p/n-Junction Formation for Advanced High Efficiency Solar Cells: Theory, Technology, Equipment

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Solar cell & Module
Thin film module
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International Presence


Headquarters, Blaubeuren


GP Solar, Constance


FHR, Dresden


Glatt, Abensberg


CTPV Korea


CTPV Shanghai

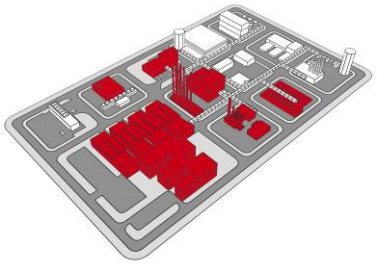

CTPV Taiwan


CTPV Singapore

Integrated Product and Technology Portfolio

Silicon & Wafer

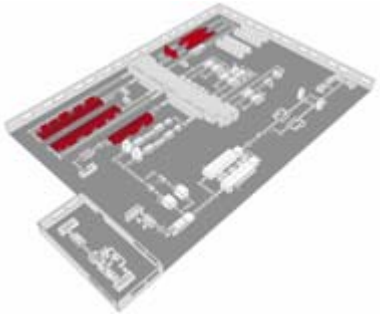
- Equipment
  e.g. CVD Reactor & STC-TCS Converter, Multi Crystalline Ingot Furnace



- **> 3000 t**
  Silicon Production Plant

Thin Film Module

- Equipment
  e.g. Sputter-Equipment



- **50/100 MW**
  CIGS-Thin Film Module Production Line

Fab Design

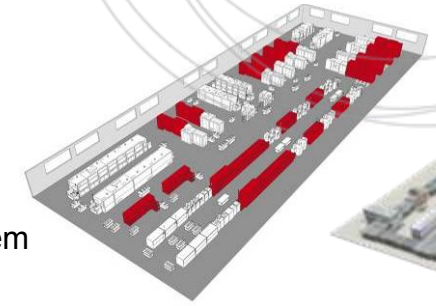
Facility Design

Technology

Turnkey & Single Equipment

Solar Cell & Module

- Equipment
  e.g. PECVD System



- **30/60 MW**
  Solar Cell Production Plant

- **30/50/60 MW**
  Module Production Lines

Semiconductor & Microelectronics

- Equipment
  e.g. Vacuum Soldering System

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Products & Technologies

Turnkey Production Plants - Turnkey Lines - Key Equipment - Services

Key Figures

	2007	2008	2009	2010	2011
Employees:	178	1,050	1,131	1,448	>1,500*
Sales:	€ 166 million	€ 375 million	€ 509 million	€ 624 million	€ 690-710 million*
EBIT:	€ 21 million	€ 43 million	€ 37 million	€ 75 million	>10%

* estimation

Ranking of Top 10 PV Equipment Suppliers

Company	Rank 2009	Rank 2010	Revenues 2010, $M
Applied Materials	1	1	1495
centrotherm photovoltaics AG	2	2	825
GT Solar Incorporated	4	3	775
Meyer Burger	6	4	735
Gebr.Schmid GmbH+Co	3	5	570
Ulvac, Inc.	7	6	380
Roth & Rau AG	8	7	325
RENA Sondermaschinen GmbH	-	8	300
48th Research Institute of CETC	-	9	295
Oerlikon Solar	5	10	195

source: VLSI

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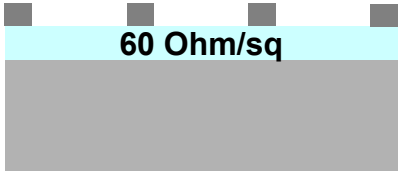
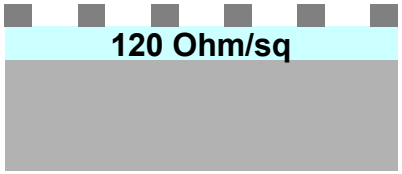
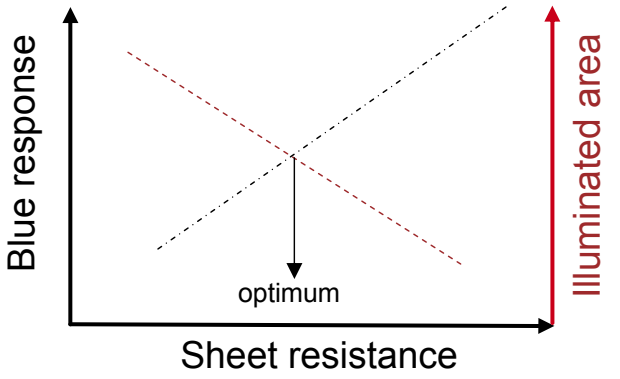
Requirements for Efficient Emitters

- low doping concentration
  → higher current (because of improved blue response)
- low doping concentration
  → high sheet resistance
- high sheet resistance
  → increased lateral (series) resistance
- increased lateral resistance
  → requirement for more fingers
- more fingers
  → more shadowing
- more shadowing
  → less current

→ trade-off between sheet resistance and shadowing to maximize generated photo current



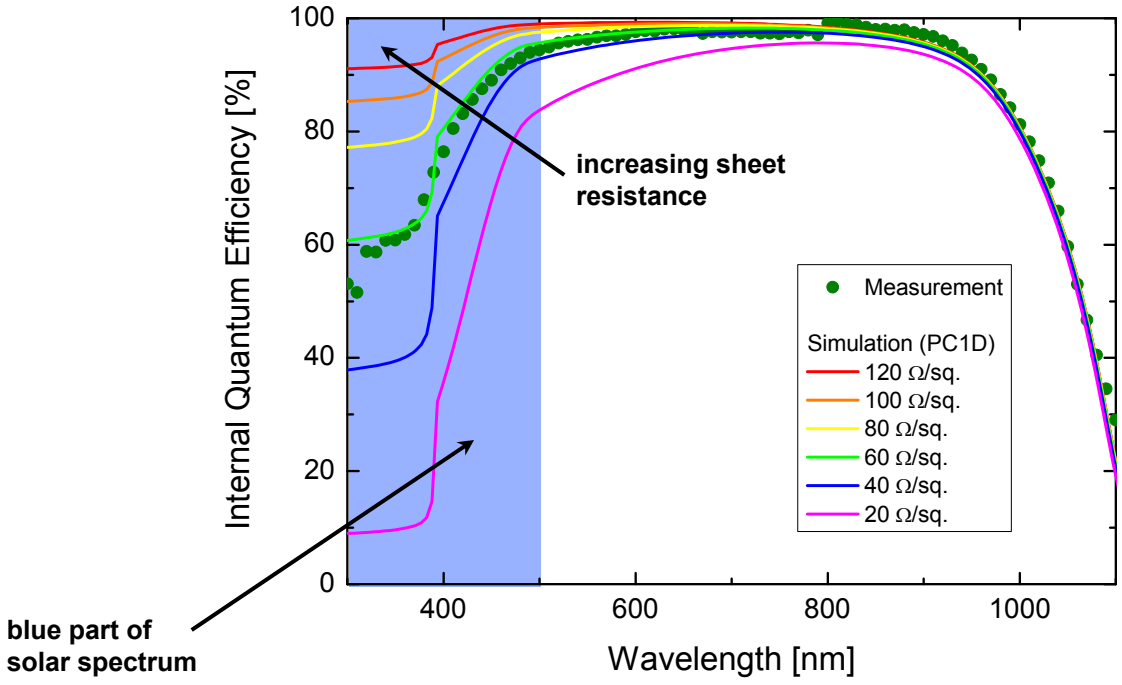




Homogeneous Emitter Technology

Facts:

- homogeneous sheet resistance across entire solar cell
- higher sheet resistance leads to higher efficiency due to improved blue response
- upper limit for sheet resistance because of contact formation by screen printing metal paste



Av. Line Efficiencies:

Efficiency (%):	**18.0**
V_{oc} (mV):	631
j_{sc} (mA/cm²):	36.3
Fill Factor (%)	78.5

@ 239 cm² Cz

Efficiency (%):	**16.4**
V_{oc} (mV):	619
j_{sc} (mA/cm²):	33.6
Fill Factor (%)	78.7

@ 243 cm² mc

But what if…

...sheet resistance is increased only between fingers

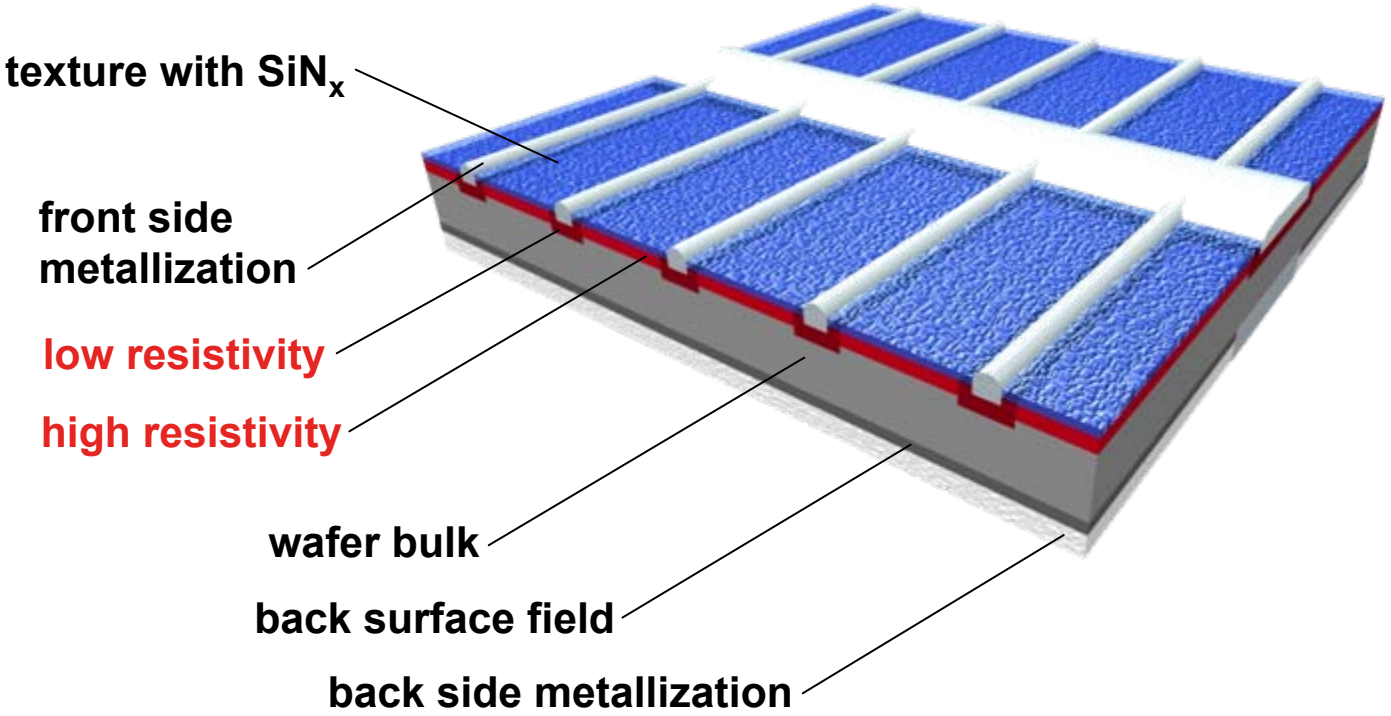
- contact formation under fingers not effected
- improved blue response between fingers
- still trade-off between sheet resistance and shadowing

→ selective emitter structure

Selective Emitter Structure

Facts:

- combines high resistance emitter between fingers and low resistance emitters beneath fingers for good contact formation through screen printing
- additional gain in current, due to improved blue response and gain in voltage due to reduced recombination in the emitter



Efficiency (%):	18.5
V_{oc} (mV):	636
j_{sc} (mA/cm²):	36.9
Fill Factor (%)	78.8

@ 239 cm² Cz

Efficiency (%):	16.9
V_{oc} (mV):	624
j_{sc} (mA/cm²):	34.1
Fill Factor (%)	79.2

@ 243 cm² mc

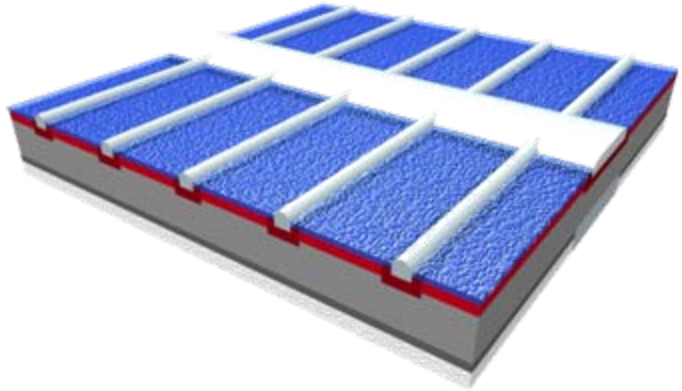
Selective Emitter Technology

Process sequence:

same as hom. emitter
- stack splitting and wafer inspection
- saw damage removal and texturization

new for sel. emitter
- $POCl_3$ diffusion with sheet resistance target of 100-150 Ω/sq.
- laser doping of emitter under fingers (remaining phosphorus in PSG selectively diffuses into emitter → 65 Ω/sq)

same as hom. emitter
- PSG removal
- ARC coating
- screen printing and contact firing
- laser edge isolation
- I-V characterization and sorting



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Inline vs. Batch Processing

Inline Process

- H_3PO_4 spray-on followed by inline diffusion

Batch Process

- in-situ PSG deposition and diffusion
- $4\ POCl_3 + 3\ O_2 \rightarrow 2\ P_2O_5 + 6\ Cl_2$
  $2\ P_2O_5 + 5\ Si \rightarrow 4\ P + 5\ SiO_2$

Comparison of Inline and Batch Diffusion

- Inline (belt furnace):
  - + high throughput
  - + cost effective setup
  - + easy wafer handling
  - - metal contamination from belt?
  - - quasi-open system?
  - - restricted gas composition?
  - - restricted process variation
    (belt speed determines through-put, temperature ramp and duration of diffusion)

→ lower efficiency of solar cells

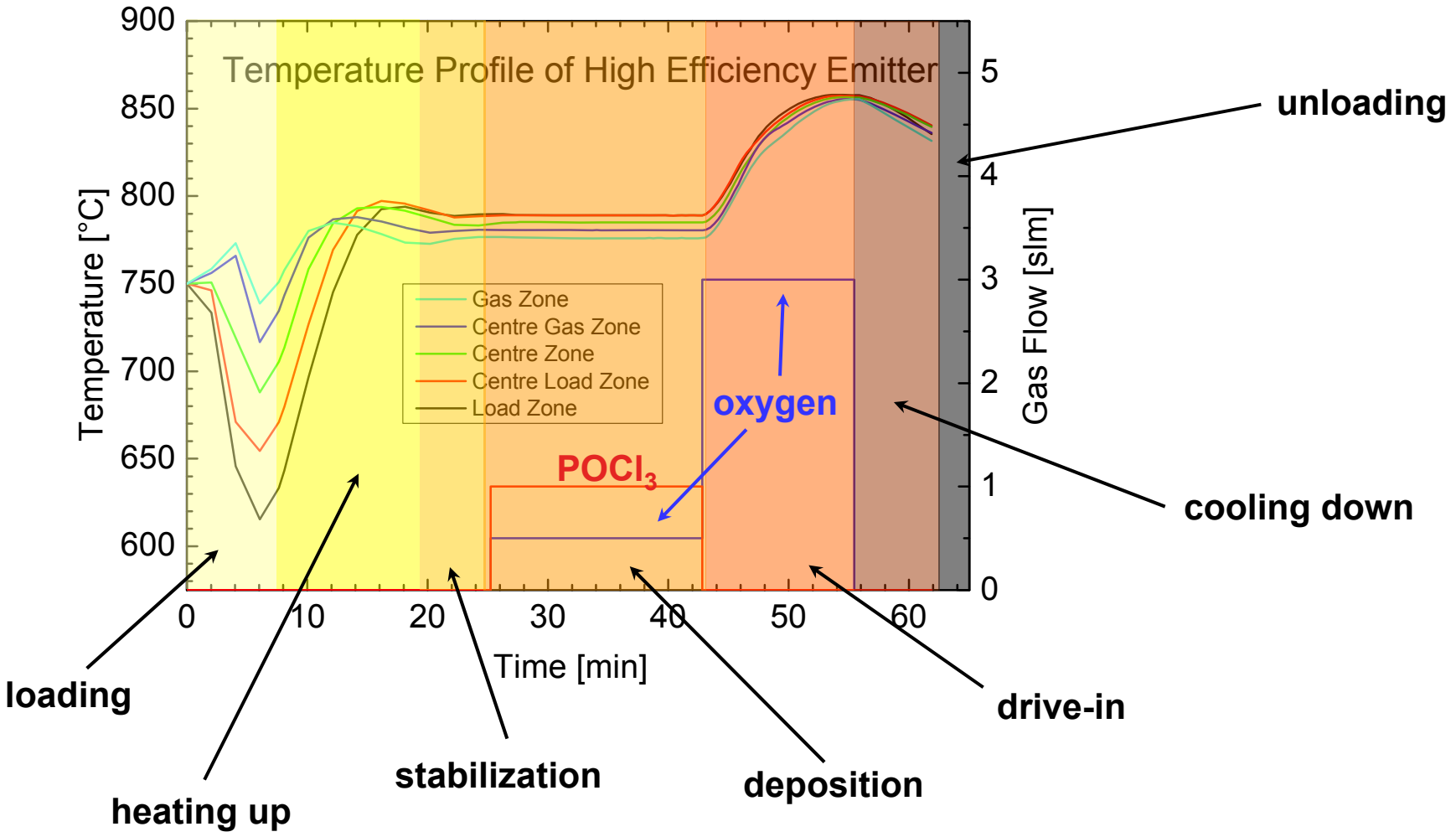
- Batch (tube furnace):
  - + high process versatility (temperature ramps, types of gas, gas flow
  - + self-cleaning (chloride)
  - + compact setup
  - + closed system (no contamination)
  - - low through-put?
  - - complex wafer handling?

→ higher efficiency of solar cells

Advantages of Batch Diffusion

- Easy realization of high emitter resistivities
  - ⇒ Lower light absorption, lower carrier recombination
  - ⇒ Higher efficiency
- Diffusion on both wafer sides
  - Extended gettering effect of Phosphorous improves material quality
  - ⇒ Higher efficiency
- High quality Phosphorus diffusion
  - Gas-phase diffusion without residues and Chlorine as in situ cleaning component
  - ⇒ Higher efficiency
- Clean diffusion environment
  - Only quartz is used inside the process chamber
  - ⇒ Higher efficiency
- Improved cleanliness
  - The unique closed tube system prevents contamination from the environment
  - ⇒ Higher efficiency
- Independent usage of every stack
  - The single tubes can be operated independently.
  - ⇒ Less downtime of machine higher throughput

Batch Process: High Process Versatility



Batch Process: Self-Cleaning

- by adding O_2 at the same time with N_2(dilution + carrier gas)+$POCl_3$ there will be a growth of PSG layer

  $4\ POCl_3 + 3\ O_2 \rightarrow 2\ P_2O_5 + 6\ Cl_2$

- P_2O_5 serves as a solid source for diffusion itself. At Si-surface P_2O_5 is reduced to elemental phosphorus

  $2\ P_2O_5 + 5\ Si \rightarrow 4\ P + 5\ SiO_2$

- **chloride serves as cleaning agent**

Batch Process: Closed, Compact System

centrotherm 5-stack diffusion furnace

automated wafer handling

Batch Diffusion: High Through-Put

- **Target: Reduce COO → Approach: increase through-put**
- **XFlat** → extend boat length
  - Diffusion: 200 → 250 slots / boat

+ **25% through-put**
  without sacrifices in results

- **Redesign combines several improvements**
  - Ease of setup & maintenance
  - Improved safety by separation of stacks

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Batch Process: High Through-Put System

Furnace type (description)	Capacity / Cycle **Single loaded (back to back)**	Year **of introduction**
4 stack	800 (1600)	1998
5 stack	1000 (2000)	2006
5 stack XFlat	1250 (2500)	2010
5 stack XFlat, reduced pitch	1500 (3000)	2012
5 stack low pressure	2000 (4000)	2011

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Batch Process: High Through-Put System

Diffusion Recipe	Time / cycle	Year of introduction
Single step	65 min	until 2008
Two step	~65 min	2009
Two step OTF	60 min	2010
Two step LD	<60 min	2011
Two step OTF^{+}	<40 min	2011

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5 stack XFlat	1250 (2500)	2010
5 stack XFlat, reduced pitch	1500 (3000)	2012
5 stack low pressure	2000 (4000)	2011
5 stack XFlat LP	2500 (5000)	2012

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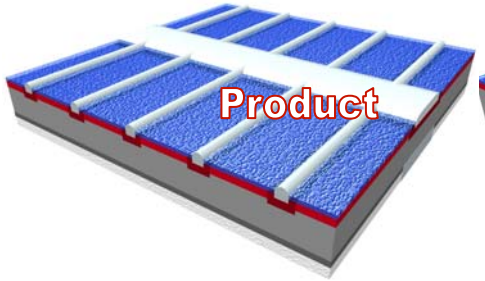
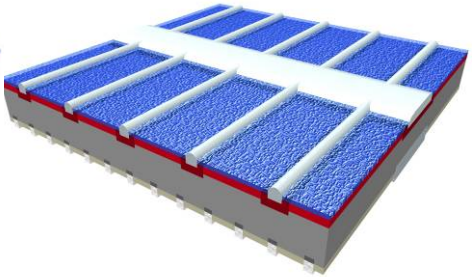
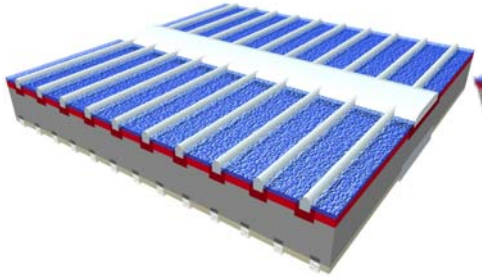
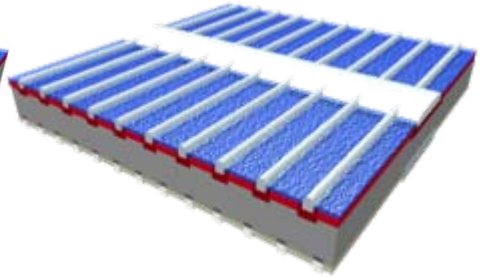
Batch Process: High Through-Put System

Diffusion Recipe	Time / cycle	Year of introduction
Single step	65 min	until 2008
Two step	~65 min	2009
Two step OTF	60 min	2010
Two step LD	<60 min	2011
Two step OTF^{+}	<40 min	2011
Two step OTF^{++}	30 min	2012

centrotherm's Roadmap on Solar Cell Technology Average Efficiency

Selective Emitter	New Back Side	New Metallization	Interface Optimization
			
Product			
≥ 19.0%	≥ 19.5%	≥ 20.0%	
18.5%	17.7 - 18.0%	≥ 18.0%	
16.8 - 17.0%	17.2 - 17.5%		
2010	2011	2012	2013

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Summary

- High efficiency emitters
  - high efficiency solar cells require improved emitter
  - new emitters are more complex
  - compromise between new emitters and standard process (mainly screen printing) requires adjustments to standard process → selective emitter structure
- Batch vs. inline diffusion
  - inherently clean and compact process
  - batch process offers many parameters to optimize process
  - new developments such as XFlat and low pressure diffusion overcome former through-put limitations
- Future development
  - further increase of wafers/cycle
  - further decrease of cycle time
  - further increase of solar cell efficiency

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Thank you for your attention!

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