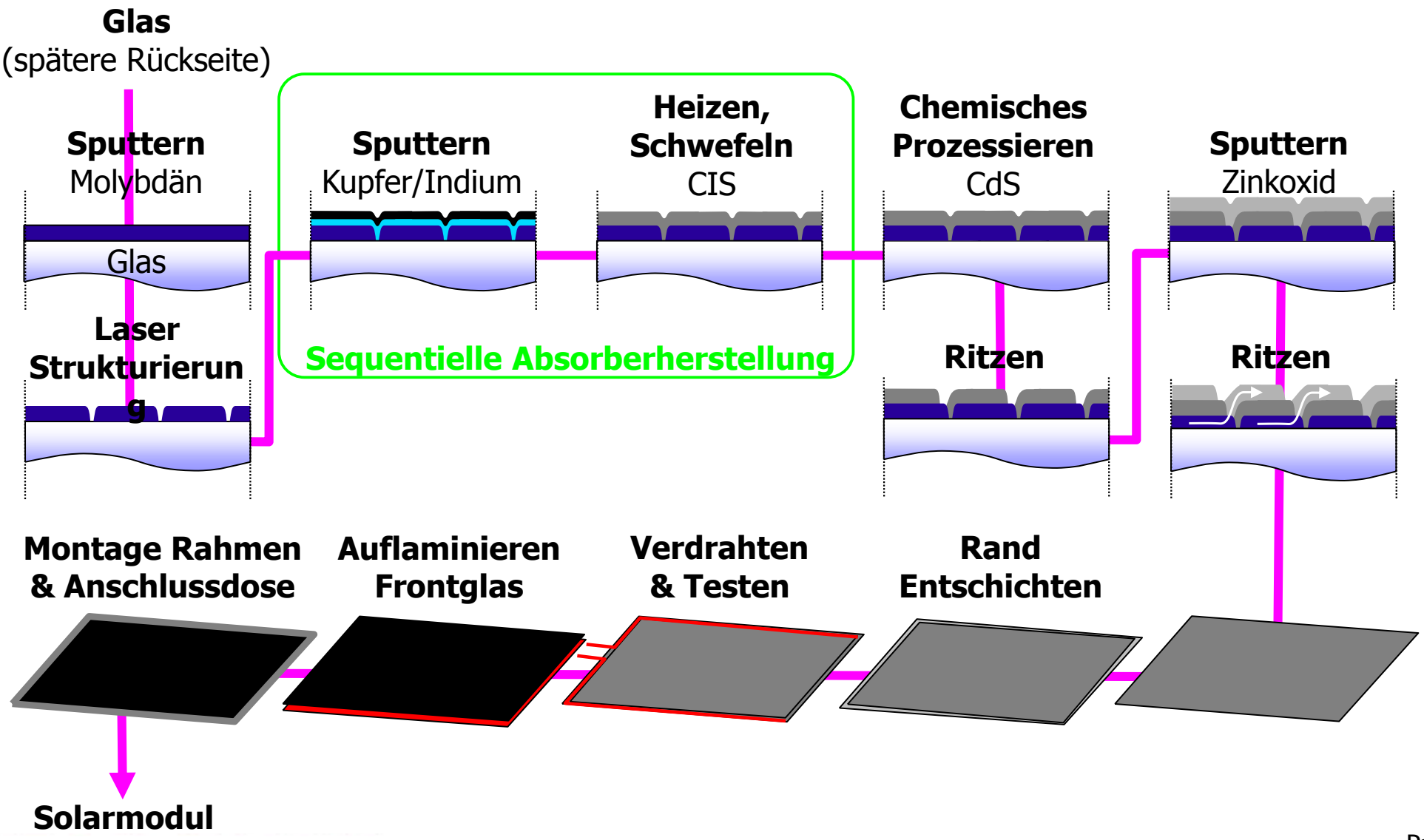
Thin film solar cell

- **Layer structure of a thin film solar cell**
- homojunction
- Metallic back contact
- CIS based absorber (1-2 µm thick)
- Transparent window, usually ZnO



Manufacturing – layer deposition, patterning, finishing

Typical thin film production process



Continuous quality control – a daily in-house job at Sulfurcell

Accelerated life-time test – Sulfurcell resources

- Damp heat test
- Dry heat test
- Thermal cycling test
- Humidity-Freeze test
- UV irradiation
- Mechanical load and deformation test
- Light-soaking test

Process control

- Electrical and optical analysis (spectroscopy)
- Microscopic analysis of layer structure
- Homogeneity analysis
- **X-ray analysis**

System test

- Monitoring of PV-test systems
- Qualification of inverters and mounting systems

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Challenges

- CIS materials are "young" industrial materials. Many material or device effects are either not yet known or not common sense. Production stability and quality assurance need:
  - CIS related expertise of the manufacturer's technology team
  - Production experience with CIS-based technology
  - Scientific support
  - Industrial knowledge

  This is different to the crystalline Silicon world where processes are well-defined and materials perfectly known.
- Production and quality issues in CIS manufacturing are frequently under-estimated. It is more than efficiency that needs to be optimized (a.o. product stability, cycle-times, yield, process % quality controls). Production phases with poor performance indicators or product issues last typically years not quarters.
- **Sophisticated equipment for advanced process control will help to accelerated learning curves, shorten ramp up times of production volumes → accelerate industrialization of CIS based technologies**

Applications for X-ray based diagnostics

Layer characterisation

- Film thickness
- Stoichiometry / Layer composition
- Phase composition
- Depth profiling - (R&D)

In-situ diagnostics

- In-line process control of film thickness
- Monitoring of very fast thermal processes for absorber layer growth - (R&D)

Reaction kinetics

- Fundamental process and equipment optimization - (R&D)

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Outlook

Requirements for analytics from an industrial point of view

- Rapid measurements – integration times below 30sec required
- Reliable
- Reproducable
- Robust – compatible with production environment (no clean rooms)
- Affordable
- In-situ diagnostics
  - In-line process control of film thickness, Monitoring of very fast thermal processes for absorber layer growth - (R&D), Reaction kinetics: Fundamental process and equipment optimization - (R&D)

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