Confidential

ROTH &RAU

For a sunny future

NCCAVS: Thin Film Applications and Equipment Solutions for Photovoltaic Applications

February 23, 2011

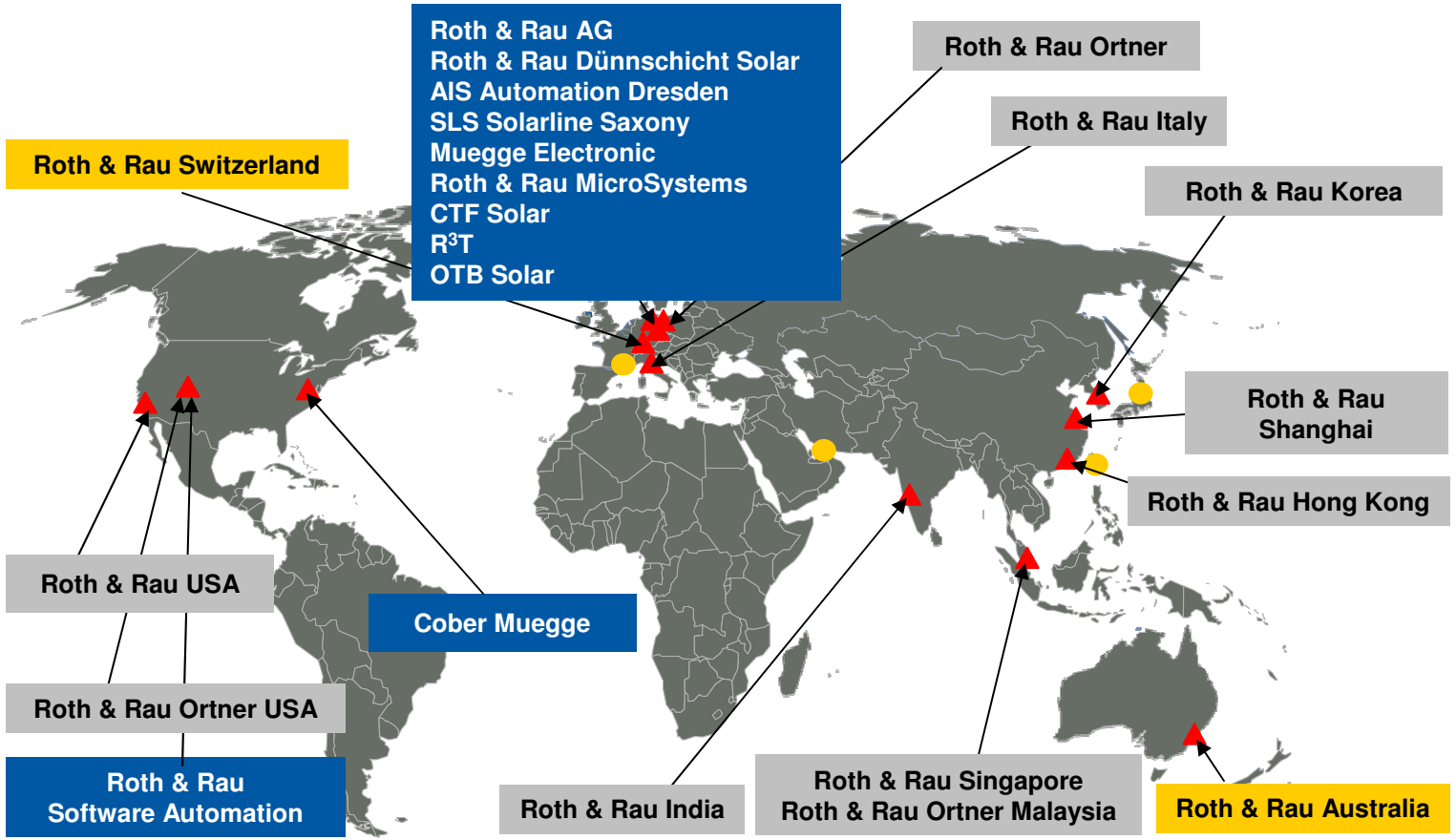
Discussion Overview

- Overview/ / Introduction Roth & Rau
- Product Introduction
- Applications & Cell Performance Benefits
- Process Discussion
- Conclusions / Questions

Roth & Rau at a glance

Segment	Leading supplier of equipment and technology for the photovoltaic industry and supplier of process systems based on plasma and ion beam technology for other sectors like the semiconductor and optical industry
Technological expertise	Comprehensive know how in development and application of plasma process equipment for surface treatment in various industrial sectors 10 years of experience with plasma technology in solar cell manufacturing
Founding year	1990
Management	Dr. Dietmar Roth (CEO, co-founder), Thomas Hengst (CSO), Paul Breddels (COO)
Location	Hohenstein-Ernstthal (headquarters)
Employees	1134 as of June 30, 2010
Listing	listed on Frankfurt Stock Exchange since May 2006, listed in TecDAX since June 2008
Shareholders	11,35% founders, 6,34% OTB Group B.V., 82,31% free float

International footprint



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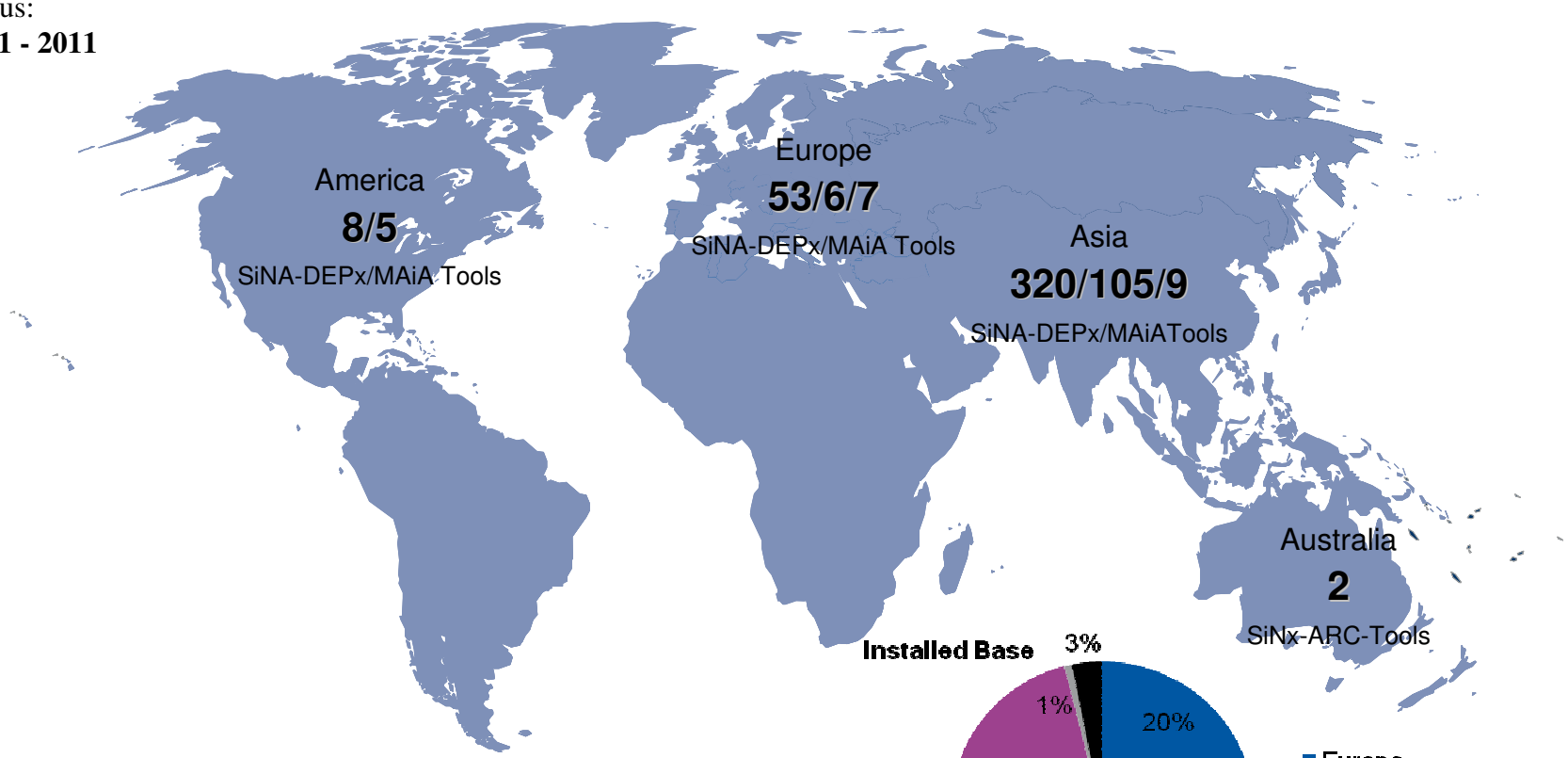
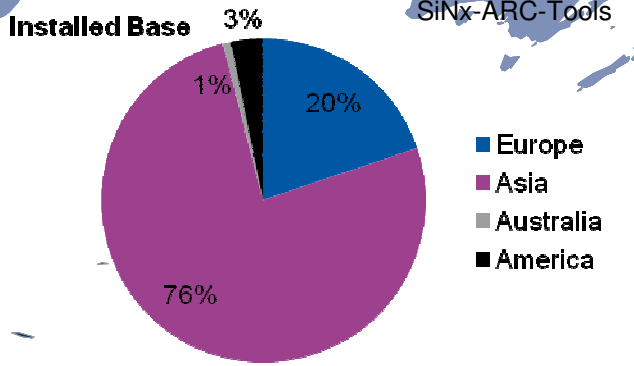
Strong customer base in the PV industry

… and many others

Installed Base SiNA® / DEPx / MAiA

Status:
2001 - 2011





Total:

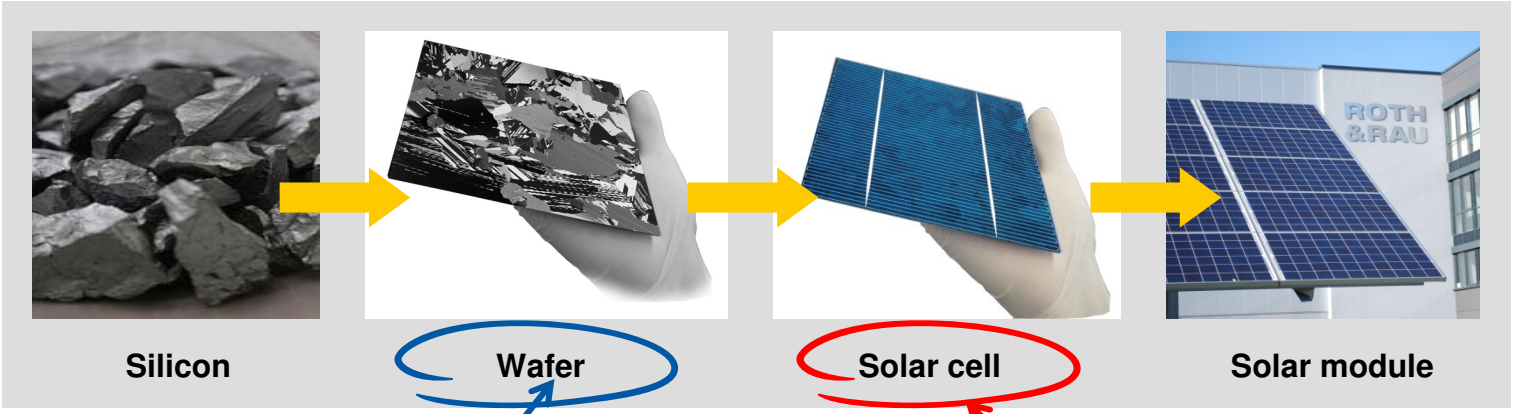
> 500 SiNA/DEPx/MAiA -Tools

129 PV Solar cell makers in 21 Countries on 4 continents

> 17 GW delivered theoretical PV power (70% already installed)

Products and technology for photovoltaic's

Value chain crystalline silicon solar module manufacturing



Products and technology for photovoltaic's

Single equipment

In-line PECVD/PVD equipment

diffusion and firing furnace

mc-Si crystallisation furnace

Turnkey solutions

crystalline Si solar cells

CdTe thin film solar modules

mc- silicon wafers

AR coating equipment for c-Si solar cells

➔ Key products of the Roth & Rau group

- **SiNA® / MAiA® by Roth & Rau AG**
  - ➔ Leading product in the market
  - ➔ Equipment with the highest throughput in combination with excellent layer quality and low running costs
  - ➔ From 2010 launch of new model with further cost advantages and possible applications for the production of new types of solar cell (e.g. with rear side passivation)
- **DEPx by OTB**
  - ➔ Most compact in-line equipment with high deposition speed
  - ➔ well suited for small to mid-scale production
  - **Next generation**:
  - ➔ Development has already started
  - ➔ Goal: modular equipment for several application combining the advantages of both systems

SiNA®

DEP_x

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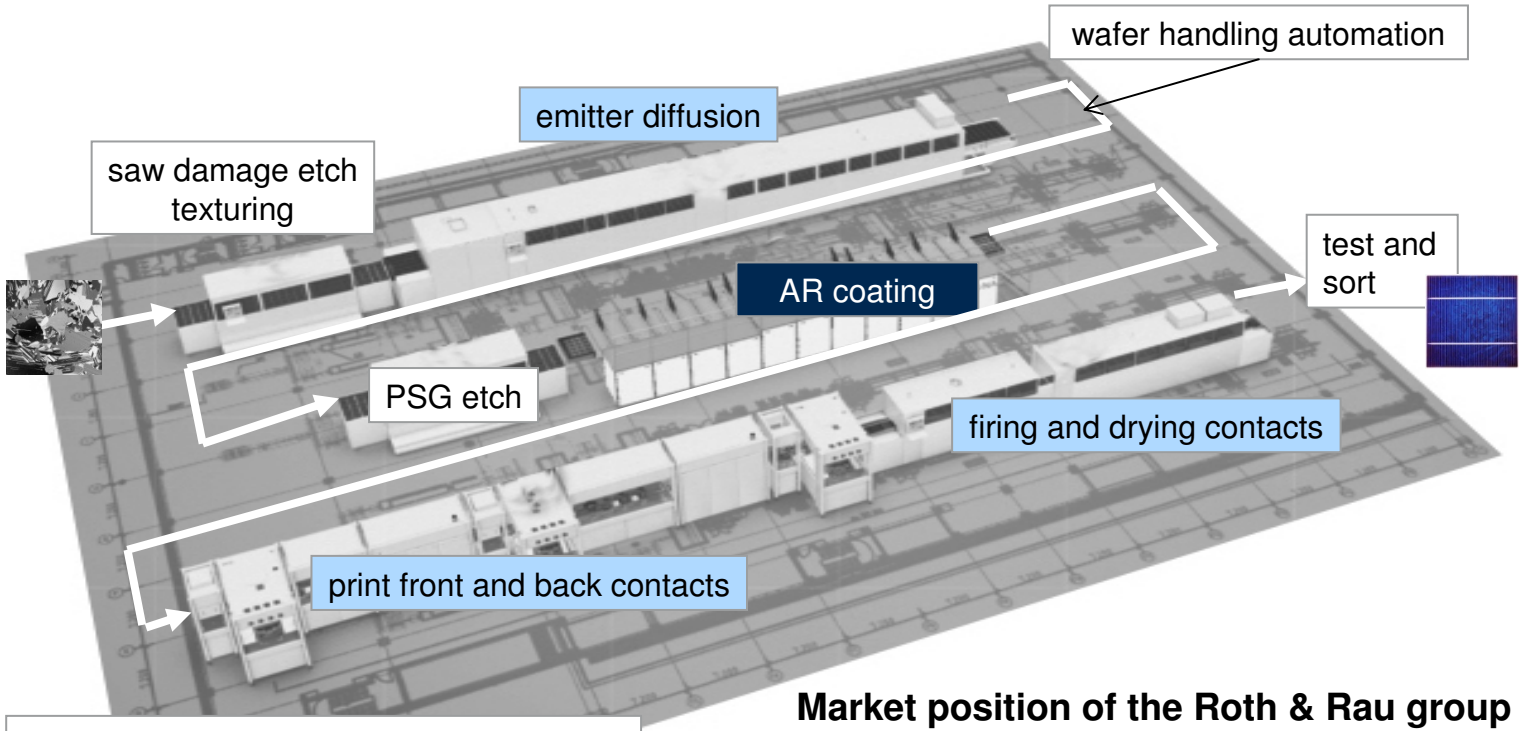
Products and technology for photovoltaic's

Standard crystalline silicon solar cell production process



Over the whole production process:

- technology know how
- manufacturing control (MES software)

Market position of the Roth & Rau group

- market leader
- among TOP 3
- market presence (new products)
- no products

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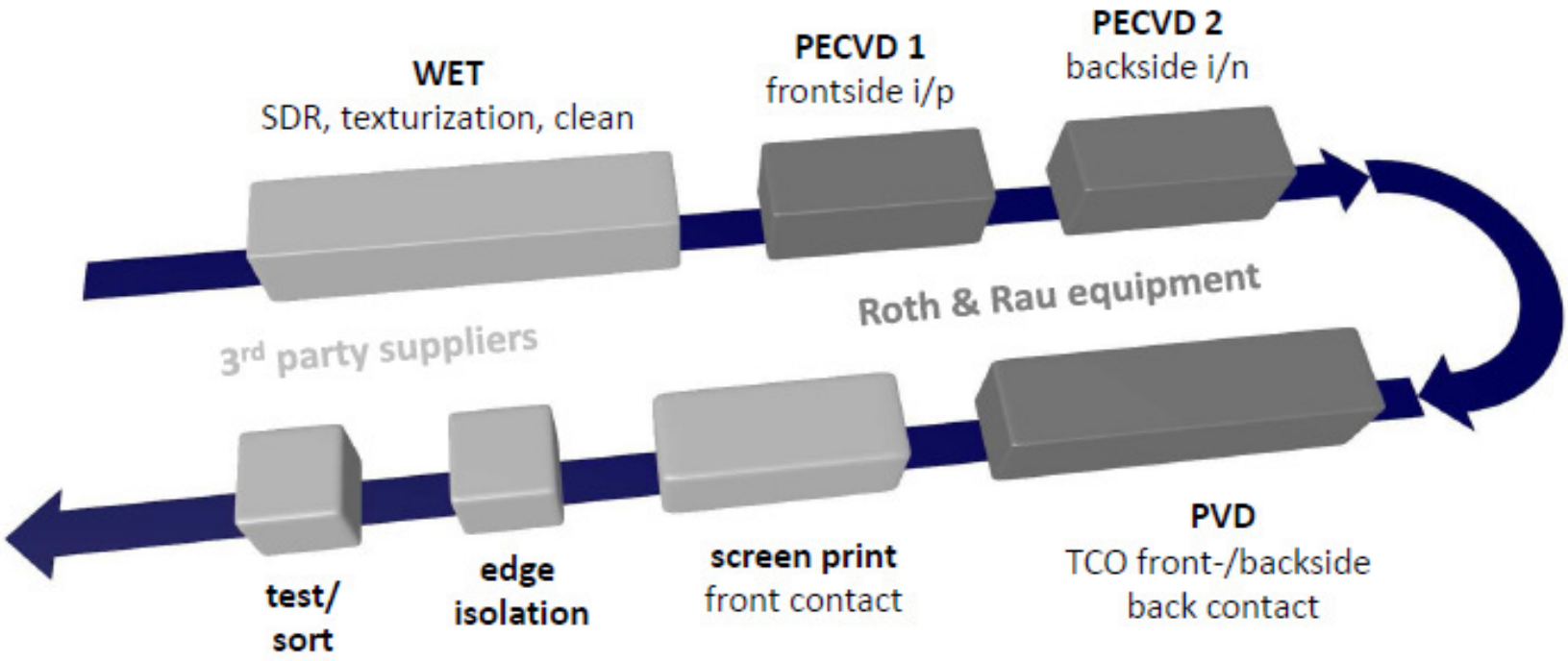
Products and technology for photovoltaic's

Heterojunction solar cell production process



Roth & Rau PRiMELiNE$_{HJT}$

- target capacity of 80 MWp
- floor space approx.140 x 10 m^2

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What is the meaning of the product name?

SiNA®

Si licon

N itride

A bscheidung (DE)= deposition (EN)

Modular Design offers HIGHEST Flexibility

C-Si Cell Format & Process Flow

Wafer Inspection

Saw Damage Etching & Texturing

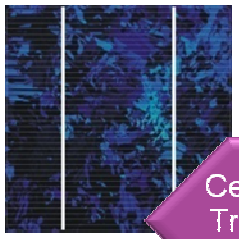
Phosphorus Doping

Emitter Diffusion

Phosphor Glass (PSG) Etching

FRONT END

ARC Layer and Front Side Passivation (SiNx)



BACK END

Screen Printing

Drying

Firing

Edge Isolation

Cell Sorter, Transfer & Storage

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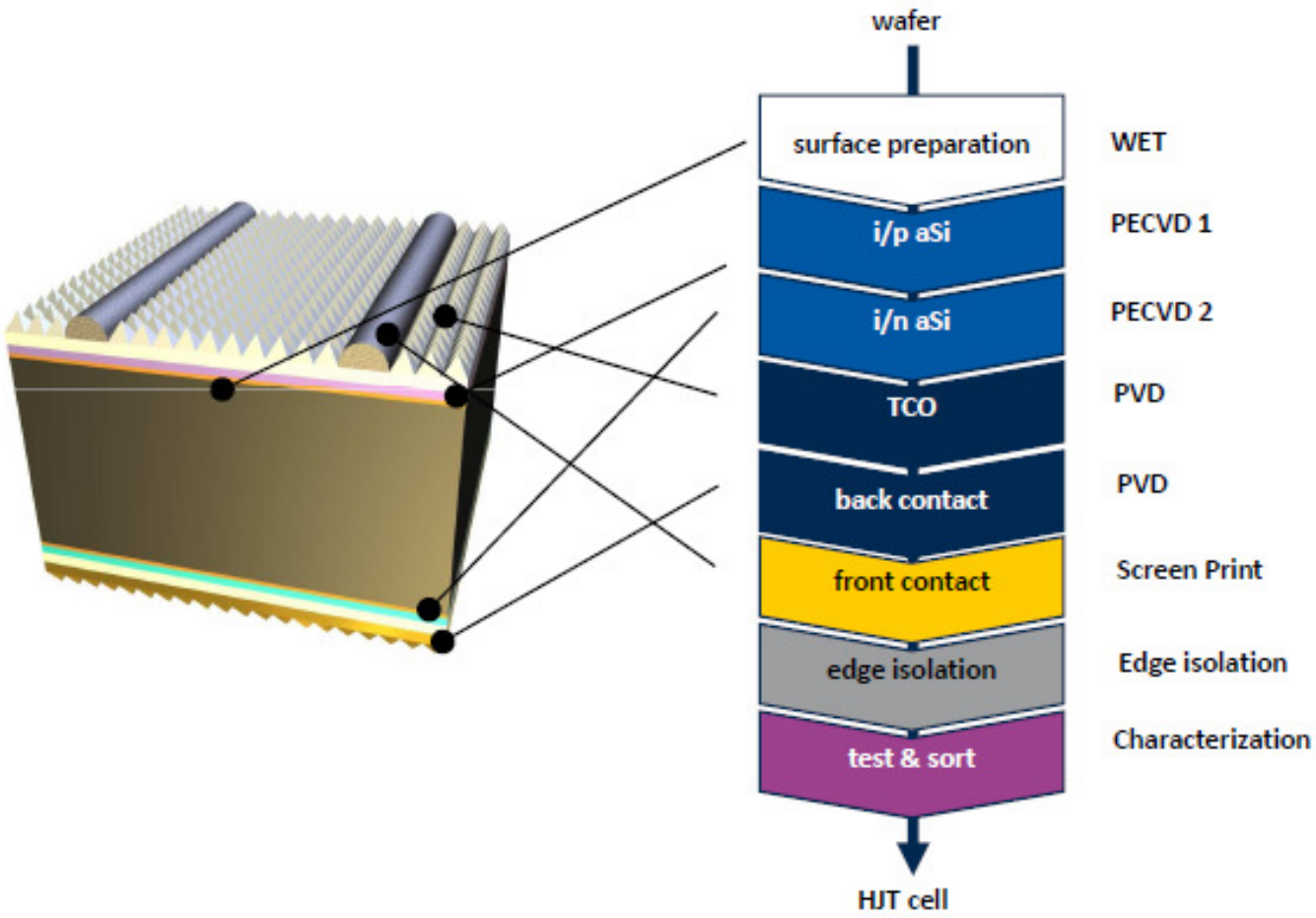
Heterojunction Cell Format



What are the product applications? C-Si

SiNA® & DEPx

Plasma deposition processes

- Production Level — Si_xN_y
- $SixOy$- DEPx

MAiA®

Plasma etch processes

- R&D Level — Texturing
- R&D Level — Saw damage etch (depends on further process requirements)
- Pilot Line Level — Pre-cleaning

Plasma deposition processes

- R&D Level — a-Si
- Production Level — Si_xO_y
- Production Level — Si_xO_y/Si_xN_y
- R&D Level — $Si_xC_yN_y$
- Production Level — Al_xO_y
- Pilot Line Level — Al_xO_y/Si_xN_y
- Pilot Line Level — $Al_xO_y/Si_xO_y/Si_xN_y/Si_xO_yN_z$

What are the product applications? Heterojunction

HELiA PECVD/PVD

PECVD deposition processes

Production Level
- a-Si un Doped (intrinsic)

R&D Level
- a-Si Doped

PVD deposition processes

Production Level
- TCO (ITO)
- Metal (e.g. Al, Ag)

Double Side MAiA® Plasma Process

Best Cell

EFF.: 17,3% !

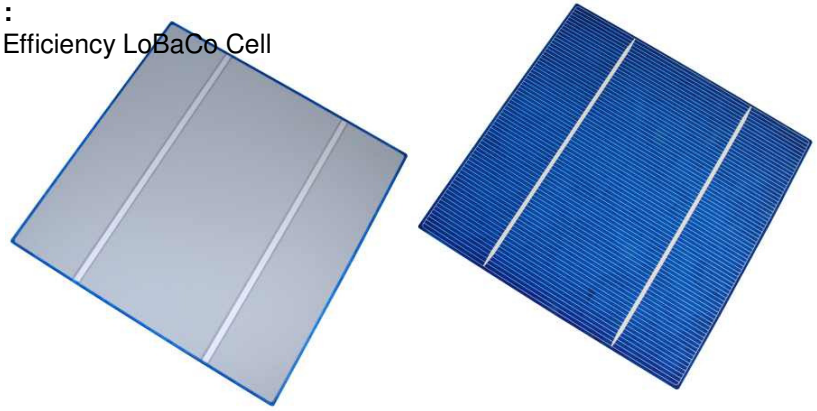
could be sucessfully proven

in Roth & Rau R&D pilot line

(Technology Centre)

Efficiency [%]	Uoc [mV]	Isc [A]	FF [%]	Rs [Ω]	Rsh [Ω]
17,29	627	8,63	77,7	0,0039	52,2

Fig1:
Top Efficiency LoBaCo Cell



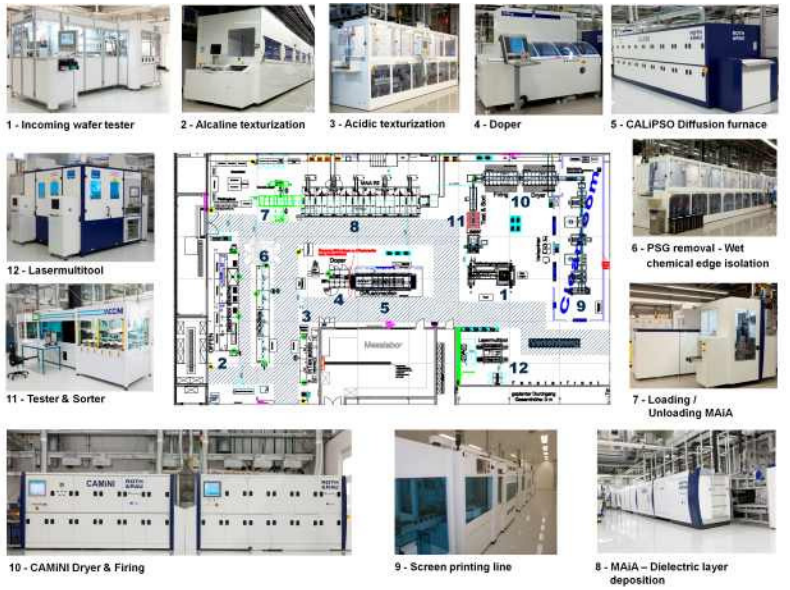


Fig2 (right):
View into the Roth & Rau R&D pilot line

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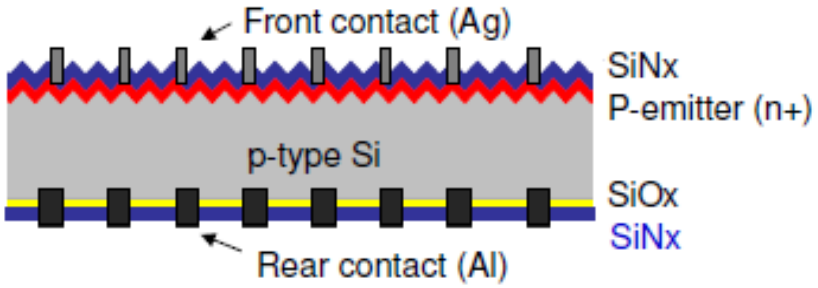
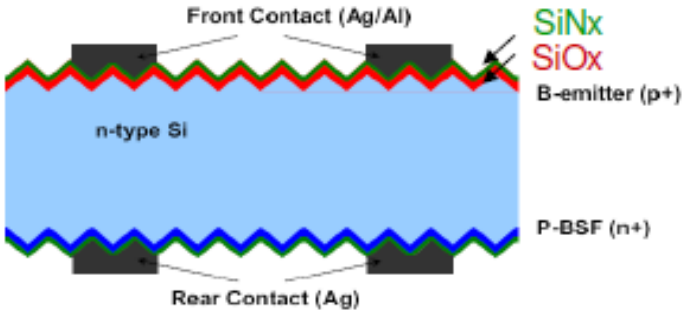
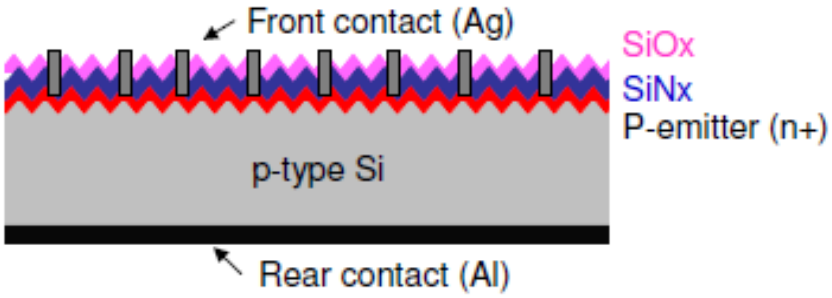
Applications for c-Si wafer processing



- Back side passivation on p-type



- Passivation of B-emitter on n-type



- Front side optical coating

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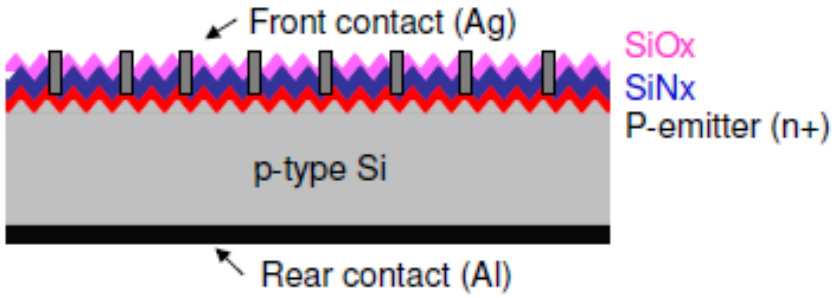
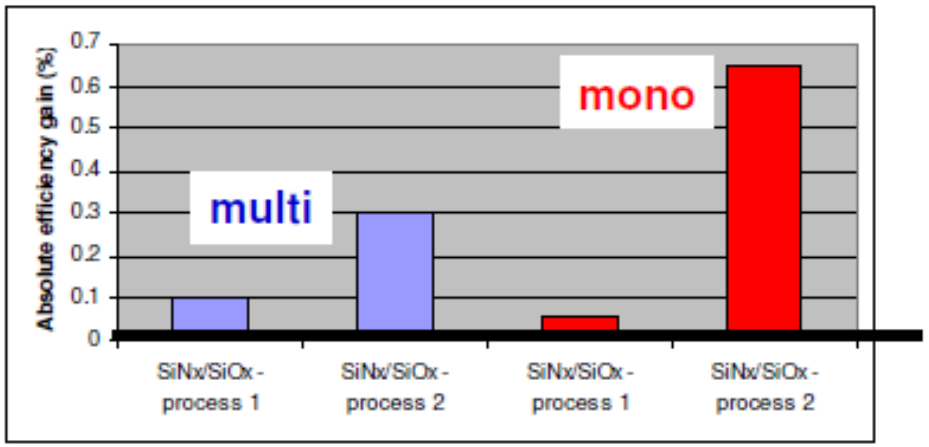
Applications for c-Si wafer processing





SiNx/SiOx stack

- SiOx layer as front side optical coating
- process improvement by changing to N2O
- significant gain on cell level both on multi and mono wafers

Heterojunction Technology Baseline

- Roth&Rau-research-center in Neuchatel, Swizerland
- Team of 10 physicists and technicians
- Fully equipped research-lab including all manufacturing steps on lab scale
- Close collaboration with EPF Lausanne

Area (cm^2)	Efficiency (%)	V_{oc} (mV)	FF (%)	I_{sc} (mA/cm^2)
4	21.0	729	77.9	37.0
148	19.3	726	76.6	34.7

results published in September 2010

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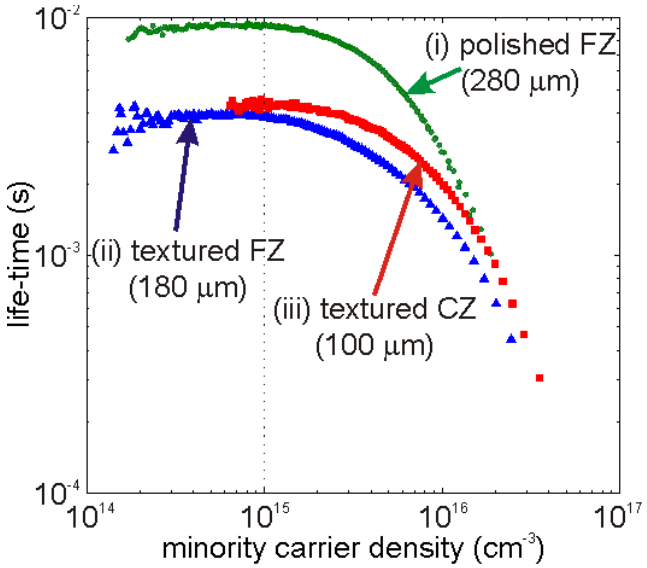
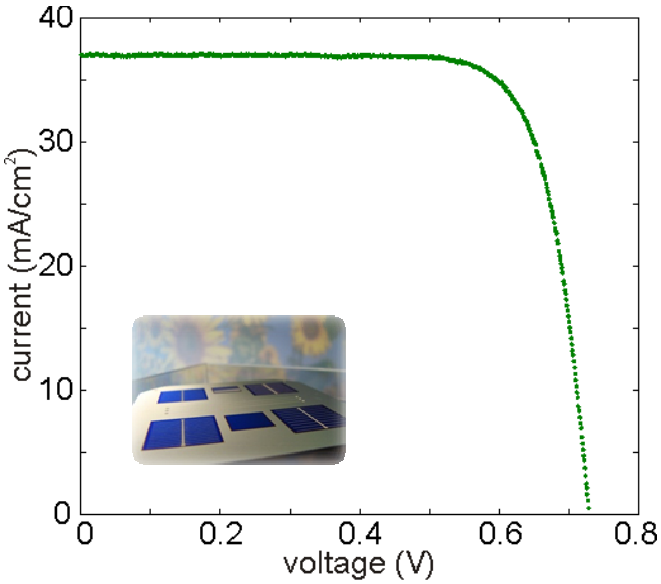
Heterojunction Technology Baseline

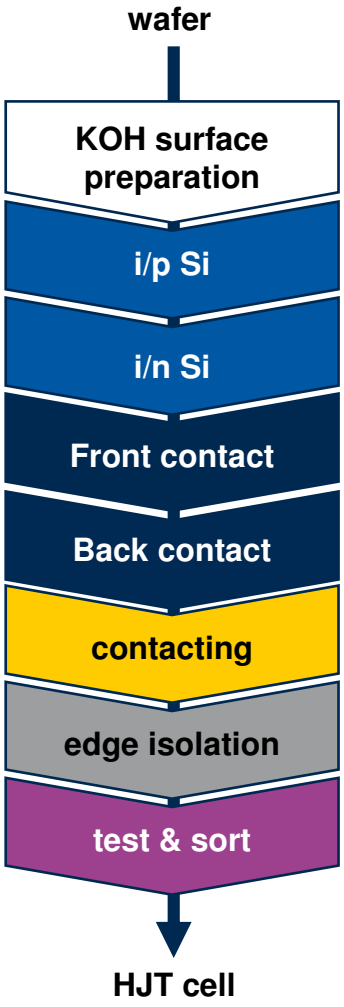
HJT Technology status

Proven carrier-lifetime of >6 ms
Demonstrated cell performance of 21% (4cm2)
Demonstrated cell performance of 19.3% (wafer)
(EU PVSEC 2010 Valencia)





(2x2 cm², VOC 7.29mV, FF 77.9%)



SiNA General Design

1. Evacuate
2. Fast heat up
3. Transfer

1. Pre-heat
2. Transfer

Process

1. Cool down
2. Transfer

1. Vent
2. Cool down
3. Transfer

Chamber Valve
(Atmospheric Gate)

Unload Module
(Cooling Zone)

Chamber Valve
(Vacuum Gate)

Buffer Module OUT
(Cooling Zone)

Process Module
(Plasma Zone)

Buffer Module IN
(Pre-heating Zone)

Chamber Valve
(Vacuum Gate)

Load Module
(Pre-heating)

Chamber Valve
(Atmospheric Gate)

GUI
(Graphic User Interface)

Modular Design

offers

HIGHEST Flexibility

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SiNA Modular Construction System

Selection based on Wafer throughput

Basic Design

Selection based on technology requirements

Selection of single modules requirements

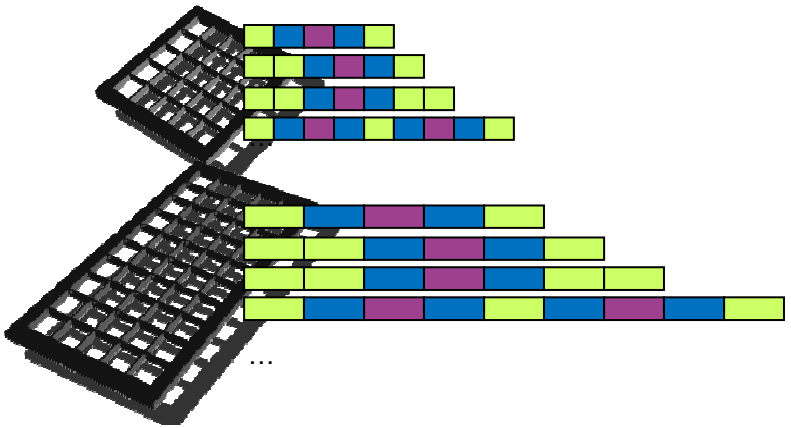
Main Function

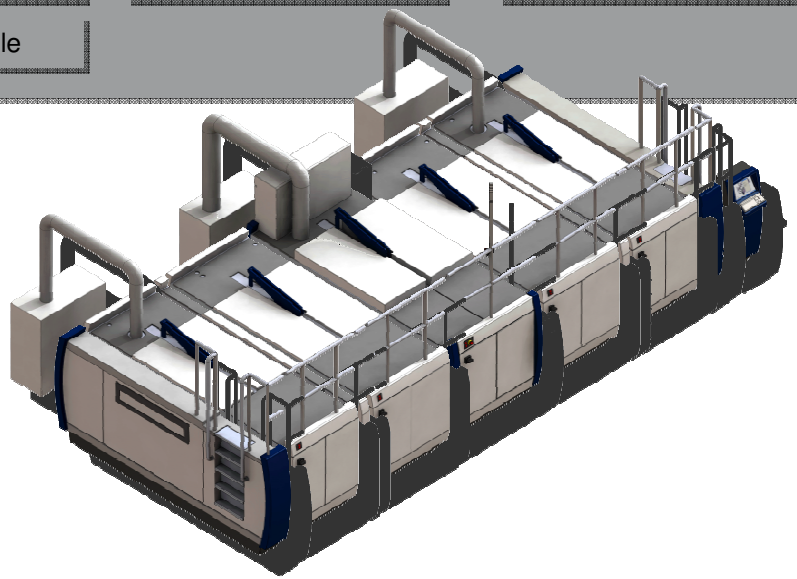
Sub Function

Modular Construction System

30-80 MWp	50-120 MWp
SiNA®	**SiNA®**
Carrier 1000 x 1000 mm 25 - 6“ – wafer	Carrier 1860 x 1000 mm 50 - 6“ – wafer
Load Lock Module	**Buffer Module (BM)**	**Process Module (PM)**
Load Module	+ Pre-heat	with **4** Plasma Sources
Unload Module	+ Cool down	with **6** Plasma Sources
Transfer Module		

POSSIBLE SYSTEM CONFIGURATION





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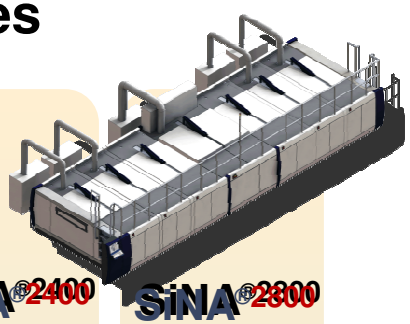
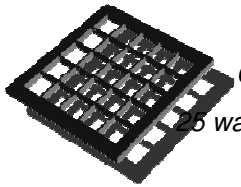
Overview – Product Types & Sizes

Capacity

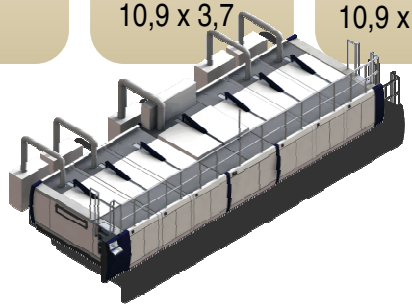


	SiNA® 1000	SiNA® 1600	SiNA® 2000	SiNA® 2400	SiNA® 2800	
GROSS wafer TpT[1]:	**1061**	**1542**	**1996**	**2426**	**2831**	[wafers/hour]
NET wafer TpT[1]:	1014	1472	1900	2302	2683	[wafers/hour]
Wafer size:	125/**156**/200	125/**156**/200	125/**156**/200	125/**156**/200	125/**156**/200	[mm]
Wafer thickness:	100…300	100…300	100…300	100…300	100…300	[µm]
MTBF[2]:	450	430	390	350	340	[hour]
MTTR[2]:	2,1	2,5	3,3	4,1	4,3	[hour]
Uptime[2]:	> 95	> 95	> 94	> 93	> 93	[%]
Foot print (LxW)[4]:	7,6 x 3,7	7,6 x 3,7	9,6 x 3,7	10,9 x 3,7	10,9 x 3,7	[m]

1) *TpT calculated for 6 inch wafers @Tk.=85nm R.I.=2,05 measured on cz-wafer*
2) *Calculations based on RR field data*
3) *Excluded scheduled preventive maintenance time.*
4) *Excluded pump units*



Carrier Capacity:
26 wafers @6"-wafers



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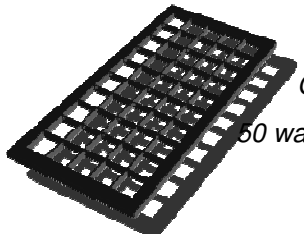
Overview – Product Types & Sizes

Capacity



	SiNA® 2200+	SiNA® 2600+	SiNA® 3200+	SiNA® 3600+	SiNA® 4000+	
GROSS wafer TpT[1]:	**2201**	**2687**	**3153**	**3593**	**4018**	[wafers/hour]
NET wafer TpT[1]:	2101	2563	3001	3413	3801	[wafers/hour]
Wafer size:	125/**156**/200	125/**156**/200	125/**156**/200	125/**156**/200	125/**156**/200	[mm]
Wafer thickness:	100…300	100…300	100…300	100…300	100…300	[µm]
MTBF[2]:	440	430	390	370	330	[hour]
MTTR[2]:	2,1	2,5	3,3	4,1	4,3	[hour]
Uptime[2]:	> 95	> 95	> 94	> 94	>93	[%]
Foot print (LxW)[4]:	11,0 x 3,7	11,6 x 3,7	13,8 x 3,7	14,7 x 3,7	16,9 x 3,7	[m]

1) *TpT calculated for 6 inch wafers @Tk.=85nm R.I.=2,05 measured on cz-wafer*
2) *Calculations based on RR field data*
3) *Excluded scheduled preventive maintenance time.*
4) *Excluded pump units*



Carrier Capacity:
60 wafers @6“-wafers

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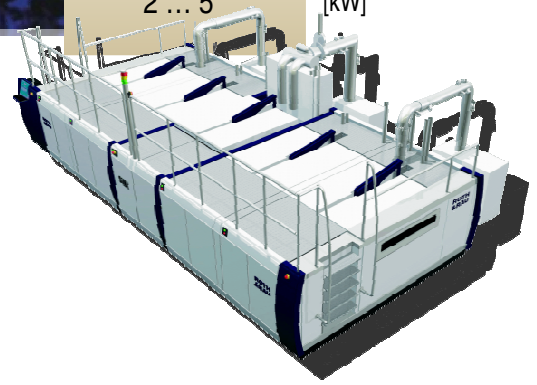
Overview – Product Types & Sizes

General Specifications

Layer thickness[1]:	20 ... 200	[nm]
Index of refraction[2]:	1.9 ... 2.3	
Layer uniformity[3]:	= (Max-Min)/(Max+Min) x 100%	
Tk (p-t-p) spec./typical:	< ± 3.0 / < ± 2.5	[%]
Tk (w-t-w) spec./typical:	< ± 3.0 / < ± 2.5	[%]
Tk (r-t-r) spec./typical:	< ± 3.0 / < ± 2.5	[%]
R.I. (p-t-p):	< ± 1.5	[%]
R.I. (w-t-w):	< ± 1.5	[%]
R.I. (r-t-r):	< ± 1.5	[%]

Process gases:	SiH_4/NH_3	
Process gases total flow[4]:	1.0 ... 4.0	[slm]
Gas ratio (Q_{NH3}/Q_{SiH4}):	2.0 ... 3.5	
$T_{process}$:	350 ... 550	[°C]
$p_{process}$[5]:	0.1 ... 0.3	[mbar]
No. of vacuum chambers:	5...8	
Base pressure:	< 1 x 10^{-3}	[mbar]
No. of plasma sources:	2 ... 8	
MW Peak power:	2 ... 5	[kW]

1) *Impact on TpT (typical: tk=85nm).*
2) *Impact on TpT (typical: R.I.=2,05).*
3) *Depends on measurement layout. The measurement layout ist attached in RR-Process-Spec.*
4) *Depends on No. of plasma sources*
5) *Impact on TpT .*



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Automation

Features

- RR own automation for all SiNA® & MAiA® applications (“all from one single source”) →defined system with defined interfaces
- Non robot solution →Less stress on wafer through belt drives →back side handling for face up deposition
- Configuration as single or double end solution according customer requirements based on a modular concept
- Compact design (small footprint)…

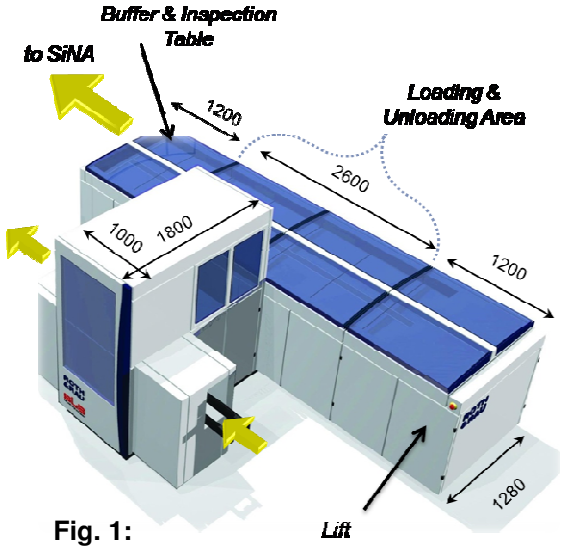


Fig. 1:
single end automation, i.e. loader
(footprint ~2m² + 5m² carrier handling)

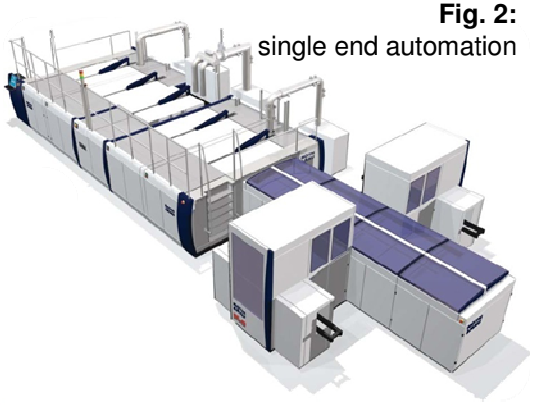


Fig. 2:
single end automation

Benefits

LESS wafer stress

LESS wafer breakage

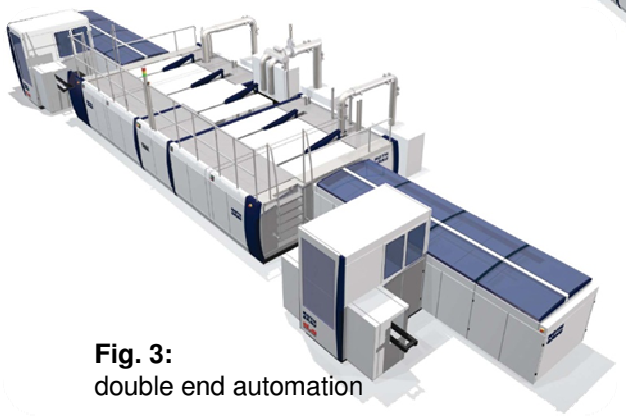


Fig. 3:
double end automation

Summary Benefits New SiNA®

- Highest flexibility in terms of throughput and process by modular design
- Highest throughput (4000wph and more)
- Excellent layer uniformity (+/-3%)
- High Uptime (>95%)
- High Yield (>99%)
- Higher process temperature (up to 550°C) and good thermal uniformity (+/-4%)
- 40% smaller total footprint compared with the forerunner model
- Low Operating Cost
- Low CoO (0,008€/Wp)
- Best Safety, Quality & Design

→ **Modular Design**

→ **Increased TpT**

→ **Reduced TCoO**

SiNA® 1600

made in Germany

HIGHEST Flexibility

BEST Throughput

BEST TCoO

What is the meaning of the product name?

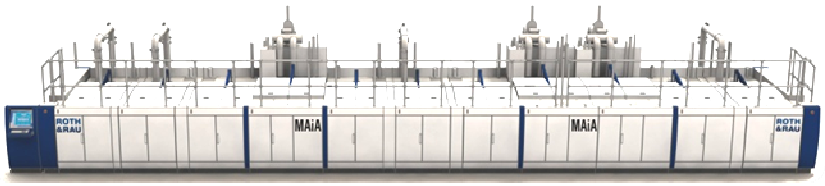
MAiA®

M ultiple

A pplication

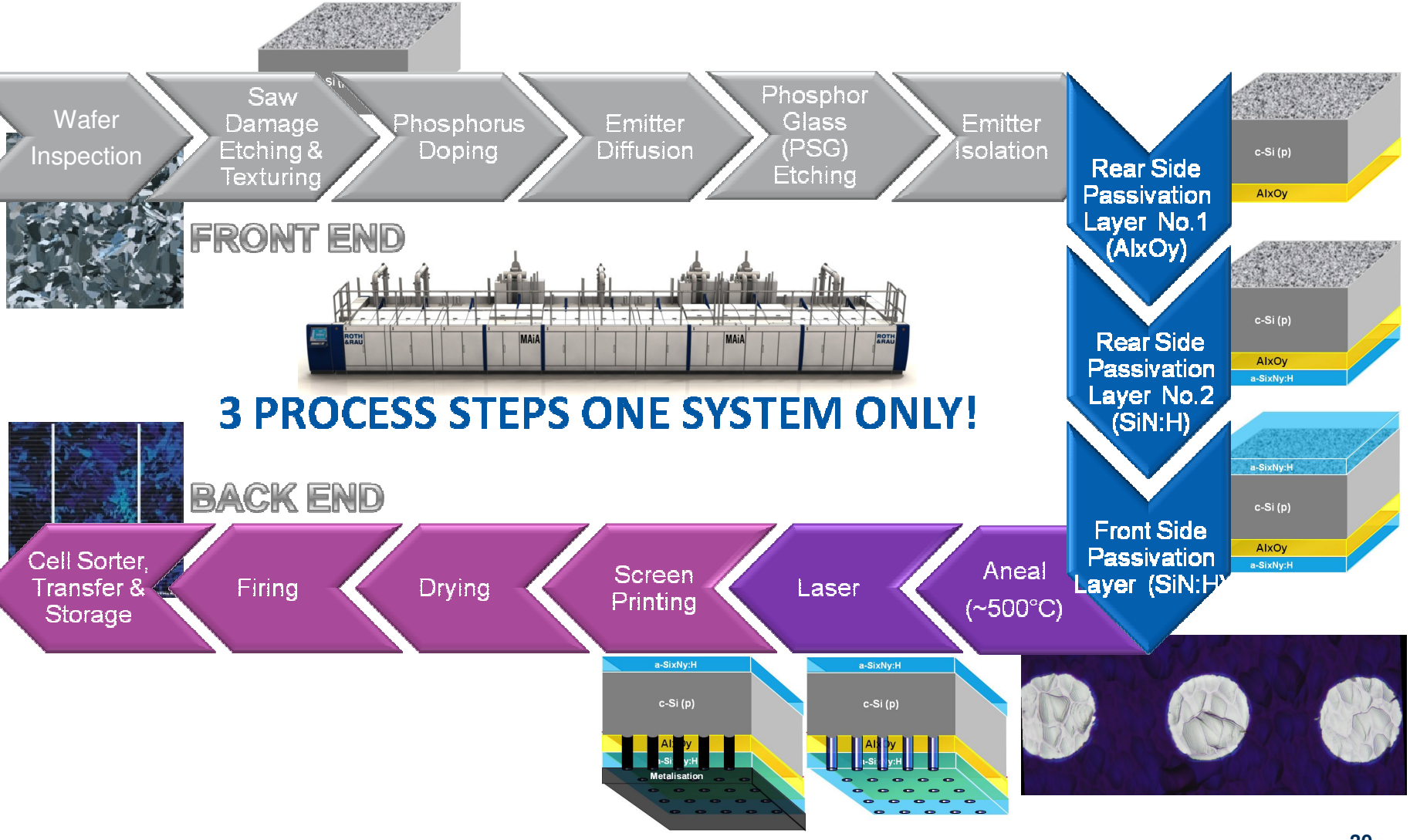
i nline

A pperatus (Latin) = Equipment (EN)



Modular Design offers HIGHEST Flexibility

Double Side MAiA® Plasma Process



Al2O3–PE CVD for backside passivation

PERC cell Passivation -> Front ARC + RS AlOx/SiN Stack
as “all in one” low cost solution for 3x dielectric coatings in just 1x pass through on MAiA inline tool with upto 3600 wph .

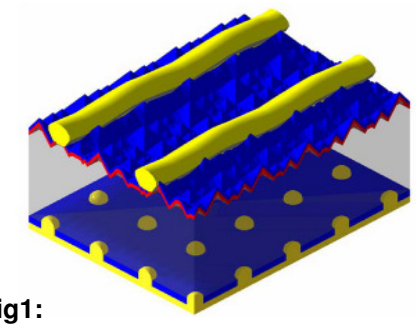
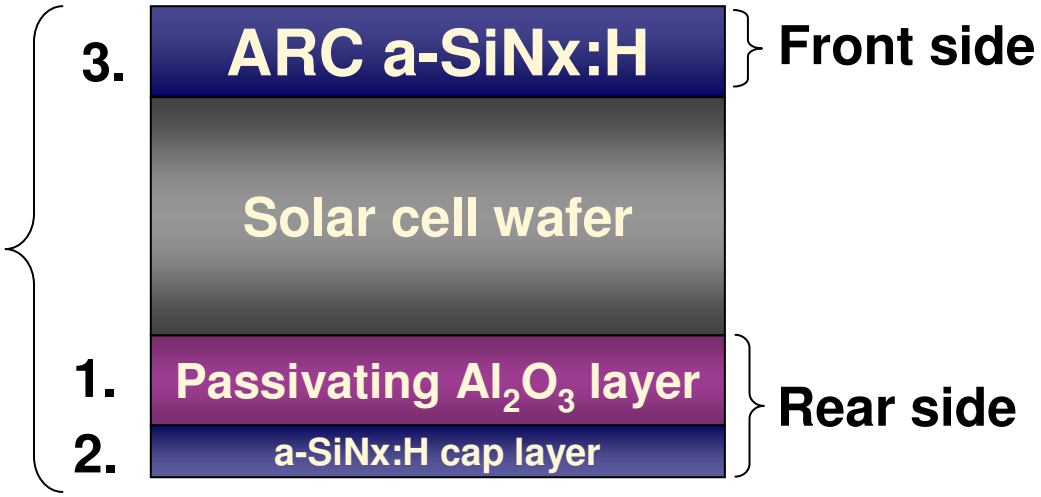


Fig1:
PERC-type solar cell structure used to demonstrate the applicability of an Al2O3 rear surface passivation to high-efficiency solar cells.
Source:
23rd European Photovoltaic Solar Energy Conference



expected Efficiency gain up to + 1%

- **Surface field passivation** to high negative fix charges in Al2O3 after anneal + firing
- **Improved IQE for red photons** with optimized SiN cap layer

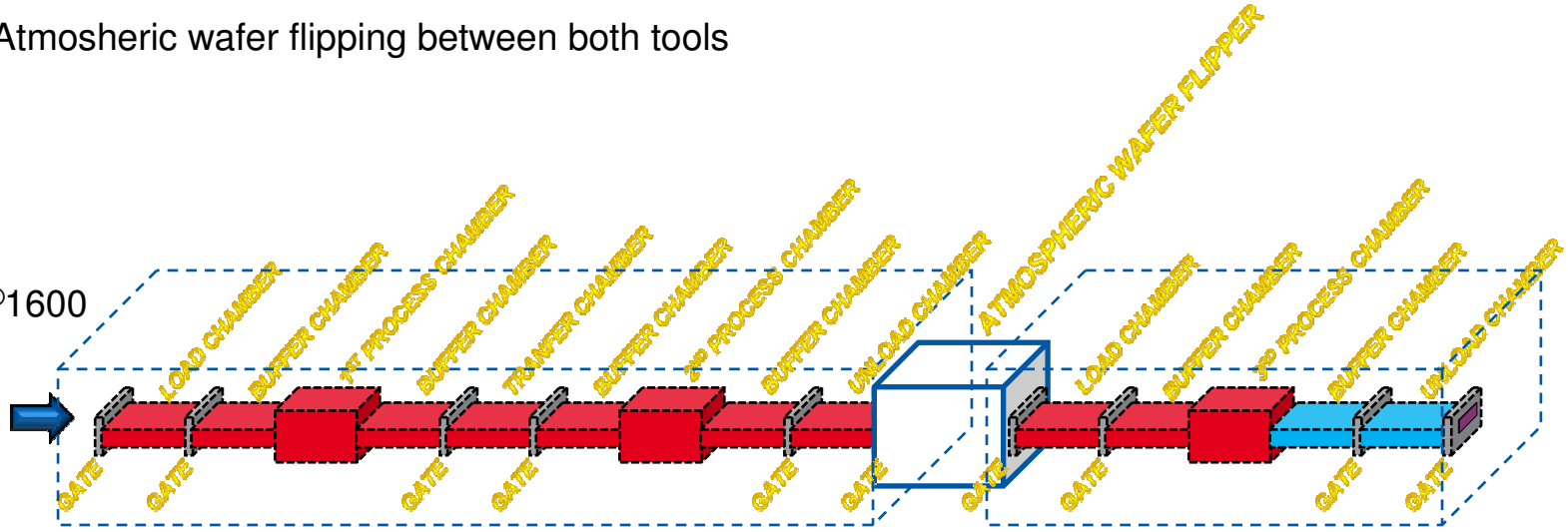
Double Side MAiA® Deposition Concepts

1st Generation

MAiA Front - Front Concept:

- separate tools for front side and for backside processing,
- only use of top down plasma processes (good layer uniformity),
- Atmosheric wafer flipping between both tools

MAiA®1600



1st ARC-System
Back Side SiOx and Back Side SiNx
(as Face Up Deposition)

2nd ARC-System
Front Side SiN
(as Face Up Deposition)

Double Side MAiA® Deposition Concepts

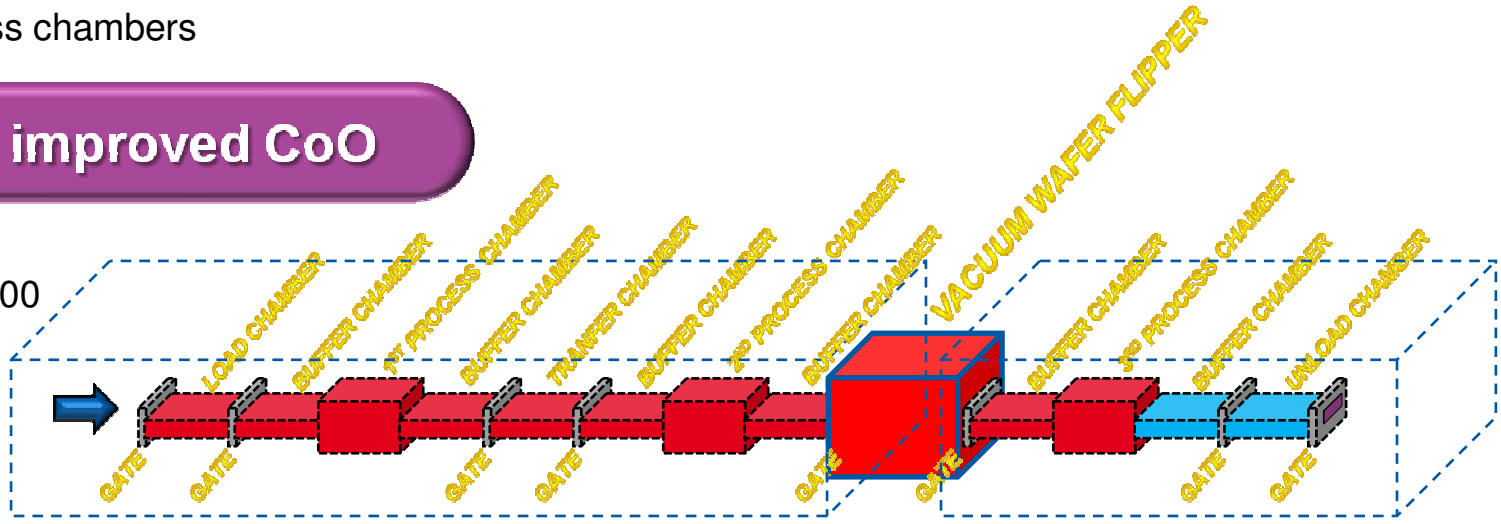
2nd Generation

MAiA Front - Front Concept:

- separate tools for front side and for backside processing, but without vacuum and thermal disruption
- Vacuum wafer flipping between both tools
- Less chambers

improved CoO

MAiA®1600



1st ARC-System
Back Side SiOx and Back Side SiNx
(as Face Up Deposition)

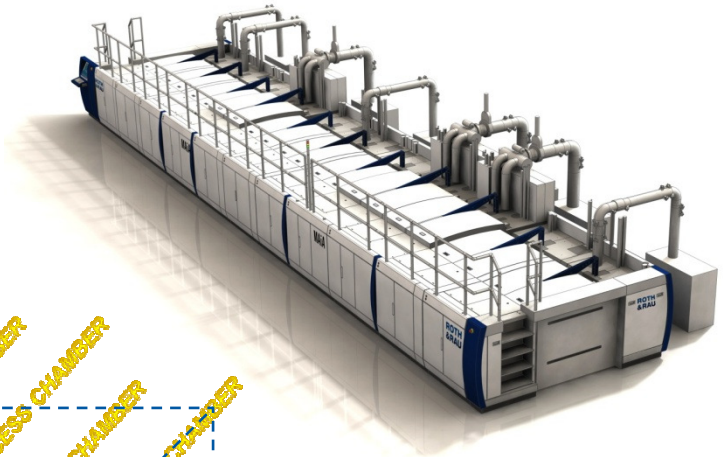
2nd ARC-System
Front Side SiN
(as Face Up Deposition)

Double Side MAiA® Deposition Concepts

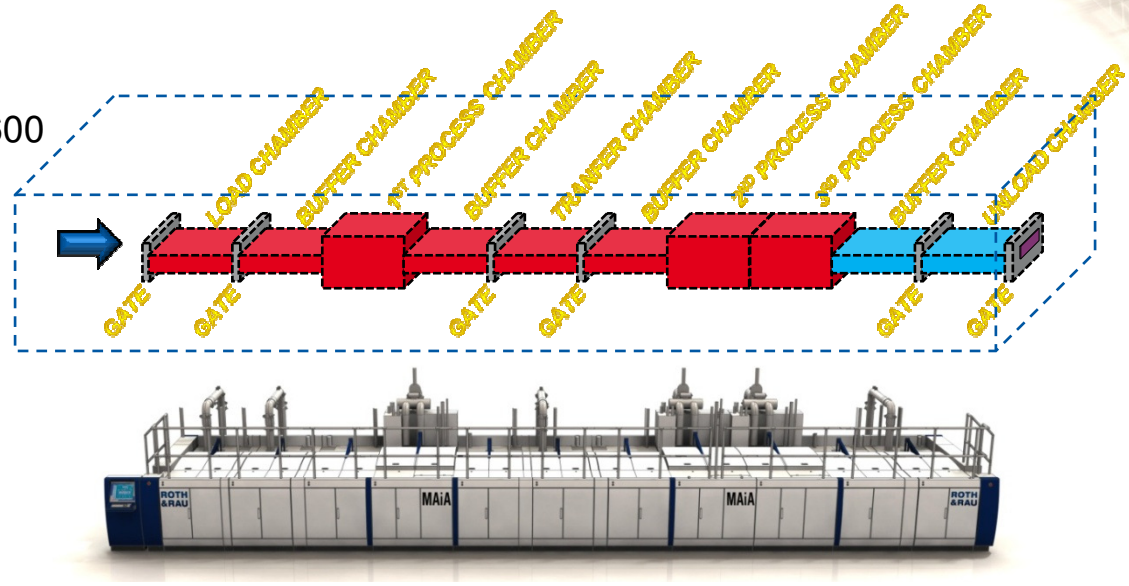
3rd Generation

MAiA Front - Back Concept:

- **ONE** tool for front side and for backside processing,
- NO vacuum and thermal disruption → less chambers
- NO wafer flipping necessary→ NO mechanical stress on wafer material



MAiA®1600

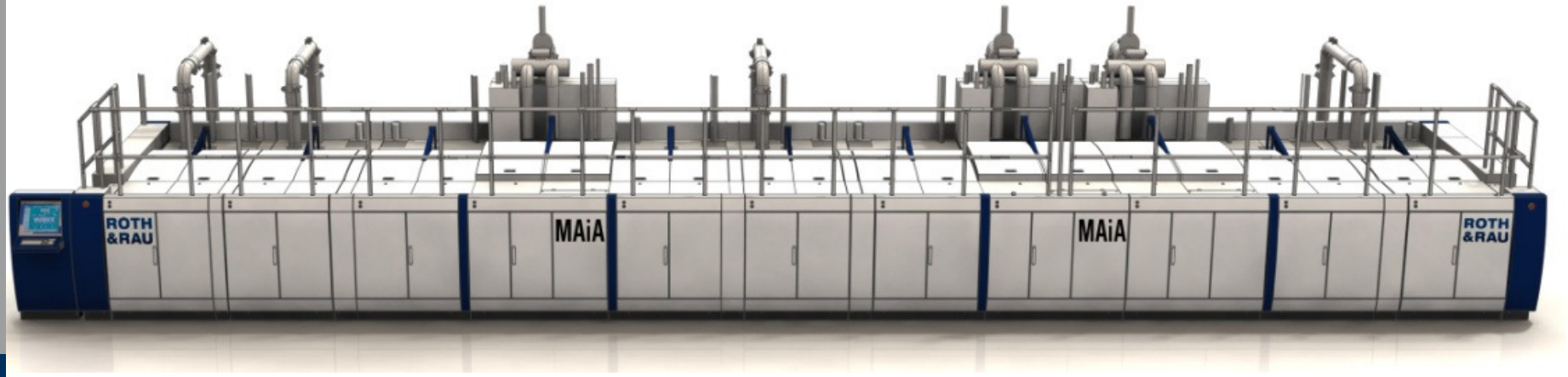


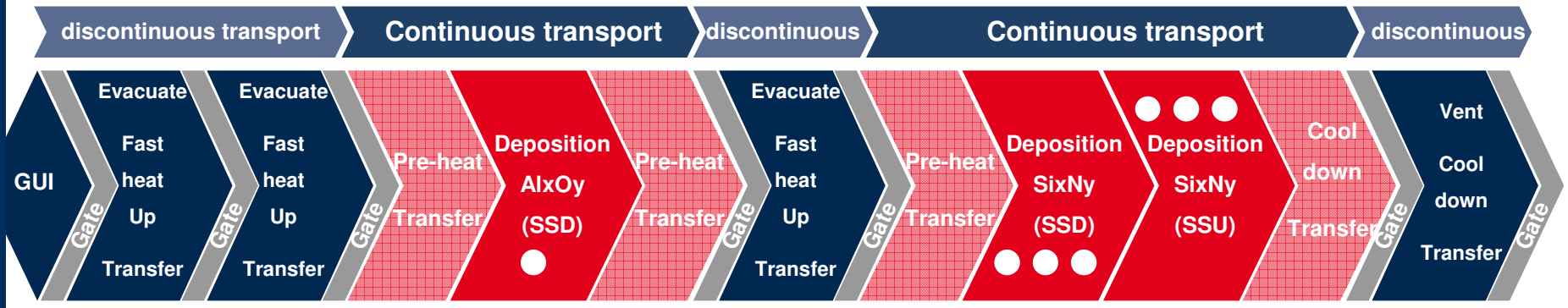
ONE ARC-System
Back Side SiOx and Back Side SiNx
(as Face Down Deposition) &
Front Side SiN
(as Face Up Deposition)

BEST CoO

Double Side MAiA® Plasma Process

ALL IN ONE





The new generation of MAiA® - Summary

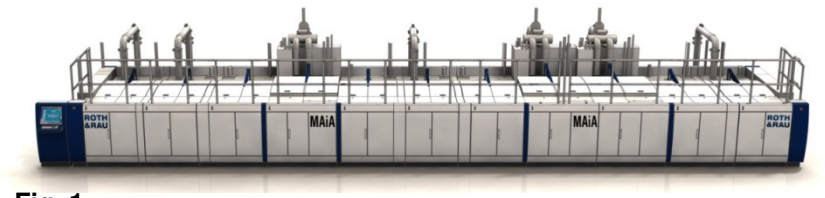
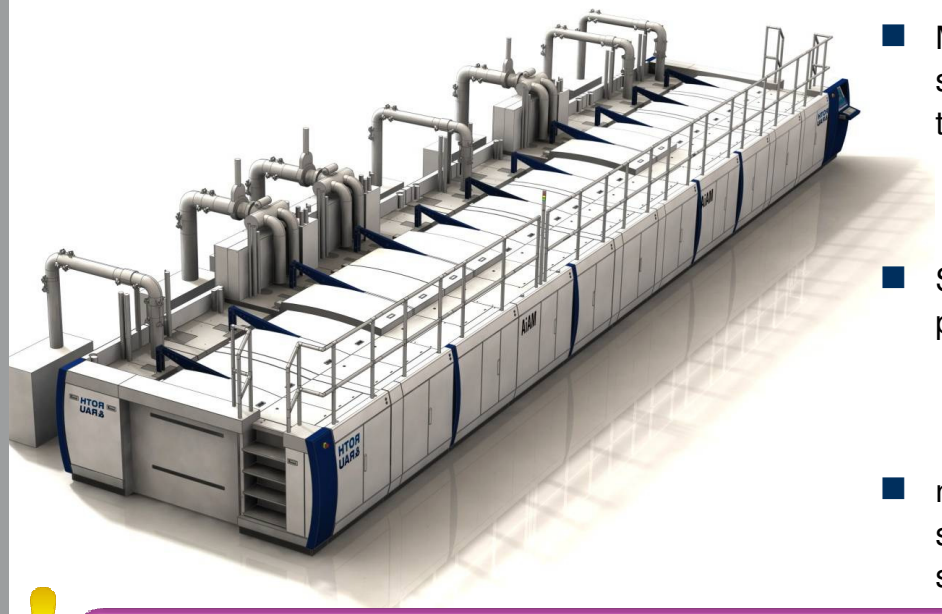


Fig. 1:
MAiA 1600 (11 chamber)



- High performed modular plasma equipment system based on SiNA platform with:
  - HIGHEST Flexibility
  - BEST Throughput
  - BEST CoO
- MAiA´s combines PE-CVD for SiN-front and dielectric layer systems for backside (SiOx/SiNx or AlOx/SiNx) in one tool as the unique PV supplier
  - 3 process steps ONE system only!
- SiOx/SiN process for backside passivation successfully placed on the market,
  - Front & Back Side ARC in ONE Step
- new AlOx-process for high efficient solar cell concepts as stand-alone or in combination with cap layer available with superiour results,

! Comparable or better to SEMI proven ALD process in Cell Efficiency at higher throughput and lower costs !

PRiME-LiNE$_{HJT}$
HELiA PECVD Tool Layout

ROTH &RAU

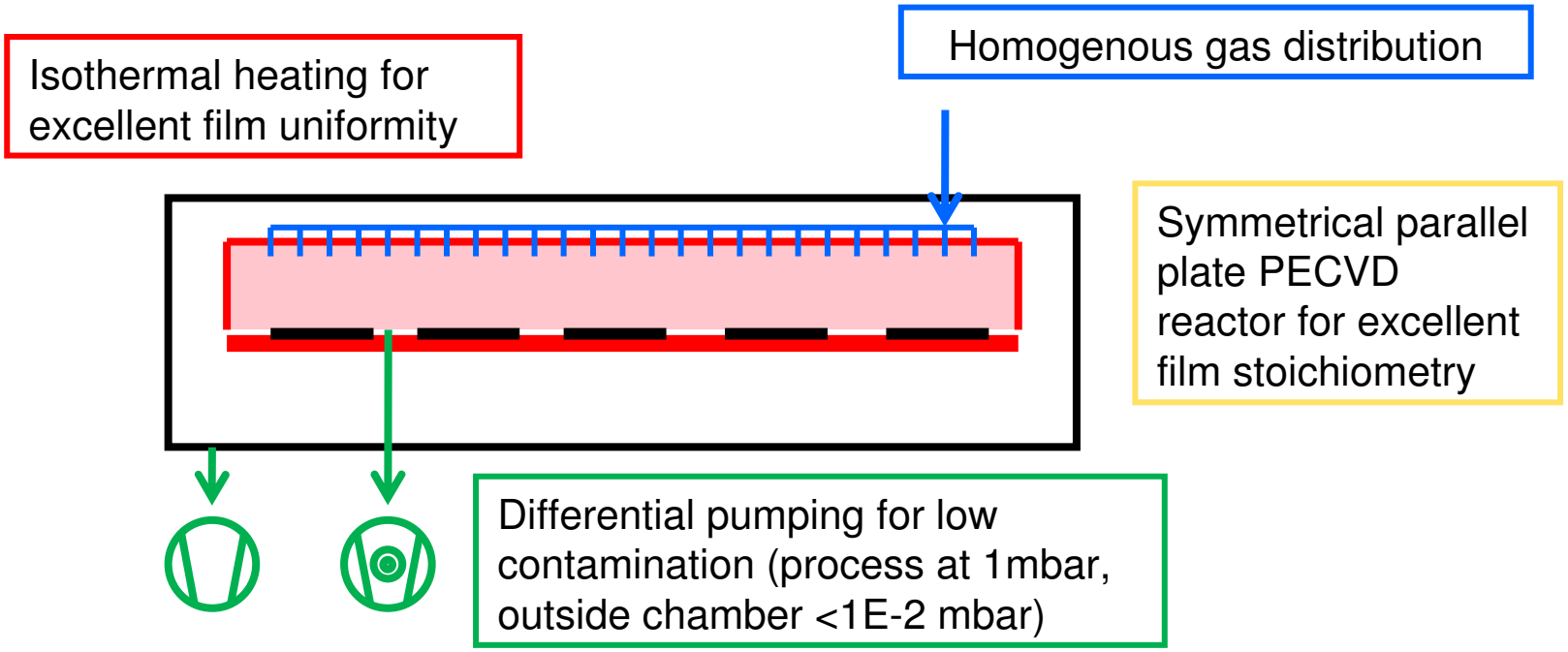
PRiME-LiNE$_{HJT}$
HELiA PECVD Deposition System

- Superior patented S-Cube Reactor for high quality a-Si:H deposition
  - Low contamination with Box-in-box reactor
  - Isothermal heating for good uniformity
  - Narrow gap electrode, symmetrical
- Carrier-less wafer handling for contamination-free processing
- High throughput of 2400 wph for i/p or i/n
  - Flexible design to accommodate 1000 – 2400 wph
- Deposition of intrinsic, p-doped or n-doped a-Si:H possible

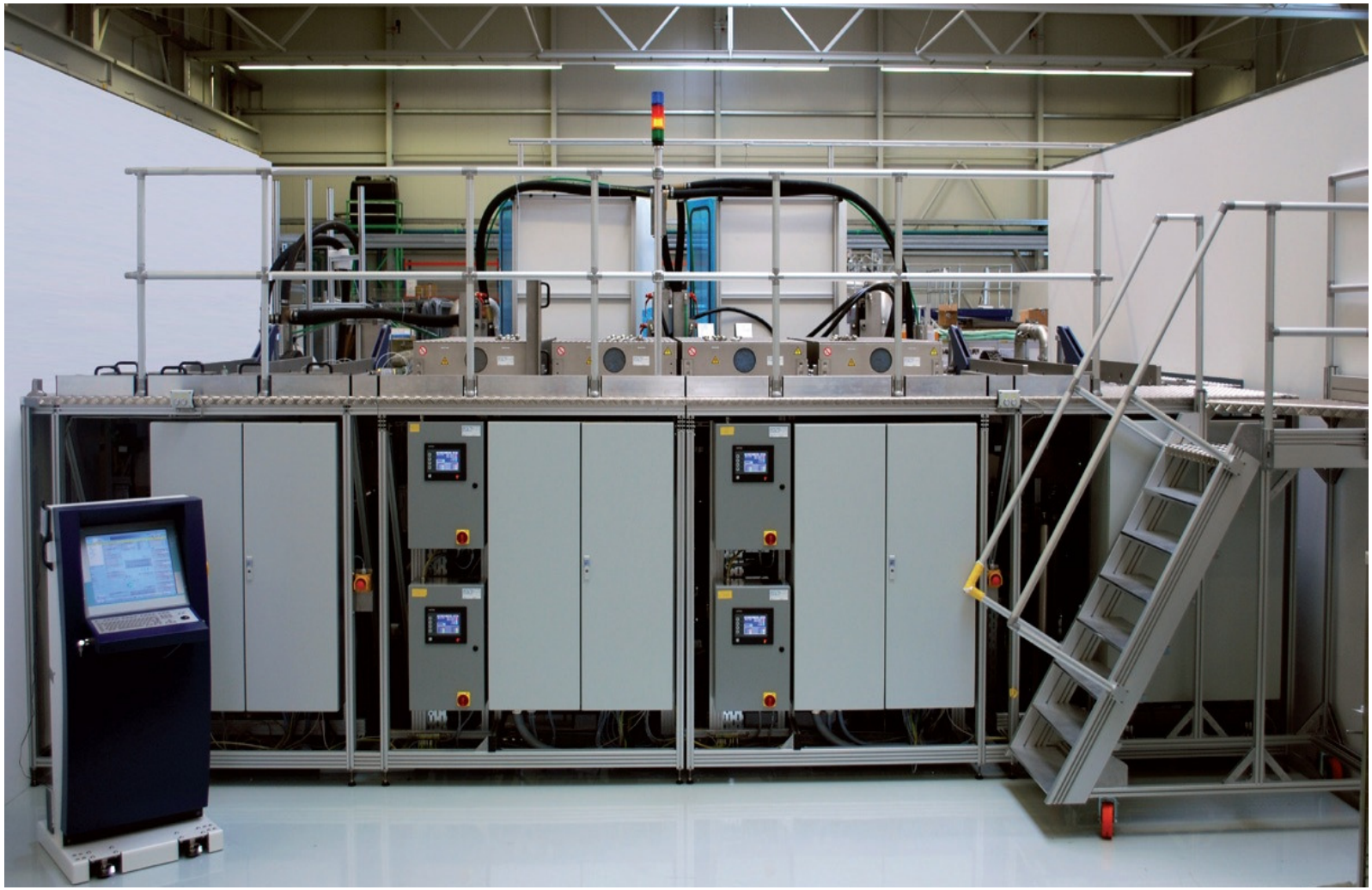
Excellent passivation quality of a-Si – layers
(carrier lifetime > 6ms)

PRiME-LiNE$_{HJT}$
HELiA PECVD Production System

- Patented S-Cube™ PECVD process system for high performance a-Si:H deposition
- Advanced, carrier-less wafer handling system for contamination-free transfer of substrates



PRiME-LiNE$_{HJT}$
HELiA PVD Production Tool configuration



PRiME-LiNE$_{HJT}$
HELiA PVD Production System

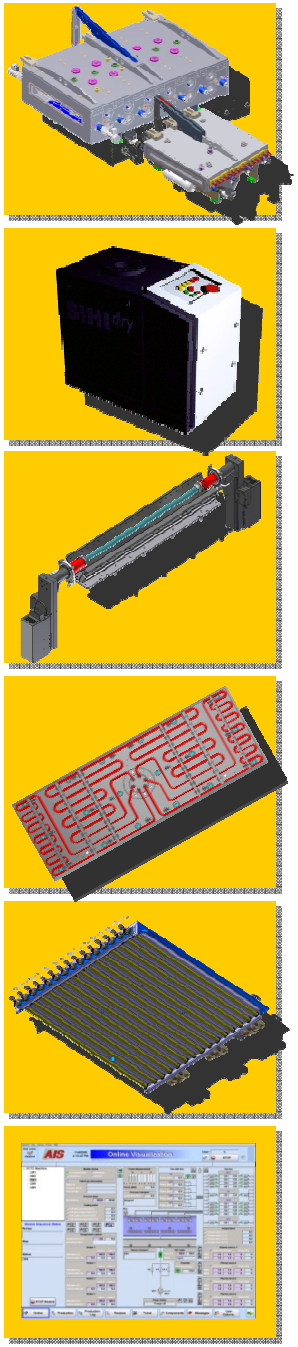
High-performance PVD Solution with rotary magnetrons:

- Proven high quality TCO and metal deposition in R&D line and pilot tool
- Lowest COO: Low material cost with rotary magnetrons (>90% Target util.)
- Tact time of PECVD tool – simple handling interface
- Capability of front and back deposition in same tool (2400 wph)
- Excellent uniformity with rotary linear magnetrons
- Long MTBM with multiple magnetrons for front and back side deposition

Turbo pump

Benefits HELiA PECVD/PVD

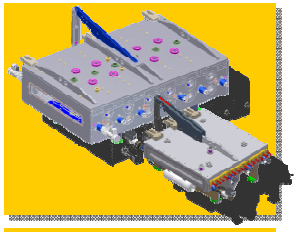
- Competence in HJT – Full R&D line and Commercially Available Deposition Systems
- Superior PECVD Solution with S-Cube, carrier-less wafer handling
  - Superior passivation quality
  - Flexible design for throughput up to 2400 gross WPH
- PVD: Excellent process conditions and CoO advantage with rotary magnetron sources
  - Option for 2 or 3 back metal deposition sources and processes
- Access to R&D line, full qualification of PECVD and PVD tools in pilot line format at Roth & Rau HQ, Hohenstein Germany

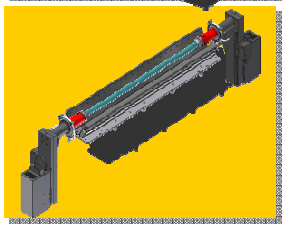
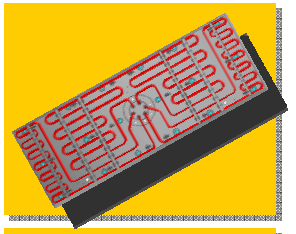
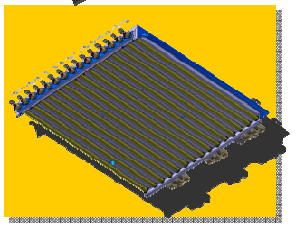
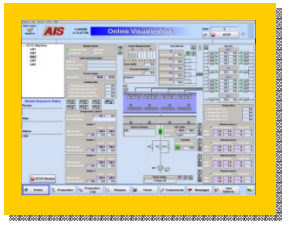


Conclusions

- Market Leader in PECVD, PVD Deposition Equipment and Process Technology
- Large Process base
- Single and multi process application
- Multi cell format base
- Focus on enhanced Cell efficiency process and equipment solutions
- Positioned for short term and long term success

How can we help?



ROTH &RAU

www.roth-rau.com

Roth & Rau USA

+ 1 614 481 6701

Roth & Rau AG
An der Baumschule 6-8
09337 Hohenstein-Ernstthal
Germany

☎ +49 (0) 3723 6685-0
Fax +49 (0) 3723 6685-100
e-mail: info@roth-rau.com

Thank you for your attention.