2012▪2013

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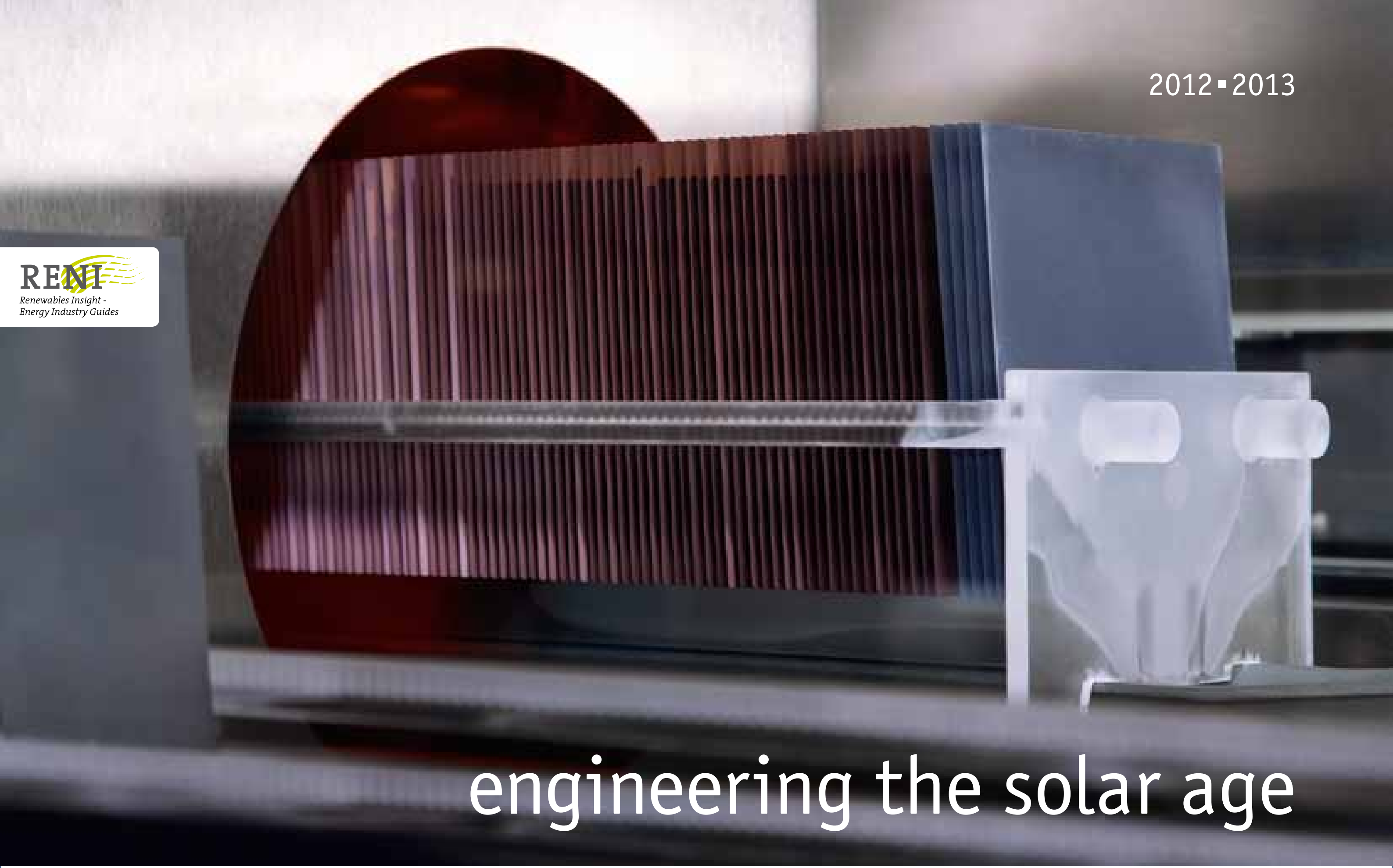
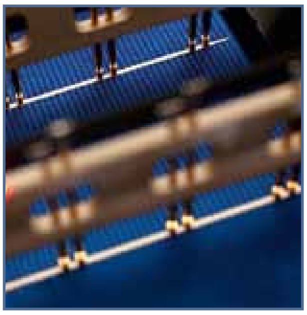
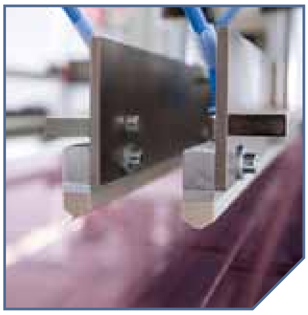
Energy Industry Guides



engineering the solar age

Suppliers for Photovoltaics



COVER IMAGES

Front large:

Wafers in a diffusion furnaces
Source: Tom Baerwald / Q-Cells International

Front small (f. l. t. r.):

Measuring electrical parameters to guarantee cell efficiency
Source: Tom Baerwald / Innotech Solar

Front side inspection with multi-color analysis
Source: Tom Baerwald / Innotech Solar

Wafer handling
Source: baumann

Thin-film automation
Source: Tom Baerwald / Mikron Berlin

Back:

Applying metal contacts to a thin-film module using soldering technology
Source: Tom Baerwald / Mikron Berlin

SOURCES USED FOR THE EDITORIAL SECTION ("THE INDUSTRY")

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www.eupd-research.com

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Forschen für das Zeitalter der erneuerbaren Energien, Berlin 2010

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www.photovoltaik.eu

SEMI
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www.itrpv.net

sologico
www.sologico.com

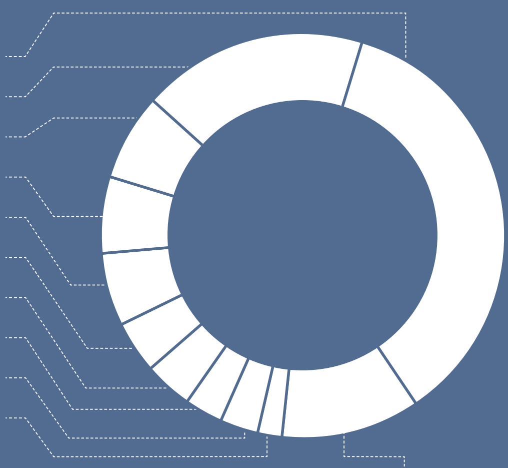
Content of this brochure

Photovoltaics, an application of electronic and semiconductor technologies, long since became an independent high-tech industry. This brochure presents the most important applications, backgrounds, technologies, and, most importantly, the key players in the fields of machine engineering, automation, raw and process materials, and factory planning.

Profiles are also included from a selection of top-quality companies specializing in machine engineering and factory equipment that will be of interest to buyers, technicians, and factory managers.

Global PV market 2011

	Annually	Cumulative	Share of global capacity (cumulative)
Installed output	29,665 MW	69,684 MW	100%
IMPORTANT MARKETS			
Germany	7,485 MW	24,678 MW	36%
Italy	9,284 MW	12,754 MW	18%
Japan	1,296 MW	4,914 MW	7%
Spain	372 MW	4,400 MW	6%
USA	1,855 MW	4,383 MW	6%
China	2,200 MW	3,093 MW	4%
France	1,671 MW	2,659 MW	4%
Belgium	974 MW	2,018 MW	3%
Czech Republic	6 MW	1,959 MW	3%
Australia	774 MW	1,298 MW	2%
Rest of the world	807 MW	7,529 MW	11%



Outlook for the global market until 2016

Output installed annually

	EPIA moderate	EPIA policy-driven
2012e	20,205 MW	40,204 MW
2013e	20,555 MW	41,361 MW
2014e	26,790 MW	52,201 MW
2015e	31,890 MW	62,095 MW
2016e	38,822 MW	77,265 MW

The "moderate scenario" assumes "business-as-usual" market behavior with no major reinforcement of existing support mechanisms, but takes into account a reasonable continuation of current FITs aligned with PV system prices.

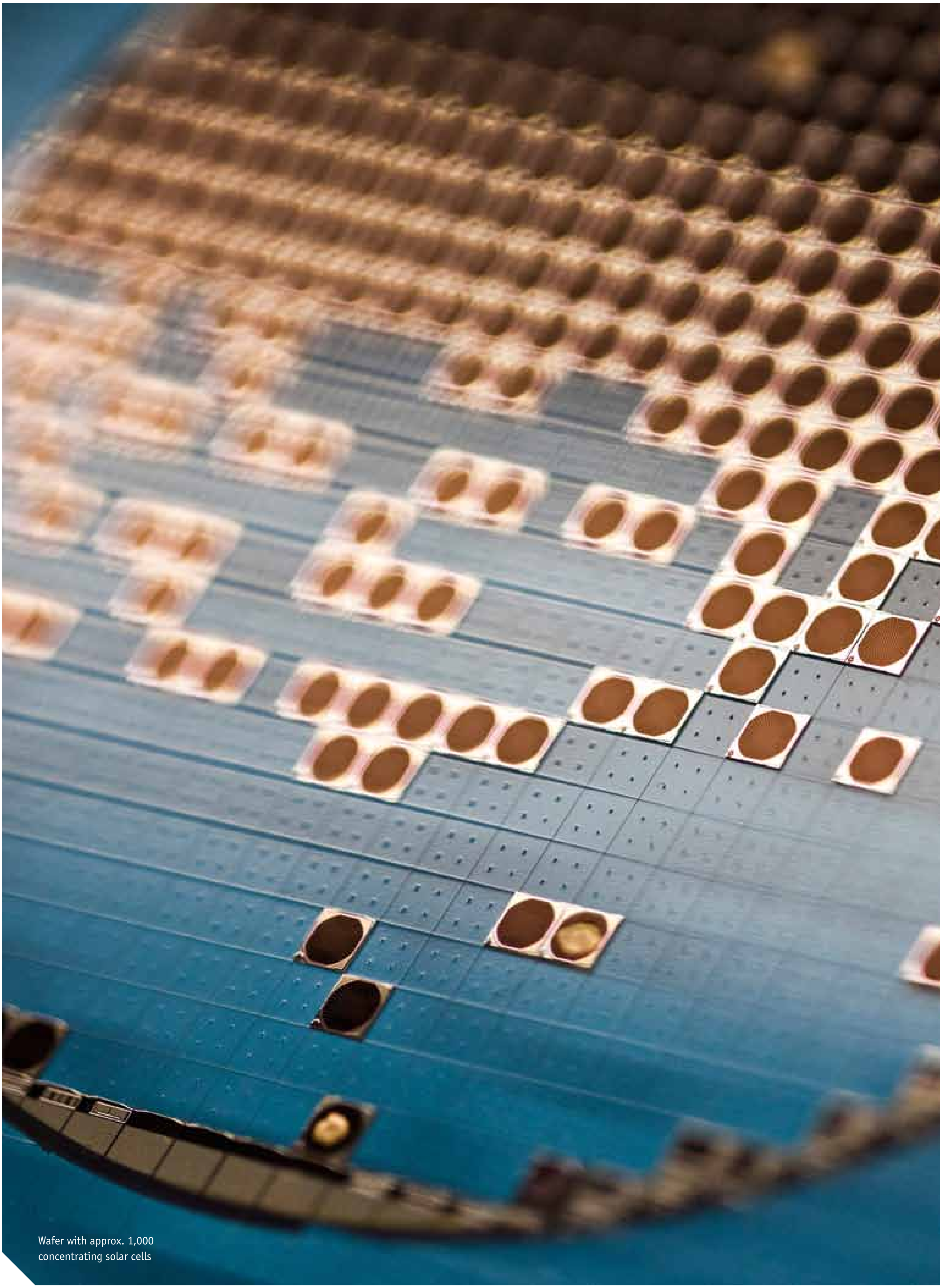
The "policy-driven scenario" assumes the continuation or introduction of support mechanisms, namely FITs, accompanied by a strong political will to consider PV as a major power source in the coming years. This must be complemented by the removal of unnecessary administrative barriers and the streamlining of grid connection procedures.

Source:
European Photovoltaic Industry Association (EPIA), Global Market Outlook for Photovoltaics until 2016, Brussels, May 2012

2012 ▪ 2013

engineering the solar age

Suppliers for Photovoltaics



Wafer with approx. 1,000
concentrating solar cells

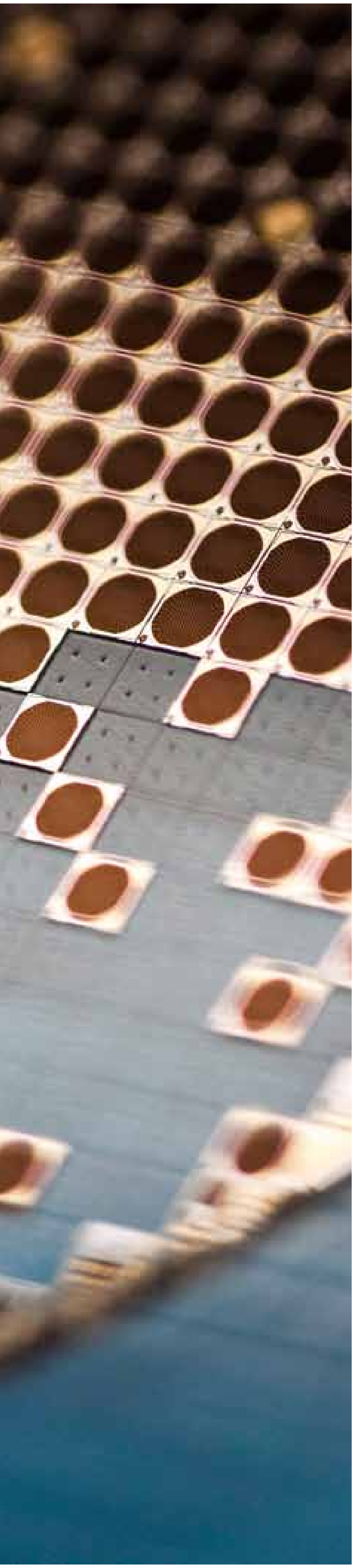


PHOTO: DEUTSCHER ZUKUNFTSPREIS

Contents

Dear Readers,


PHOTO: SOLARPRAXIS

Karl-Heinz Remmers
CEO of Solarpraxis AG

There is no doubt that 2012 and large parts of 2011 have been extremely difficult times for the entire photovoltaics industry, despite the fact that the global market has continued to grow in terms of new installations.

While installation figures are expected to increase further, 2013/2014 is nevertheless likely to remain tough. This is because the price of solar power installations and their main components, solar modules, have plummeted and are continuing to fall. This development has placed a severe financial burden on producers and has led to losses along the entire value added chain. Many companies are literally struggling to survive.

At the same time, the dramatic price drop has made photovoltaics viable in many markets and for many applications, reducing – or even eliminating – dependence on government incentive programs (or at least on the volumes they pay out). Globally, this new situation, the full extent of which is scarcely known, has already given rise to many new applications and will soon trigger further growth in the industry.

We firmly believe that new installations could reach a capacity of 300 GWp/year by as early as 2025, a conclusion corroborated by extensive new research based on the economic viability already achieved with many solar installations, the ongoing improvements in this area, and the new system solutions that are now available. That being said, the prices of solar modules will not rise again in this new market – on the contrary it needs further cost cuts, and thus price reductions, in order to develop.

The numerous benefits of photovoltaics and the easy application of this technology make this development very sustainable, particularly since it is becoming less and less dependent on political support for major market incentive programs. The industry is entering the post grid parity phase several years sooner than even recently expected. We will continue to rely on the substantial innovations which are necessary to achieve our goal of 300 GWp/year (2012: approximately 30 GWp). To still be among the leading producers in 2025, today's major product manufacturers will have to keep reinventing themselves.

The intrinsic truth is that, even today, more than three quarters of all production capacity installed should be seen as outdated – meaning that cells can be produced much more cheaply on new lines. As a result, even plants that are just a few years old are no longer competitive. This puts their owners in a difficult position: Even though operating their plants is too expensive, they have to continue running them in order to generate any yields at all and thus to survive.

Even if, for many companies, making new investments is currently very difficult or even impossible, equipment manufacturers and the entire upstream industry can expect enormous demand for replacing and expanding production lines in the medium term. The price pressures that are triggering the need for much larger capacities will also lead to an increased demand for modern, highly efficient production equipment.

The industry is facing a pork cycle which can be expected to last until the end of 2013 or even 2014. This is a positive outlook amidst the crisis, and the industry ought to communicate this to banks, governments and customers. This brochure, apart from being an industry guide, wishes to contribute to this with its 2012 edition. Along with its sister publication, "Solarenergie in Deutschland – Solar Energy in Germany", it is celebrating its tenth anniversary this year. The two publications have accompanied the rapid and impressive developments within the industry and attempt to provide stimulation for new ideas.

I would like to take this opportunity to thank all those who have been loyal to us and have supported us over the years, and continue to do so in these financially constrained times. Continuing along the path – and more than this, forging ahead – will be worthwhile. The mission of providing safe, affordable and green energy with solar power is within reach: Even in our home country, Germany, which is not exactly renowned for its abundance of sunshine, an impressive 5.3 percent of electricity came from photovoltaics in the first half of 2012. Globally, we will reach much larger shares of the energy mix over the coming decades, creating a solid basis for lasting investments and stable businesses.

Karl-Heinz Remmers

There's No Stopping the "Photovoltaics Train"

PHOTO: SEMI

Heinz Kundert is President of SEMI (Semiconductor Equipment and Materials International) Europe.

At the beginning of every new year, the same questions are raised: "Will we see more gigawatts of photovoltaic capacity installed than last year? Will the installation record be broken yet again?" In recent years, forecasters have been more modest in their predictions – but the facts quite clearly show that photovoltaics is now an indispensible part of the energy mix. The belief is already widely held that more systems will be installed in 2012 than in 2011.

It is particularly pleasing that many other countries besides Germany are contributing to the ongoing expansion of PV. Across the world, people have recognized that we need to rethink the way energy is produced and that energy supply can only be made viable through flexible, intelligently shaped energy policies. Even countries that have long been seen as the heartland of fossil fuel energy supply (such as the Middle East) are today already working towards ensuring they will still have sufficient energy to sustain food supplies, for example, in 50-100 years.

It is important to view photovoltaics from the perspective of the entire PV system – in order to remain successful, it is now crucial that companies along the value chain come together to join forces and discuss fields of application, storage solutions, grid expansion and integration as well as the challenges they face together.

However, this also means that the photovoltaic manufacturing industry has reached a point where a "green vision" is no longer the sole objective. PV is now in direct competition with other energy sources and as such must adapt to a new set of game rules. The past few years have undoubtedly been marked by extremely high cost pressures, which sometimes even took priority over technological development – the overriding aim was clearly to reduce unit costs in production. The next stage of PV development, however, needs to focus increasingly on technology and technological advances.

SEMI has made it its task to accelerate the growth of the manufacturing industry by repeatedly collaborating on technical topics. Innovative activities such as the International Technology Roadmap for PV (www.itrpv.net) and the SEMI International Standards Program (www.pvgroup.org/standards) contribute significantly to ensuring that leading companies come together when faced with challenges and jointly seek pre-competitive solutions.

Experience in related industries (such as semiconductors and flat panel displays) has clearly shown that active involvement from technical bodies brings a unique competitive advantage and over the long term leads to huge cost savings in manufacturing. In one study, for example, the US National Institute of Standards and Technology (NIST) showed how the semiconductor industry saved around 9.6 billion US dollars between 1996 and 2011 alone by employing industrial standards.

It must also be stressed that standardization and roadmapping by no means undermine the innovative strength of the companies – on the contrary, these measures help them to focus on what the key factors and competitive advantages are.

A world without solar power generation is now unimaginable. The global photovoltaics industry has achieved this milestone as one force. SEMI is now ready to support every company through the next chapter of the story.

Heinz Kundert

The Photovoltaic Equipment Industry – Key Players on the Path towards Cost Effective and Sustainable Photovoltaic Production

The photovoltaic industry finds itself in perhaps the most challenging time of its short history. Falling prices of solar products and excess capacities, uncertain installation market developments, as well as strong international competition require significant efforts to be made on the part of the photovoltaic industry.

The situation for photovoltaic equipment suppliers is no exception to this. Market prospects in the medium and long term still remain positive. Currently, all market participants need to optimize all their Key Performance Indicators (KPIs) and resolve the tension between short-term market downturn and long-term prospects.

In addition to the continuous improvement of production processes and targeted cost reduction, it is necessary to strive for the strategic development of new markets. The key to long-term competitiveness also lies in closer cooperation along the value chain, starting with production-related research, to combine the expertise of the supplier industry and photovoltaic manufacturers.

Creating successful synergies is a feasible target, the importance of which has been impressively proven over the last decade. The success story of photovoltaics would not be possible without the unique combination of domestic markets, local production, excellent research communities and the wide-ranging expertise of the supplier industry. Photovoltaic equipment makers sustainably contribute to the immense decreases in photovoltaic production costs. They focus on high performance, uptime and yield, and are forerunners in process innovation. Low overall life cycle costs for machinery and equipment guarantee energy- and resource-efficient production so that, in addition to investment decisions, the "eco-image" of photovoltaic products can be upheld. German machinery manufacturers are pioneers in this area and have even shaped eco-standards in Germany and the European Union.

With approximately 948,000 employees and a turnover of 201 billion euros in 2011, the machinery industry is Germany's largest industrial employer and one of the leading German industry sectors in general. The manufacturers of components, machines and equipment for photovoltaics in Germany form part of this tradition. They have reached an average world market share of 46 percent and with a turnover of 2.7 billion euros in 2011, they have even exceeded the results of the boom year of 2010. As usual, the export ratio was at a high level and exceeded 80 percent. Business with Asia has the greatest share of the entire turnover, accounting for more than 70 percent. This shows the impressive size, success and importance of the photovoltaic supplier industry.

The present brochure vividly demonstrates the extensive competence of the entire photovoltaic equipment sector, which serves the production industry as a whole. Enjoy the read!

Dr. Peter Fath

PHOTO: VDMA

Dr. Peter Fath is Chairman of the Board of VDMA Photovoltaic Equipment and CTO of centrotherm photovoltaics AG.

The Industry

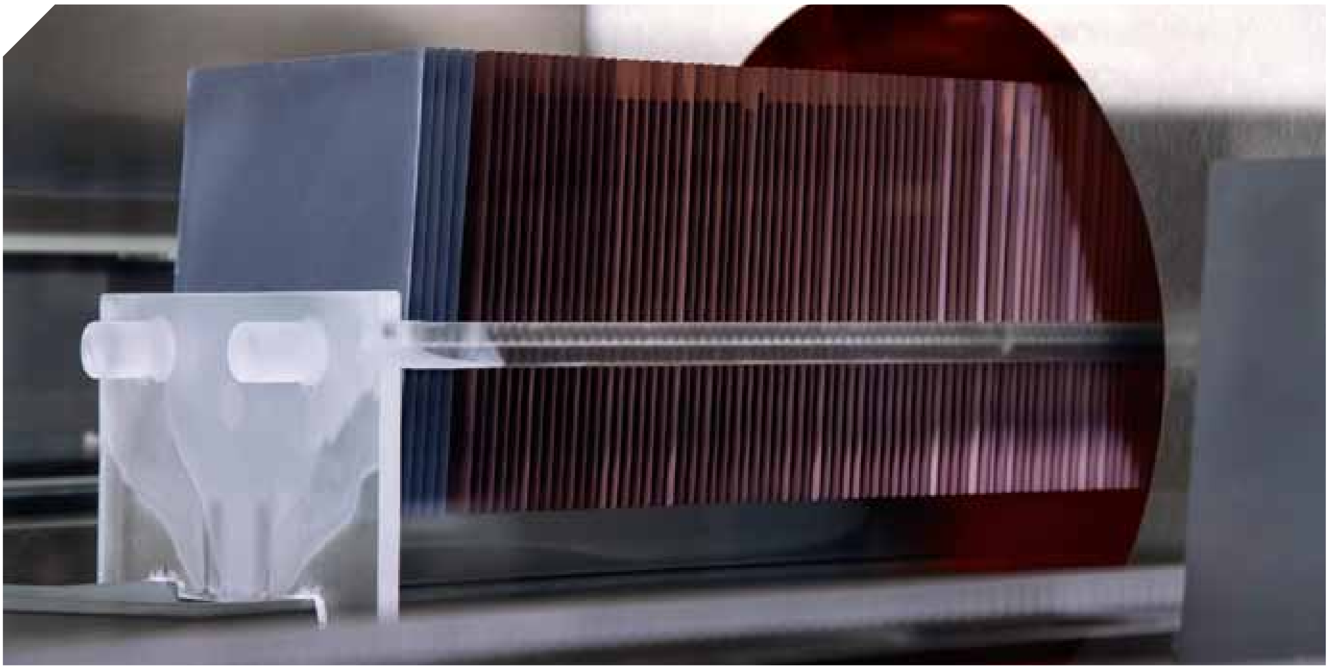


PHOTO: TOM BAERWALD / Q-CELLS INTERNATIONAL

Wafers in a diffusion furnace

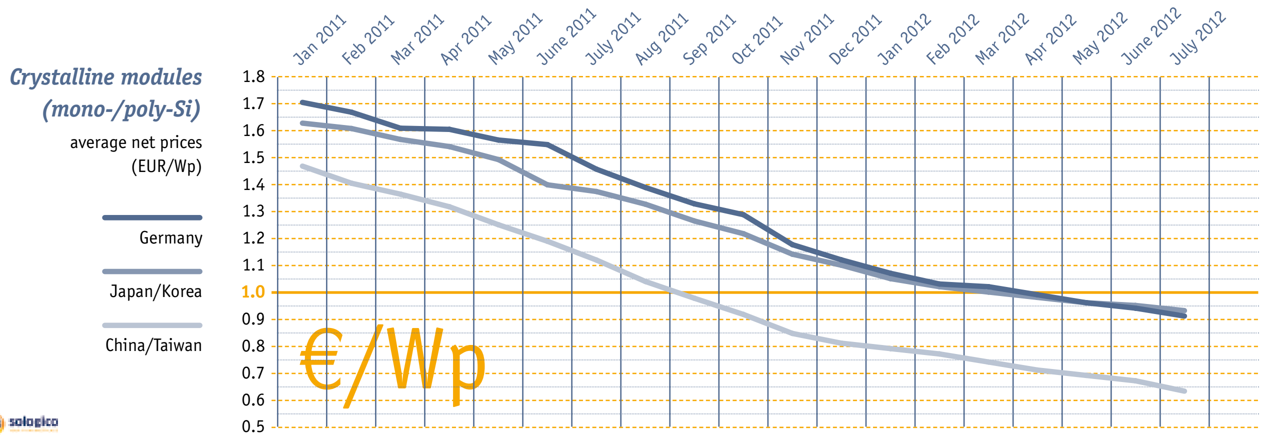
The Market

Photovoltaics achieved an important milestone last year: It is no longer an expensive means of generating electricity. A drop in solar module prices of up to 50 percent over the last 12 months has turned the industry's key indicators on their head. And an end to these falling prices is not yet in sight.

Even in less sunny regions, such as Germany, solar power generated on homeowners' roofs is now cheaper than conventional power from the public grid, which is lowering dependence on market launch programs. In sun-rich areas, such as the Middle East or India, sizeable markets are able to emerge with the most limited of public start-up funds. If they succeed, they will be able to share the experiences they gain in planning and installation. This process will lead to rapid growth in the global photovoltaics market over the coming years.

The PV industry is characterized by dynamic market developments. The impressive rate of growth is being driven by the many PV projects in North America and Europe. Above all development in the Far East is significantly expanding installed PV capacities.

Consolidation is currently taking place at all levels of the manufacturing chain, from wafers to modules, and numerous companies are set to disappear from the market as a result. Despite this, the unmatched advantages of photovoltaic power generation remain the same, meaning growth will soon accelerate once more and the companies which are able to stay afloat in the market will expand more rapidly again. The cost of photovoltaics will fall further and solar installations will spread to an increasing number of countries.



Source: sologico

PHOTO: TOM BAERWALD / Q-CELLS INTERNATIONAL

Cell sorting

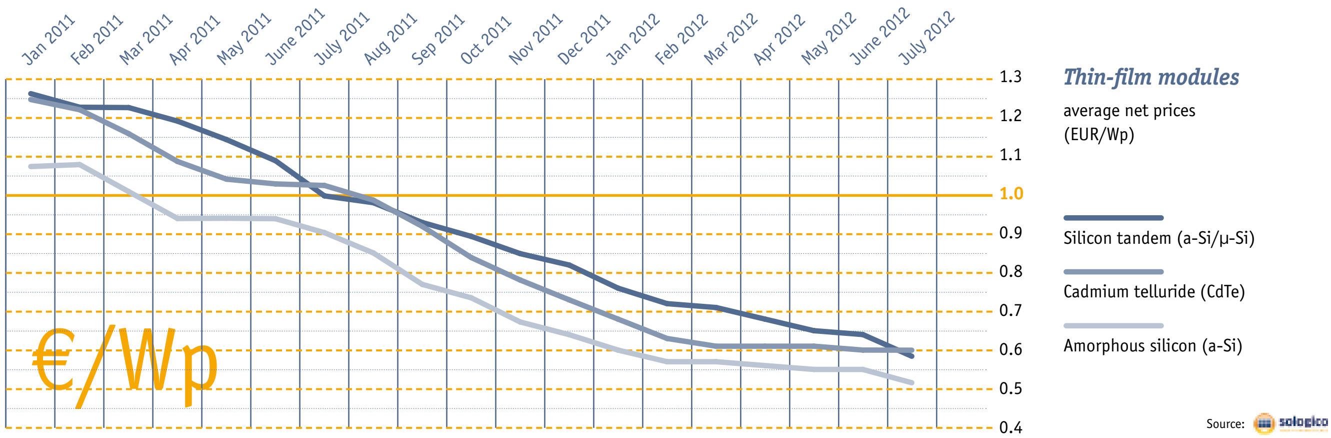
Silicon production capacity

Photovoltaics are inconceivable without silicon: All other elements that have been tested and are theoretically suitable for solar power generation have, to date, only ever played a minor role in solar power generation. As a result of its significance for the industry, solar-grade polysilicon has undergone dynamic market development over the past years, characterized by rapid growth, shortages and surpluses, as well as the dramatic price fluctuations that follow.

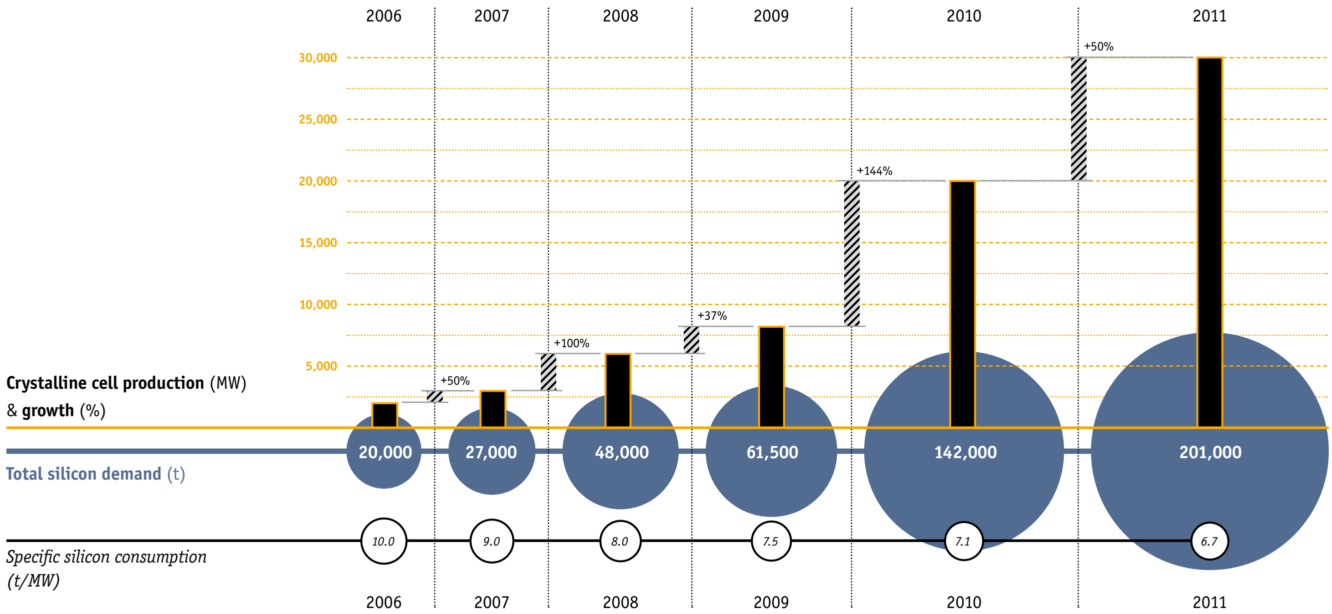
A high number of factories have emerged since 2006 in response to polysilicon shortages, which first occurred a few years ago, and the sharply rising demand expected to continue in North America, Europe and Asia. However, the process of constructing new production capacities is relatively drawn out. Newcomers in particular need a lot of time to master the demanding engineering procedures. In the first quarter of 2008, demand rose considerably more quickly than supply, leading to the spot price climbing as high as 500 USD/kg.

This price was significantly higher than the actual production costs, prompting many small factories to spring up, particularly in China. Established manufacturers were also seen to greatly increase their production. By the start of 2009, the spot price had fallen to 150 USD/kg and by the end of that year it had dropped further to 55 USD/kg. High demand during the following year saw the price recover temporarily, and by March 2011, it had climbed to nearly 80 USD/kg.

The second half of 2011 marked an end to the carefree expansion of capacity, as oversupply started having an effect and pushed the price down to around 25 USD/kg by the end of the year. This put particular pressure on the many small Chinese polysilicon manufacturers who are



PV industry silicon demand



Source: Bernreuter Research

PHOTO: DEUTSCHE SOLAR

Raw silicon

unable to produce more than 3,000 metric tons a year, and the majority were unable to hold out against the drop in price. Since the fourth quarter of 2011, many Chinese manufacturers have ceased production. Around three quarters of the 40 plus Chinese companies that originally existed have now disappeared from the market.

Despite a short-lived recovery in prices, which reached as much as 30 USD/kg at the beginning of 2012, no reversal of the trend is in sight. Since March 2012, the spot price has slumped to between 20 and 23 USD/kg. The entire industry, from silicon manufacturers to module factories, is simply suffering from surplus capacities.

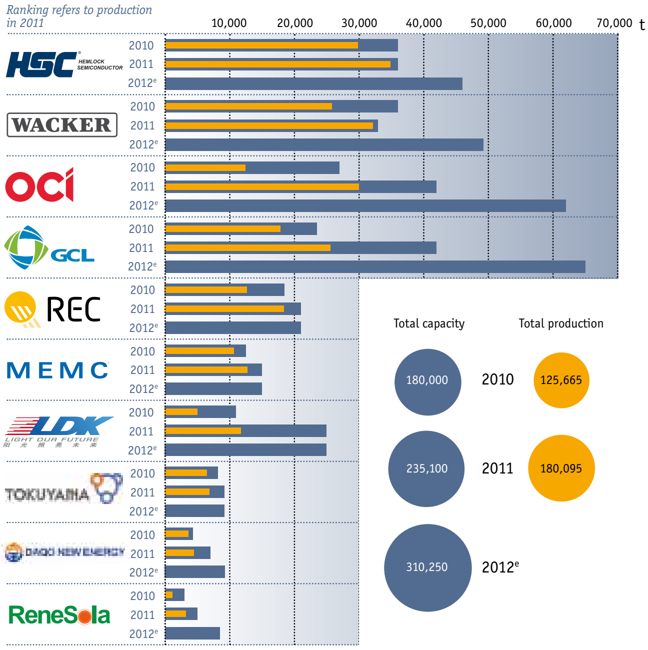
To calculate production volumes as precisely as possible, Bernreuter Research has analyzed the production figures of around 70 manufacturers. According to these figures, the production volume reached around 250,000 metric tons in 2011, added to which another 4,500 to 5,000 metric tons of UMG silicon brings total production to around 255,000 metric tons.

Figures relating to demand differ significantly, meaning the extent of excess production is not easy to establish. Current studies have shown that in 2011 the PV manufacturing industry produced cells with a total output of between 26 gigawatts (GW) (iSuppli) and 33 GW (GTM Research). If we assume that the total output amounted to 30 GW and that 6.7 metric tons of silicon are required per megawatt (MW), this gives a demand totaling 201,000 metric tons.

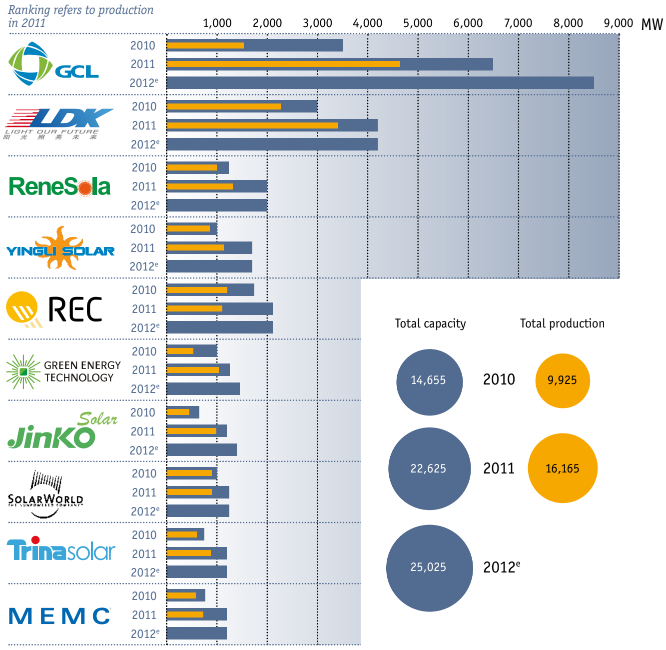
Taking into account the needs of the semiconductor manufacturing industry (29,000 metric tons), the total demand amounts to 230,000 metric tons. This equates to a surplus of 25,000 metric tons in 2011. In 2012, supply may potentially reach around 300,000 metric tons to meet a maximum demand of between 250,000 and 280,000 metric tons. The continued existence of this large surplus is chiefly explained by the fact that, during 2011, the four largest silicon manufacturers drastically expanded their capacities once again.

Producing raw materials from silicon waste
Compacting silicon powder allows the material to be melted later.
Melting silicon
(f. l. t. r.)
PHOTOS: DEUTSCHE SOLAR

Top ten silicon producers (t)



Top ten wafer producers (MW)



Capacity data always refers to the end of the year (2012: estimated). The figures are based on manufacturer statements and calculations performed by IHS iSuppli Corporation.
Source: IHS iSuppli Corporation, quoted in: photovoltaik 02/2012

Wafer and cell production capacity

Two factors put pressure on wafer manufacturers in 2011. Firstly, the dramatic fall in cell and module prices meant that wafer manufacturers also had to lower their prices in response and secondly, silicon prices, which had remained high for a relatively long period of time, eventually fell in the second quarter of the year.

As a result, prices were virtually in free fall, dropping from around 3.50 USD per wafer in the first quarter to between 1.10 and 1.20 USD by the end of the year. Wafer manufacturing margins have plummeted sharply and it is likely that many wafer manufacturers made no money in 2011. The manufacturing industry must consolidate itself from now on.

The list of the top ten manufacturers in 2011 no longer includes any companies that exclusively produce wafers. Wafer manufacturers either produce silicon or cells as well. Integrated solar companies that carry out all the steps in the supply chain under one roof, from silicon to module production, are better shielded against price drops – as long as the fall in prices is limited to an intermediate product. If the entire value-added chain is affected, they too would no longer be able to compensate for these losses.

The dramatic slump in prices could lead to wafers being produced by merely a few specialized manufacturers, which would be able to survive on low margins by producing a vast number of units. This is a trend which has already emerged in silicon manufacture.

2012 is no easier for wafer manufacturers than 2011, as market conditions are still shaped by surpluses. The market shakeout will continue and, as long as this persists, prices will fall further with cells and modules becoming cheaper as a consequence. Generating solar power will then become even cheaper.

The demanding art of manufacturing solar cells, which is the task involving the highest pro-

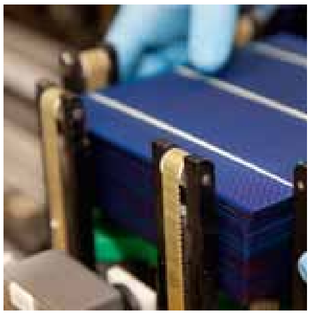
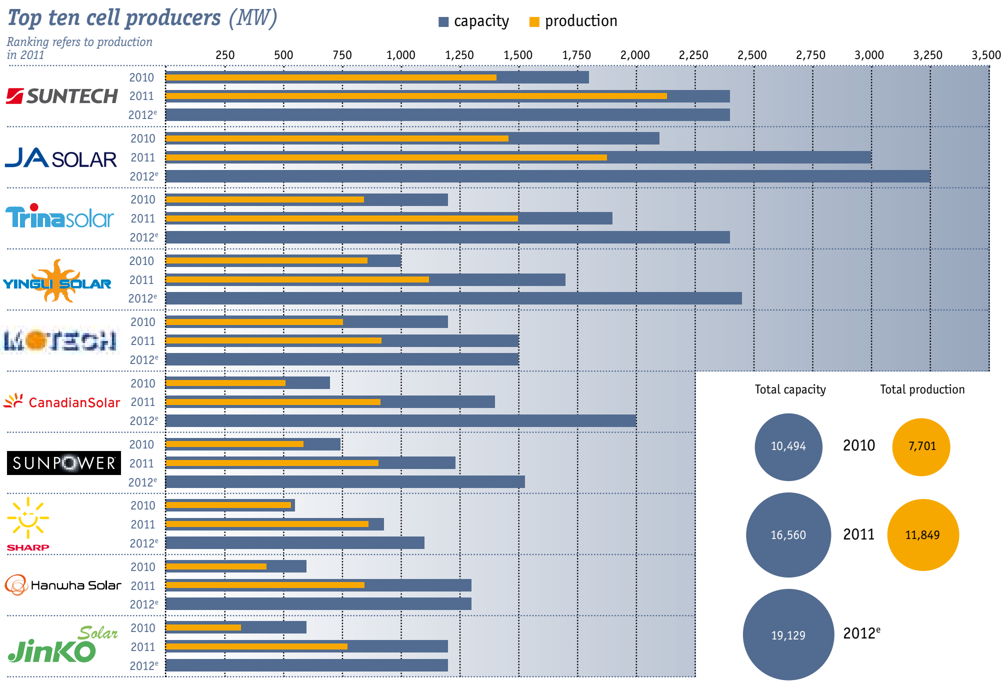


PHOTO: TOM BAERWALD / INNOTECH SOLAR

Automated line: cell loading

Quality controls during manufacturing: ingot, wafer, cell (f. l. t. r.)
PHOTOS (F. L. T. R.): DEUTSCHE SOLAR / HÜTTINGER ELEKTRONIK / BOSCH



Capacity data always refers to the end of the year (2012: estimated). The figures are based on manufacturer statements and calculations performed by IHS iSuppli Corporation.
Source: IHS iSuppli Corporation, quoted in: photovoltaik 02/2012

PHOTO: REC GROUP / RENEWABLE ENERGY CORPORATION ASA

Silicon factory

PHOTO: REC GROUP / RENEWABLE ENERGY CORPORATION ASA

Producing raw silicon

portion of production technology in the entire chain, was a low-risk sector within the industry for many years. However, the large surpluses have also affected this part of the supply chain, reducing margins to a minimum.

2012 could mark a turning point for the PV manufacturing industry, as this is the first year where there is no expectation that all cell manufacturers will increase their capacities. The top ten manufacturers in 2011 include four companies that are not extending their capacities.

However, a significant number of companies remain undeterred and are continuing to increase their production rates. Surpluses will squeeze prices further and competition is increasing. Some companies are even tolerating losses to put others out of business.

The PV market changes much more quickly and aggressively than we are accustomed to with other markets. It is not only dominated by the unwavering laws of the market economy but also by constantly changing government policies. Photovoltaics receives government funding in almost all countries, but if this support is suddenly reduced – as was most recently seen in Germany in March 2012 – the market's already fragile balance is tipped over the edge.

In light of this difficult situation, cell manufacturers are trying to stand out from the competition by increasing their cell efficiency, lowering their production costs and making their products unique. Alongside their standard cells, they are producing special high-performance cells in an effort to enhance the prestige of their brand name.

It is still uncertain whether wafer and cell production will be integrated in the future or carried out separately by specialist companies. This mainly depends on how margins for the individual products in the supply chain develop. For the time being, there are no safe strategies for manufacturers to follow.

Thin-film production capacity

Thin-film technology is currently being challenged on two fronts: The first challenge is the general fall in prices and the second is the success of crystalline silicon technology, which thanks to its high rate of efficiency and mass production is now able to produce a kilowatt hour of electricity much more cost effectively than two or three years ago. Thin-film technology in free-standing installations is also no longer necessarily more profitable than crystalline technology.

The proportion of thin-film modules in the overall amount of modules produced is therefore in steady decline. According to calculations by EuPD Research, it stood at 19 percent in 2010, 15 percent in 2011 and is expected to fall to between 11 and 12 percent over the course of this year.

Manufacturing capacity is also set to shrink for the first time, which can be attributed to both the closure of CdTe factories and numerous

PHOTO: TOM BAERWALD / MIKRON BERLIN

Applying metal contacts to a thin-film module using adhesive

cases of insolvency in the thin-film sector. Many manufacturers of micromorph silicon modules (a-Si/µc-Si) and CIS/CIGS expect the capacities produced by their factories to increase slightly in 2012. However, in light of their continuously decreasing share of the overall PV market, it is likely that the majority of factories manufacturing thin-film modules will suffer from low capacity utilization rates.

Low utilization rates mean that significant increases in manufacturing capacity are out of the question. No significant investments are currently being made, which is why manufacturers are trying to improve throughput and lower production costs within the current manufacturing constraints.

Research and development aim to improve efficiency further in order to reduce the market lead held by crystalline silicon technology. This is especially vital for micromorph silicon, which needs to increase its efficiency by two percentage points if it is to become competitive again.

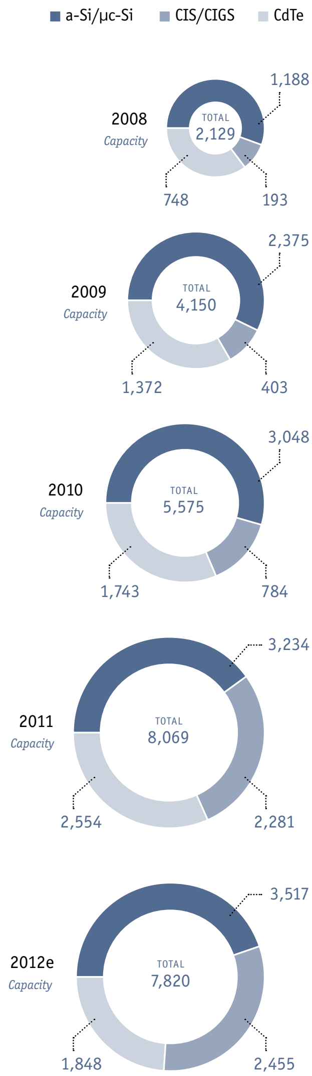
Top Ten countries

The PV market's astonishing boom also continued in 2011. Given the continuing financial crisis, this growth indicates robust market development, which is even able to prevail during political and financial crises. It is certainly possible that regional markets may go through weak phases in the future, but the global market as a whole will be able to continue growing as photovoltaics spreads to an increasing number of countries.

2011 was predominantly influenced by two factors, namely the favorable political conditions in Italy and Germany and the surplus capacities of PV manufacturers in East Asia, which triggered a sharp fall in prices and fueled the dramatic increase in demand. This climate led to the installation of more than 9 GW in Italy and almost 7.5 GW in Germany. The dominance of these two national markets, which accounted for 76 percent of European demand and 57 percent of worldwide demand, is not conducive to sustainable market development.

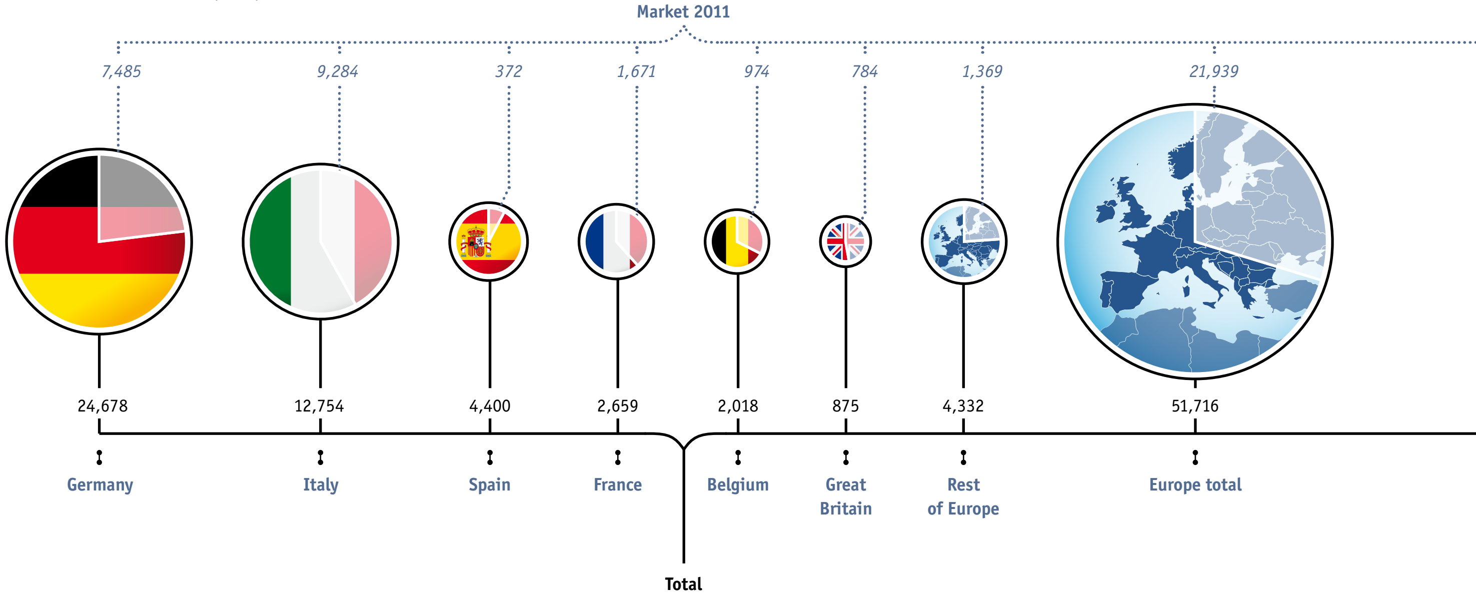
Political policies in Germany and Italy will lead to the markets in both of these countries weakening again. At the same time, the continuous drop in prices is expected to lead to demand rising in other countries. This is especially the case in nations that consume a lot of power but, as of yet, have exploited only a very small part of their PV potential. As a result, sustainable growth is anticipated in China, India and the USA in particular.

Capacity of thin-film module producers (in MW)



Source: EuPD Research

2011 market volume and cumulative capacity in selected countries (MW)



Market outlook until 2016

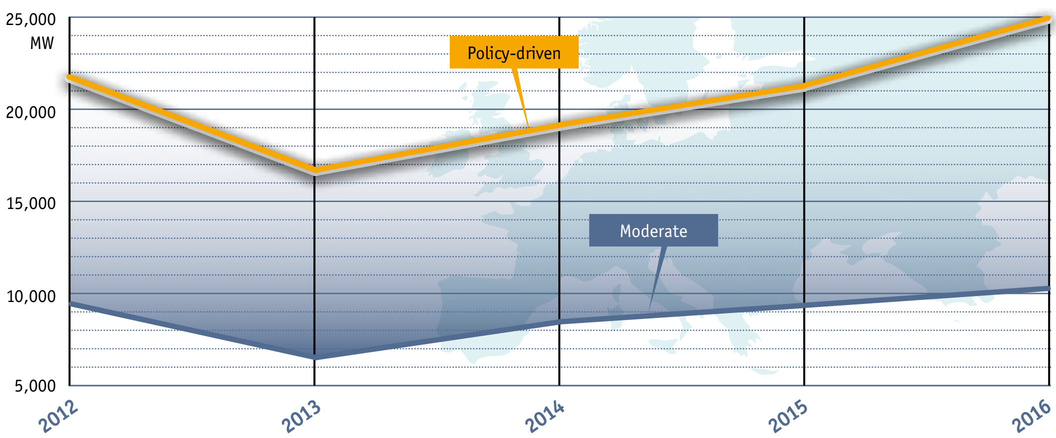
The European Photovoltaic Industry Association (EPIA) analyzes the development of the PV industry under two scenarios:

The moderate scenario assumes rather negative market behavior with little reinforcement of existing support mechanisms, significant decreases in supportive measures and limitations being imposed on existing schemes. In countries close to transition, consumers are not reacting well to the prospect of PV markets without feed-in tariffs (FITs).

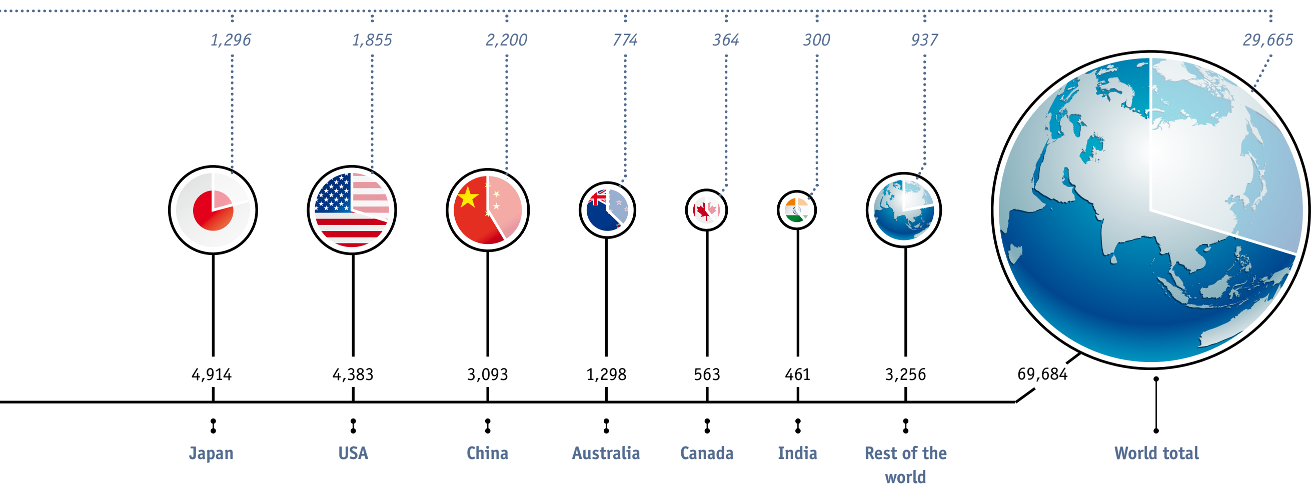
The policy-driven scenario assumes the continuation or introduction of adequate support mechanisms, accompanied by a strong political will to promote PV as a major power source in the years to come. This also requires removing unnecessary administrative barriers and streamlining grid connection procedures. In some extreme cases, this scenario assumes market booms caused by inadequate support mechanisms – such as those observed at the time of publication.

Under the moderate scenario, EPIA assumes a severe market setback in Europe between 2012 and 2016, in which the market will reach a low point in 2013 (6.5 GW) before growing again to 10.3 GW by 2016. Under the policy-driven scenario, the market will shrink from 21.6 GW in 2011 to 16.6 GW in 2013. This will be followed by a rapid recovery phase, during which the market will regain the level achieved in 2011 and will subsequently grow to almost 25 GW by 2016.

European annual market scenarios until 2016 (MW)



Source: EPIA



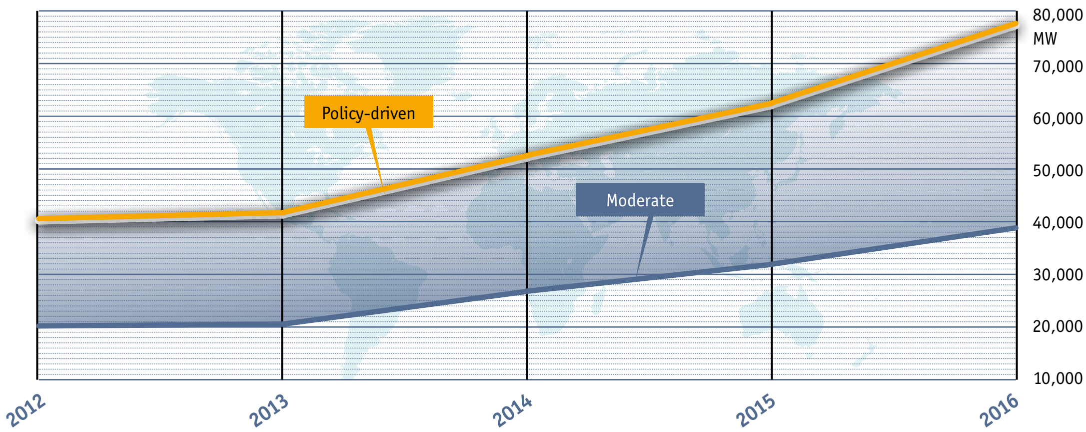
Source: EPIA

Global market development is dependent on many factors, making it even harder to predict than European development alone. Besides political and economic conditions, which are strongly influenced by the financial crisis, the unpredictable fluctuations in price must also be considered. Although a further price reduction is expected, the inevitable consolidation process will force many companies out of the market. Consequently, oversupply will ease and prices will fall more slowly.

However, the general increase expected in electricity prices will make photovoltaics more economically viable, particularly in regions far away from central power networks. As a result, global growth will stabilize.

EPIA also analyzes global growth under two scenarios. The moderate scenario predicts that the worldwide market will grow from almost 30 GW in 2011 to around 39 GW in 2016. The policy-driven scenario estimates precisely double this figure, predicting that the volume will reach more than 77 GW by 2016 and that capacity installed worldwide will increase to 343 GW. Both scenarios foresee that the world market will be predominantly shaped by demand in Europe, China and the USA.

Global annual market scenarios until 2016 (MW)



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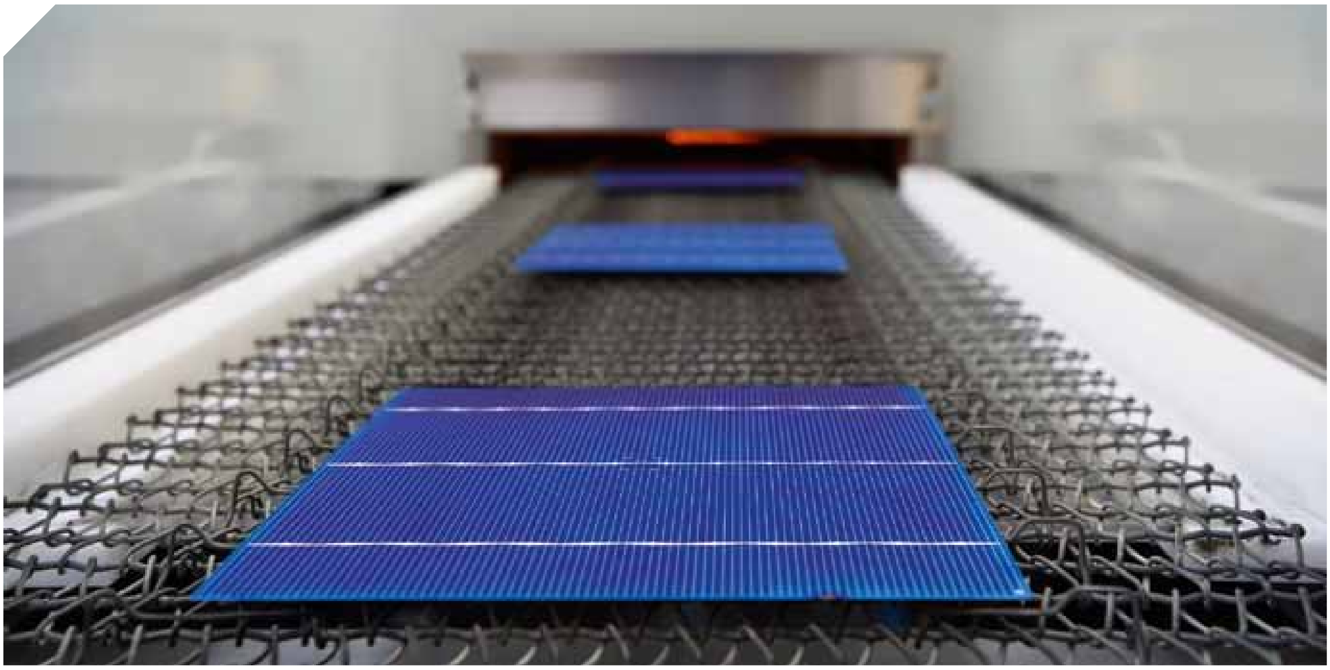


PHOTO: TOM BAERWALD / Q-CELLS INTERNATIONAL

Rear side passivation: A reflective coating of silicon nitride is applied to the cell rear, which reflects light back into the cell.

The Technology

PHOTO: CENTROTHERM PHOTOVOLTAICS

PHOTO: HÜTTINGER ELEKTRONIK

Process steps in cell production (above and below)

Photovoltaics uses the internal photoelectric effect to generate electricity from sunlight. Incoming light which is absorbed by a semiconductor crystal releases electrons from their bonding state. An electric field is then required to conduct them away from the solid state.

Solar cells have an n-type layer which can emit electrons (emitter) and a p-type layer which can absorb electrons (base). At the boundary interface between the two layers (p-n junction) an electric field is formed, which separates the light-generated charge carriers. A voltage corresponding to the electric field is produced at the terminal contacts of the cell, meaning that current is able to flow as soon as the contacts are connected to each other.

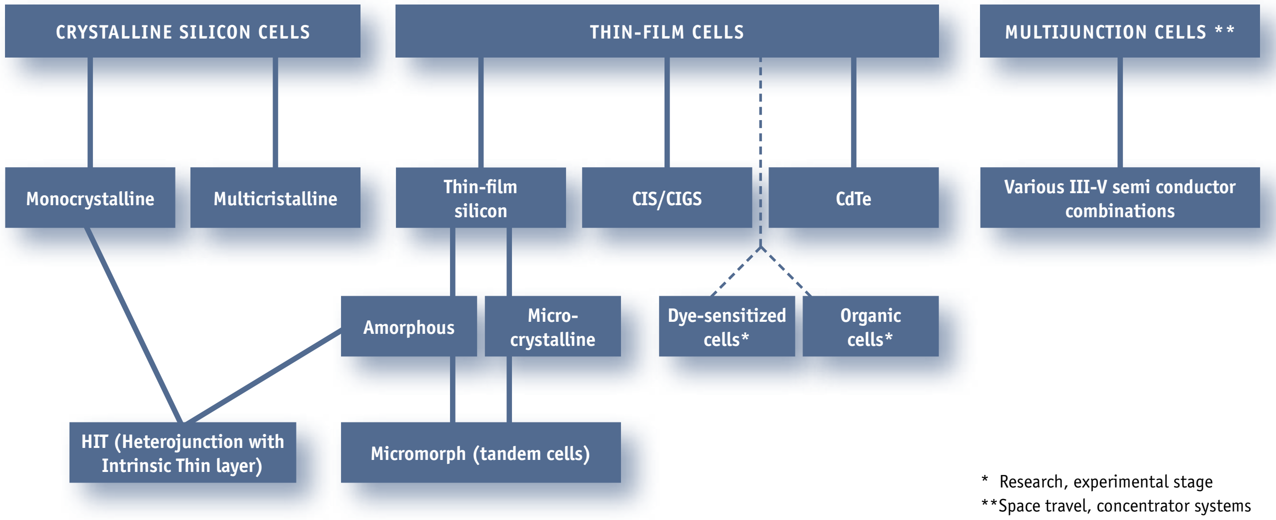
Many types of solar cell have already been developed in laboratories to increase efficiency and reduce costs. Five of these are used commercially today and play a role in the market. The fundamental difference between them is the semiconductor material used and their crystal structure (crystalline or amorphous).

Silicon is the prevailing semiconductor in photovoltaics. Monocrystalline (mono-Si) and multicrystalline (mc-Si) are mainly used. Crystalline silicon solar cells achieve the highest efficiency, however the manufacture of high-purity silicon requires relatively large amounts of energy and brings with it high costs. Thin-film technology, which requires significantly less material, is therefore used in an endeavor to avoid both of these drawbacks. The following materials are chiefly considered to be suitable semiconductors:

- amorphous silicon (a-Si) and microcrystalline silicon (µc-Si)
- copper indium diselenide (CIS)
- cadmium telluride (CdTe)

First generation photovoltaics technology is based on crystalline silicon. The second generation is based on thin-film technology and the third generation encompasses new technologies which have not yet reached a commercial stage – mainly organic solar cells.

Types of solar cells



Crystalline silicon cells

A crystalline silicon solar cell consists of a mono- or multicrystalline silicon wafer approximately 180 micrometers (μm) thick. In order to increase its conductivity, the crystal structure is doped, i.e. foreign atoms are added to the material in a targeted manner. The p-type conductive layer is created by doping the structure with boron; the n-type conductive layer is generated through doping with phosphorus.

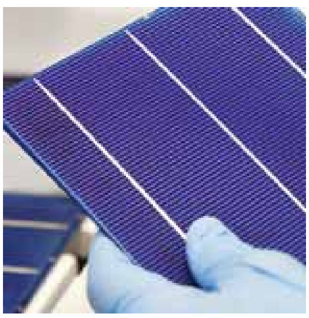
On the front side of the cell, the electrical contact fingers that conduct charge carriers away form a lattice structure of thin conductors which meet in wide metallic strips called busbars. A large aluminum coating forms the contacting on the cell rear.

Monocrystalline cells have a perfectly regular crystal structure. Multicrystalline cells consist of silicon crystals with grain sizes measuring just a few millimeters. The grain boundaries represent crystal defects to which charge carriers can be bound (recombination), which is why the efficiency of multicrystalline cells is somewhat lower. Standard monocrystalline silicon cells achieve an efficiency of 17 to 18 percent in commercial manufacturing, while multicrystalline silicon cells achieve 16 to 17 percent.

Special technologies have been developed to increase efficiency. The majority concern front-side contacts, where the conductors and busbars which cover part of the front surface prevent the maximum amount of sunlight from being utilized. Narrower conductors embedded in deep grooves (buried contact cells) can therefore increase the absorptive area without impairing the conduction of electrical current.

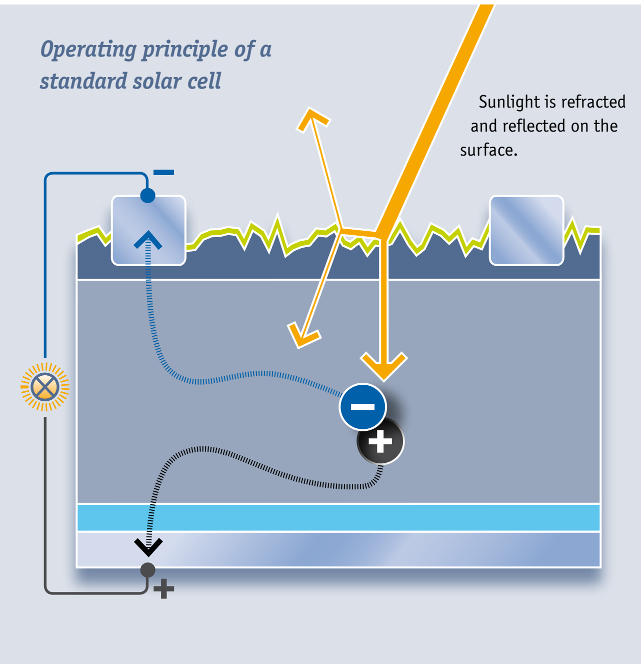
PHOTOS: Q-CELLS INTERNATIONAL

Polycrystalline (top) and monocrystalline solar cells

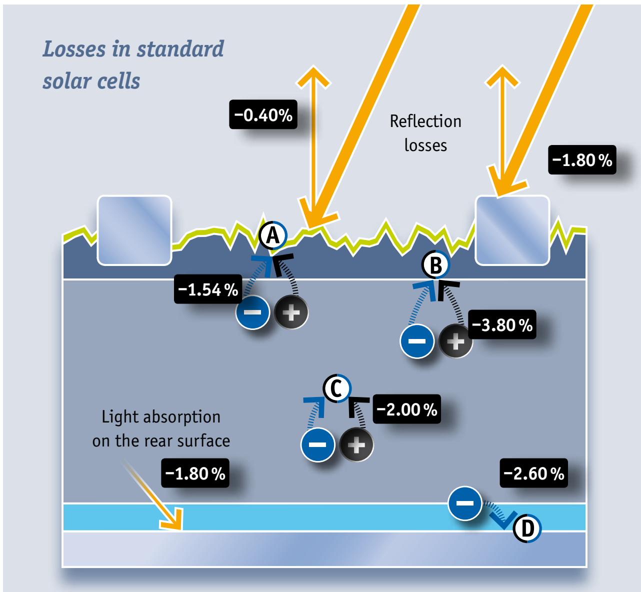


PHOTOS: TOM BAERWALD / INNOTECH SOLAR

Measuring electrical parameters to guarantee cell efficiency



Operating principle of a standard solar cell



Losses in standard solar cells

- silicon nitride anti-reflective coating
- wafer: with phosphorus-doped n-type emitter
- wafer: with boron-doped p-type base material
- with highly aluminum-doped back surface field
- metal contacts: silver on the front and aluminum on the rear
- electron, negative charge
- positive charge

The light transfers its energy to electrons. These become free moving and migrate through the p-n junction to the front contact grid. A positive charge remains in the 'holes' they leave behind, which then moves to the rear of the cell.

The light energy can only be used if the negative charge carriers reach the contacts on the front side of the cell and the positive charge carriers reach those on the rear. The greatest losses that occur in the cell therefore result from positive and negative charge carriers neutralizing one another.

Experts call these recombination losses. They occur wherever the semiconductor crystal contains defects and deviates from its strictly regular structure. This is the case in the anti-reflective coating, the emitter, and even in the base material on the back of the cell. Cells also sustain reflection losses on the top surface and absorption losses on the back surface.

If it were possible to eliminate all these losses, solar cells would achieve an efficiency of 29 percent. As it is, they achieve just 14.4 percent.

This illustration by Richard Swanson is now several years old, but is still used in many research laboratories. Although standard solar cells have improved, those who wish to achieve efficiencies beyond 19 percent need to find new ways to reduce the losses illustrated here.

Holes are lasered into wafers in MWT cell processing.

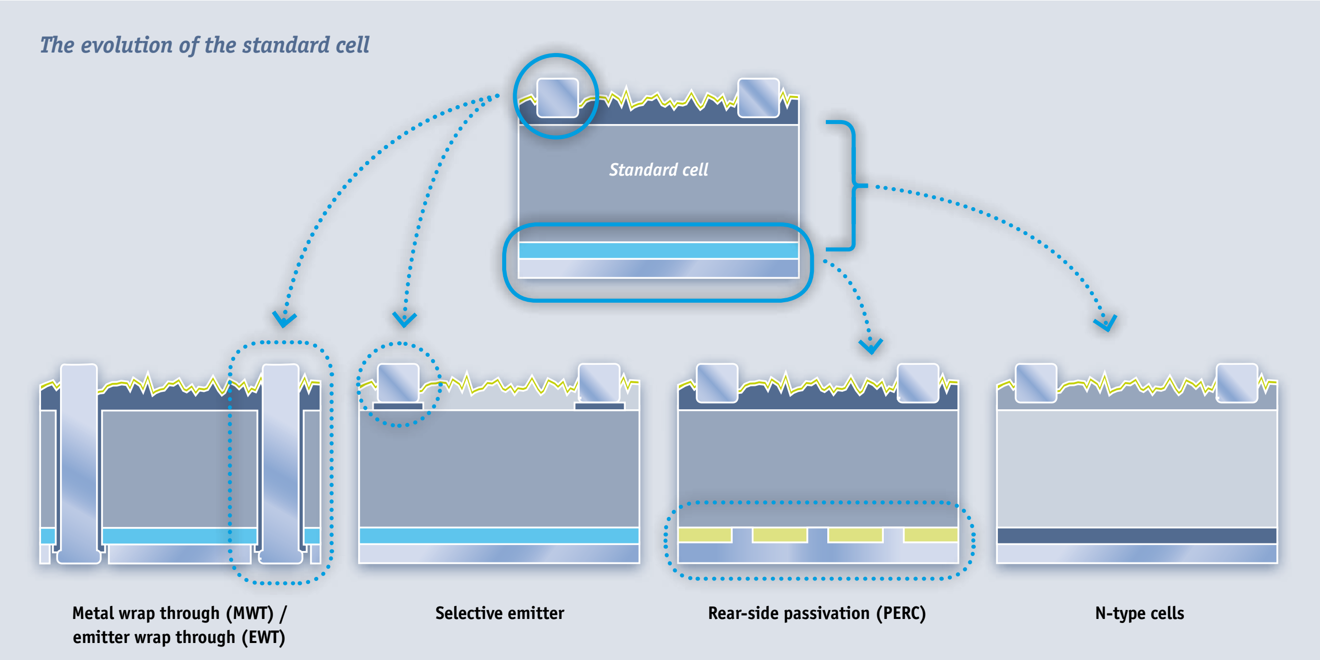
PHOTO: ASYS GROUP

Rates of efficiency can be increased further by moving all contacts to the rear side. Numerous research departments are investigating the potential held by this option and, as a result, an entire range of back contact solar cells already exists. This development took place in three stages:

- Metal wrap through cells (MWT cells) still have a metallic contact grid on the front side but the busbar is found on the rear side. The charge carriers flow through the silicon wafer from the front side to the rear side via 50 minute holes filled with metal.
- Emitter wrap through cells (EWT cells) are similarly constructed to MWT cells. EWT cells require significantly more holes, as they are filled with less conductive, doped semiconductor material as opposed to metal. Several tens of thousands of holes are needed and this density means that the contact grid is not required on the front of the cells. Consequently, shading no longer causes a problem.
- Interdigitated back contact cells (IBC cells) go one step further. Here, the light-generated charge carriers are no longer separated at the p-n junction but on the rear side, where positive and negative conductive sections alternate. Interlocking metal contact fingers form plus and minus poles and conduct the charge carriers away. This "original" high-efficiency cell was first conceived in the mid-1980s and now achieves efficiencies of 24.2 percent. However, structuring the rear side is very expensive. Additionally, the silicon wafer must have the highest level of purity, as the charge carriers have to travel relatively far through the silicon. These long distances increase the likelihood of the charge carriers recombining with impurities or defects in the crystal lattice.

Rear contact cells bring the advantage that they are easier to manufacture, as there are no contact ribbons to be soldered. Instead, the cells are placed with their rear side on a film that already contains conductors and integrated contact points and which is melted on with a laser to create a conductive connection. Additionally, rear contact cells can be positioned more closely together to increase surface area efficiency.

Rear-side passivation with a dielectric material (e.g. silicon dioxide) increases the efficiency of cells even further. This passivation prevents the charge carriers recombining on the rear side. The layer also acts like a mirror, reflecting long-wave (red and infrared) light into the active layer so that it can be utilized. Cells enhanced



silicon nitride anti-reflective and passivation layer

wafer: with phosphorus-doped n-type emitter

wafer: lightly-doped n-type emitter

wafer: with boron-doped p-type base material

with highly aluminum-doped back surface field

metal contacts: silver on the front and aluminum on the rear

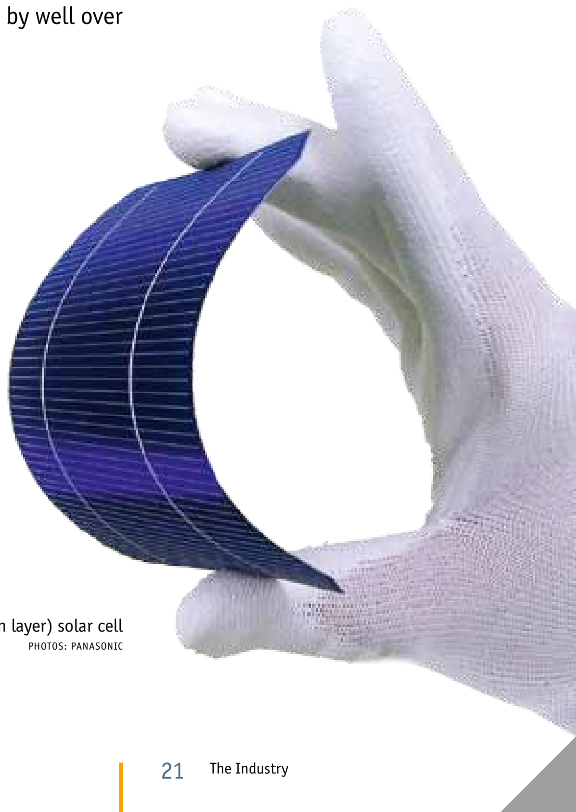
in this way are known as passivated emitter and rear (PERC) cells or, less commonly, passivated emitter with rear locally diffused (PERL) cells. This design can in principle also be applied to rear contact cells in order to improve their efficiency further.

Cells with selective emitters are characterized by n-doped front sides (emitters) with inhomogeneous doping: The silicon is more heavily doped under the printed fingers than between the contacts. The higher level of doping under the contact fingers lowers contact resistance, while the lower level of doping between the contact fingers results in a higher rate of efficiency.

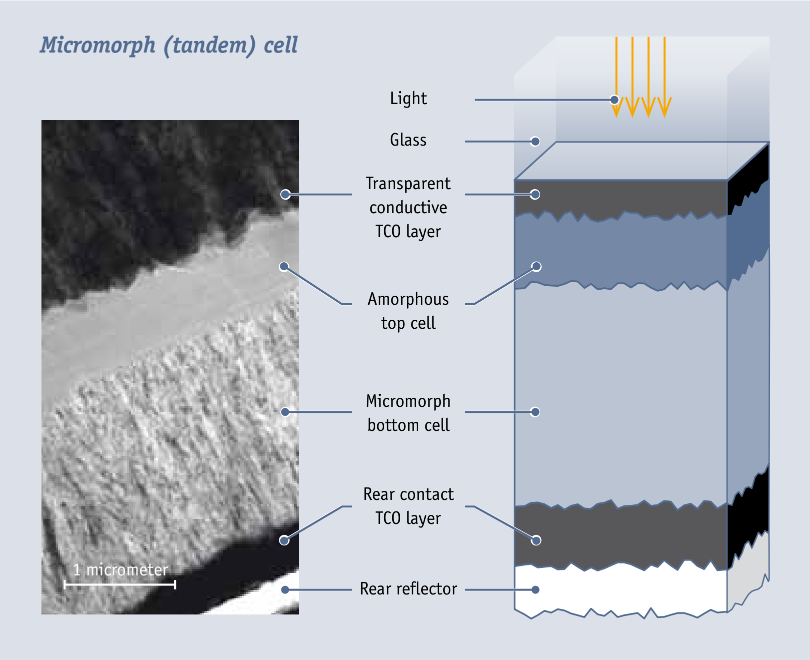
A completely different approach is adopted when n-type cells are used. Here, rather than being p-doped, as is usually the case, the silicon wafer base material is n-doped to reduce recombination losses. An important advantage of n-type silicon is that almost all metallic impurities and many other defects in the silicon provide very asymmetric capture cross sections for the electrons and holes. The lifespan of charge carriers in n-type silicon (n-type Si) is greater than those in p-type silicon (p-type Si) or, in other words, the recombination losses are lower. A further crucial advantage of n-type Si is that, when it is exposed to light, it is not affected by the typical degradation effects found in boron-doped silicon. N-type cells are now gaining importance as a result of these factors.

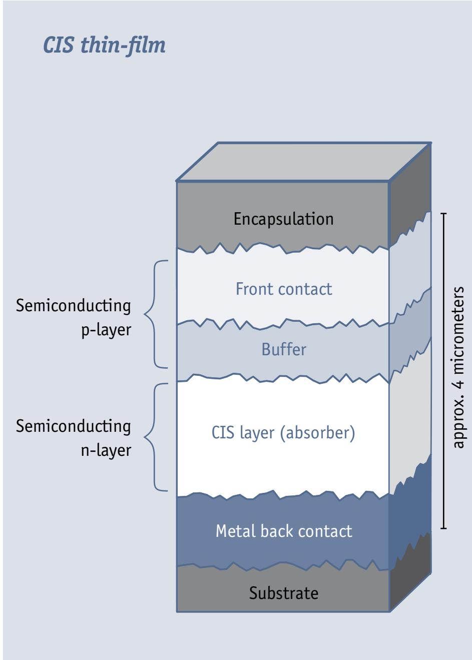
HIT cells

The most successful n-type cell to date is the heterojunction with intrinsic thin layer (HIT) cell. The HIT cell consists of a thin, single-crystal wafer which is covered on the front and rear with an ultra-thin layer of amorphous silicon. Using both crystalline and amorphous silicon layers increases the cell's efficiency by well over 20 percent.



HIT (Heterojunction with Intrinsic Thin layer) solar cell
PHOTOS: PANASONIC





Source: Institute of Microengineering Neuchâtel (IMT)

PHOTO: TOM BAERWALD / MIKRON BERLIN

Applying contacts to thin-film cells

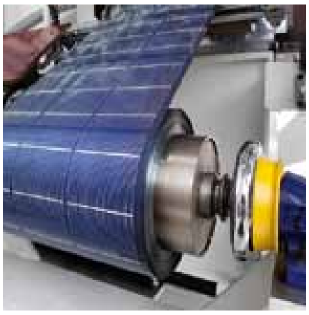


PHOTO: TOM BAERWALD / GLOBAL SOLAR

One advantage of thin-film cells is their considerable degree of flexibility.

Thin-film modules

Thin-film modules are photovoltaic modules with an active photoelectric layer only a few micrometers thick, which is deposited using large-area, thin-film technology. The deposition methods employed are mainly those commonly used to coat architectural glass and VDUs. The production units are at least one meter square in size and surpass the area of a silicon solar cell by some two orders of magnitude.

These extremely thin layers are not self-supporting, and consequently need to be mounted on a substrate. Glass is generally used for this purpose, although flexible plastic films are also employed, allowing roll-to-roll coating which offers advantages in terms of production.

Thin-film modules are less efficient than those made with crystalline cells, but this is offset by the following advantages:

- the energy payback time is relatively short due to the low amounts of material and energy consumed
- the manufacturing process can be automated for large-area modules
- a high degree of vertical integration can be achieved, with only a few production steps necessary
- flexible substrates open up new areas of use for the product and its integration into buildings

The most important advantage is that fully-developed production, which allows large production volumes and efficiency to match, brings such major cost benefits that crystalline technology can be equaled or even bettered. This means that a kWh of solar power can be generated at a lower cost. Three technologies have already made the transition to mass production and are enjoying commercial success:

Silicon-based thin-film modules are generally made from amorphous silicon (a-Si). Since amorphous silicon can absorb light considerably better than crystalline silicon, a film thickness of about 1 µm is sufficient. However, this material generates fewer charge carriers so the efficiency is substantially lower, lying between four and eight percent. Thin-film modules made from amorphous silicon can be manufactured to very large dimensions (the maximum as at June 2011 is 5.7 m^2).

In order to increase the efficiency of an a-Si module, microcrystalline silicon (µc-Si) is added to the amorphous silicon, thereby producing a tandem or micromorph solar cell. The µc-Si layer absorbs more light in the red and infrared parts of the spectrum, and the efficiency increases to ten percent.

PHOTO: TOM BAERWALD / INNOTECH SOLAR

Organic solar cells: preparing a sample in an inert gas atmosphere

Copper-indium-selenium is the active semiconductor material in a CIS module, and is often alloyed with gallium to produce a CIGS module. Sulfur can also be used as an alloying agent to increase efficiency. CIS and CIGS modules have the highest efficiencies of all thin-film modules; an efficiency of 20 percent has already been reached in laboratory conditions, and commercial modules have efficiencies of between seven and twelve percent. The crystal structure of these chalcopyrite compounds corresponds to that of silicon, with the lattice sites occupied by elements of different valences (monovalent copper, trivalent indium, and hexavalent selenium). The outstanding characteristic of these semiconductors is their high tolerance of crystal defects and impurities, as these can combine to form electrically-neutral complexes. Consequently, the demands placed on the raw materials and processes are lower than for other semiconductor materials, resulting in greater scope for savings. The most recent research has shown that, in principle, it is possible to replace indium, a particularly costly element, with zinc.

Cadmium telluride (CdTe) modules are characterized by a relatively high efficiency (eleven percent) combined with low production costs, and are already being manufactured in very high quantities at reasonable cost. Currently, this is the most economic thin-film technology. Use of the heavy-metal cadmium poses particularly high expectations on module recycling, however.

Organic solar cells

The steadily growing demand for photovoltaic modules means that more cost-effective production processes are becoming increasingly necessary. In view of this, the use of organic semiconductors represents a promising approach as they can be processed into large-area, thin layers on flexible films using simple print and film coating methods or vacuum sublimation.

Organic solar cells use a process to generate electricity that works in a similar fashion to the way in which photosynthesis converts the radiant energy from sunlight into chemical energy. This mechanism can be exploited using a suitable combination of strongly absorbing chromophores (semiconducting organic molecules or polymers may be considered) as donors and strong electron acceptors (e.g. fullerenes) for the photovoltaic generation of charge carriers. A layer thickness of around just 0.1 µm is required for the incident light to be completely absorbed.

Organic solar cells produced in the laboratory can reach an efficiency of eight percent. It has been possible to increase their service life to some 5,000 hours, but this is still far too short. Improvements achieved thus far have concentrated above all on the packaging of the cells and less on extending the photoactive materials' service life.

It will be necessary to synthesize new donor and acceptor materials if organic solar cells are to be further improved. These must firstly be ca-

PHOTO: DEUTSCHER ZUKUNFTSPREIS

Manufacturing organic solar cells in a vacuum chamber

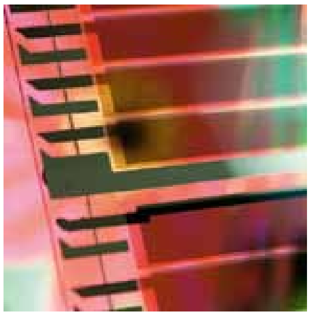
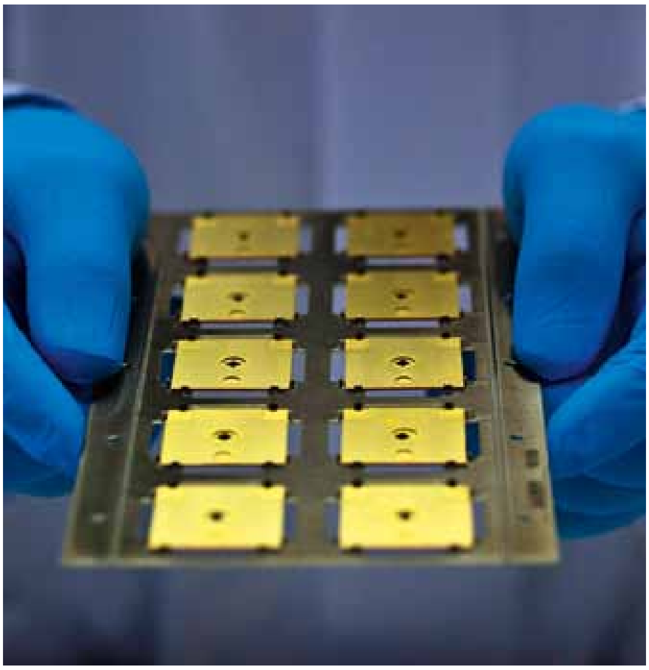


PHOTO: DEUTSCHER ZUKUNFTSPREIS

Organic solar cells (detailed view)



PHOTOS: DEUTSCHER ZUKUNFTSPREIS

Stacked or multijunction cells (3 mm diameter) with metal plates to dissipate heat

Multijunction cells are produced for use in concentrator systems.

Concentrator systems: lenses to focus sunlight onto solar cells

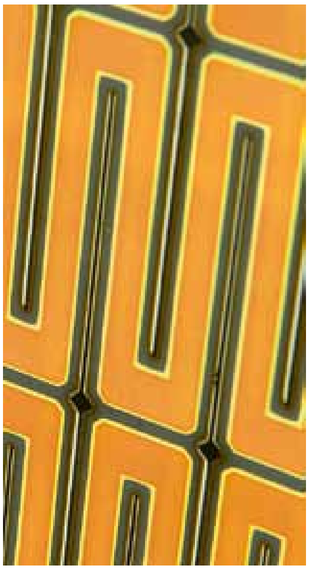


PHOTO: FRAUNHOFER ISE

Dye-sensitized cell

pable of self-organization (as this is crucial for the resulting coatings to be highly ordered) and secondly offer as broad an absorption spectrum as possible, so as to be able to better utilize the sunlight. Hence there is still great potential for increasing photocurrent.

Dye-sensitized cells

A photoelectrochemical reaction ensures the flow of current in dye-sensitized cells. The reaction proceeds in an aqueous environment between a photosensitive dye, which provides the electrons, and electrolytes and a semiconductor material, which transport the charge. While theoretically very inexpensive owing to low material costs, dye-sensitized cells have hitherto suffered from difficulties encountered in sealing the modules. Efficiencies of up to eleven percent have been achieved in laboratories.

Multijunction cells

Multijunction or stacked cells make the best possible use of the solar spectrum. In multijunction cells, alloys of semiconductors with varying band gap energies are layered on top of one another. The band gap energy indicates the wave length until which a semiconductor can absorb light and convert it into electricity. While solar cells with just one semiconductor material reach a theoretical efficiency of 33 percent, the theoretical maximum for solar cells using two semiconductors with different band gaps is 42 percent.

Multijunction or stacked cells are generally made of elements of the third and fifth group of the periodic table. Elements of the third main group are indium (In), gallium (Ga) and aluminum (Al), while arsenic (As), phosphorus (P), nitrogen (N) and antimony (Sb) belong to the fifth main group. The compound semiconductors are separated onto monocrystalline germanium wafers, where the germanium is the solar cell with the lowest band gap.

As the production of stacked cells is very complex and expensive, generally only small cells (100 square millimeters) are produced for use in concentrator systems with up to 700-fold concentration.

Concentrator systems use optical lenses to bundle sunlight onto small multijunction cells. These installations generally use tracking systems to follow the sun over the course of the day for optimum yields. The lenses are made of glass or plastic.

Thanks to their heat resistance and their favorable output-to-weight ratio, stacked cells are also used for satellites.

PHOTO: JWS FOTOLIA

Inverters form the interface between PV generators and the power grid.

Monitoring on-site consumption in the home

PHOTO: TOM BAERWALD

From cell to grid

In a module, solar cells are connected to form an electric unit. Under standard conditions, commercial solar modules achieve an output of between 60 and 360 W. At 25 to 50 V, open-circuit voltage is considerably below grid voltage.

When a string is created by series-connecting several modules, the open-circuit voltage rises. By connecting several strings in parallel, almost any voltage can be achieved.

The direct current supplied by this PV generator is converted into alternating current at grid voltage and frequency by one or several inverters. If required, this conversion can occur with a specified phase shift, in order to feed reactive power into the grid (e.g. in the event of grid failure) and lend it support. Thanks to state-of-the-art power electronics, converting direct current to alternating current now only incurs minimal losses.

The inverter is connected directly to the public grid and must therefore perform several tasks simultaneously. It constantly searches for the maximum power point (MPP) of the PV generator, and records and saves the operational data necessary for monitoring the PV installation's efficiency. It also displays error messages and sends them to a computer when required. Furthermore, the inverter monitors the grid connection and checks if this has failed or been switched off.

As a result of converting the direct current, losses are incurred which can be relatively high within the partial load range of the inverter (zero to 20 percent of the rated power), but which are usually less than five percent at the rated output. Inverters usually achieve maximum efficiency at around half the rated output; some even reach over 98 percent.

Microgrids and smart grids

In future, inverters are set to become increasingly important for grid services and grid management, and their range of functions will constantly expand. Static and dynamic grid support are among the grid services that are already mandatory.

Static grid support is required when grid voltage rises or falls slowly. This support is provided by supplying reactive power and limiting active power dependent on the frequency. Dynamic grid support is predominantly required when voltage dips occur in the upstream high-voltage grid. Here, inverters ensure that PV plants remain connected to the grid and feed in reactive power (fault ride through, FRT) so that the grid voltage rises again.

Grid management is also set to gain in significance, particularly in the case of distributed generation. This is because several neighboring PV plants can be connected to form microgrids

PHOTO: BOSCH

Intelligent inverter with storage function

Jännersdorf 40.5 MW solar park in Brandenburg (Germany)

Installing a large-scale photovoltaic plant

An investor inspects a PV installation

with the aim of directly utilizing the greatest possible proportion of the power generated. Furthermore, by using intelligent control engineering, virtual large-scale power stations can be created in conjunction with other decentralized suppliers and consumers of electricity. As elements in such power plants, PV installations would contribute to decreasing the amount of electricity bought from the national grid, which is chiefly fed by conventional power stations. In addition, the possibility of temporary off-grid operation would improve supply security.

Bidirectional network interfaces are required for such microgrids to provide the necessary communications and to link the large number of distributed suppliers and consumers together in "smart grids". Their most crucial role is that of coordinating feed-in and consumption as closely as possible.

Inverters are assigned an important task in these smart grids, as they are required to regulate the on-site consumption of solar power and to supply neighboring homes with solar power. Controlling the charging and discharging of the battery storage system also falls to them. As a result, inverters have evolved into energy management systems.

An average Central European household uses 20 to 30 percent of its total power consumption during periods when solar power is generated. A few simple measures could easily raise this proportion by ten percentage points or more.

As energy managers, inverters could automatically switch on individual household appliances (washing machines, dishwashers, dryers, etc.) as soon as enough solar power is generated. The PV plant and the home power network would form a single system, and electronic appliances would be supplied with either pure solar power or a mix of solar and grid power, depending on insolation.

The next step is to bring together on-site consumption control and battery storage – either as a stationary battery bank or in mobile format in an electric vehicle. Conventional batteries are not ideal for this purpose because high storage losses and low efficiency lead to relatively high costs. These costs can, however, be reduced by increasing on-site consumption, improving load shifting and, above all, by increasing energy conservation. The load shifting options are markedly increased when 50 or 100 neighboring homes are connected in a microgrid.

Applications

Photovoltaics was originally used for supplying autonomous systems, mainly in aerospace applications. A satellite was first equipped with solar cells as early as 1958. After photovoltaics proved successful in space applications, it was soon used to power small devices for daily use, such as pocket calculators and watches, later even parking meters, traffic signs and solar lights.

In the mid 1970s, the first commercial, 20 to 30 W modules became available, creating larger stand-alone systems. In 1983, a village in the Philippines was the first village to be entirely supplied with solar power. In Europe, isolated farmhouses or hiking cabins were equipped with PV installations which had an output of between 1 and 4 kW. In response to the Chernobyl nuclear reactor disaster in 1986, private individuals started testing stand-alone solar power systems for single family homes. These projects were successful, but too costly to become widespread. Above all, storing electricity in batteries was too expensive.

As shown by the Australian annual solar mobile race, solar mobility is still in its experimental stage rather than a commercial sector. On many lakes, tourist boats are powered by special solar modules installed onto the roof of the passenger cabin. Unmanned zeppelins and solar planes whose wings are completely covered with solar cells have already been tested; a scientist is planning a trip around the world in a solar plane in a few years' time.

The scalability of photovoltaics (from mini solar cells with just a few milliwatts output to large 360 W modules) has contributed to a wide variety of stand-alone systems around the world today. These range from minute applications (pocket calculators) to the electricity supply of remote settlements, or solar mobility.

Stand-alone systems play but a minor role due to the fact that they produce relatively little electricity. Since powerful inverters were developed in around 1990, and since the systematic subsidization of feeding solar power into the grid started in 2000, grid-connected photovoltaics has developed into the predominant method of solar power generation.

Its typical applications range from a roof-top PV system on a family home (from 1 kW) to large, free-field power plants with ten thousand times that output. The largest plants have an output of almost 100 MW, and an end to this growth in scale is not in sight.

Today, wherever fed-in solar power is remunerated well enough to cover the costs, available roof space is slowly but surely being used. PV modules are being installed on single and multi-family homes, on schools, agricultural buildings, factories, and warehouses. With falling investment costs, it is no longer just south-facing roofs that are suitable, but also east- and west-facing ones.

This increases the amount of solar power fed into the grid in the mornings and afternoons. The typical "noon peak" is thus evened out, and the feed-in period is lengthened. This makes the grid integration of solar power, whose production is naturally fluctuating, easier.

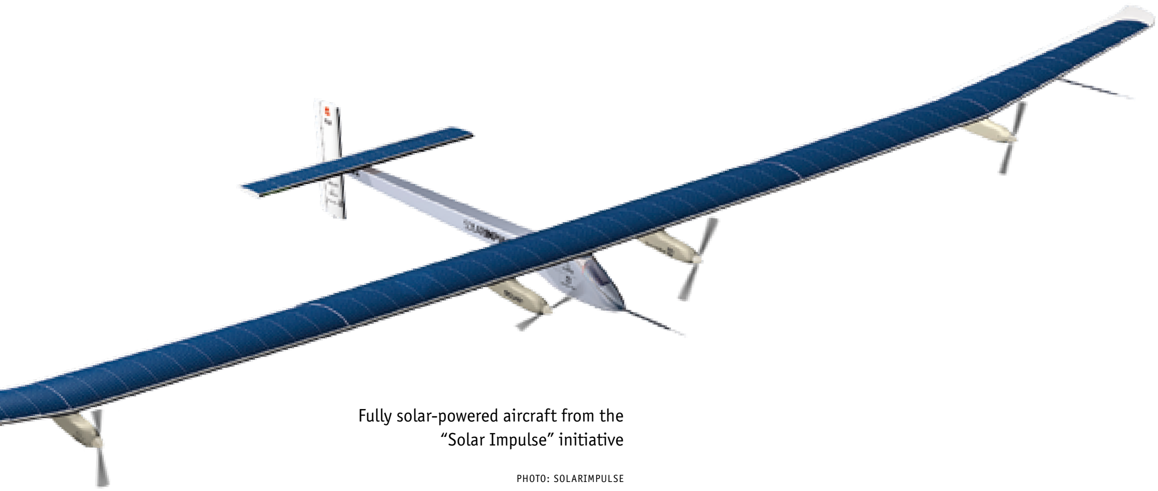
Solar car at the "World Solar Challenge" in the Australian desert

Solar power system on a private home

Photovoltaics was first used in the space industry.

(f. t. t. b.)

PHOTOS: HOCHSCHULE-BOCHUM.DE / FOTOLIA.DE, MARINA LOHRBACH / NASA (F. T. T. B.)



Fully solar-powered aircraft from the "Solar Impulse" initiative

PHOTO: SOLARIMPULSE

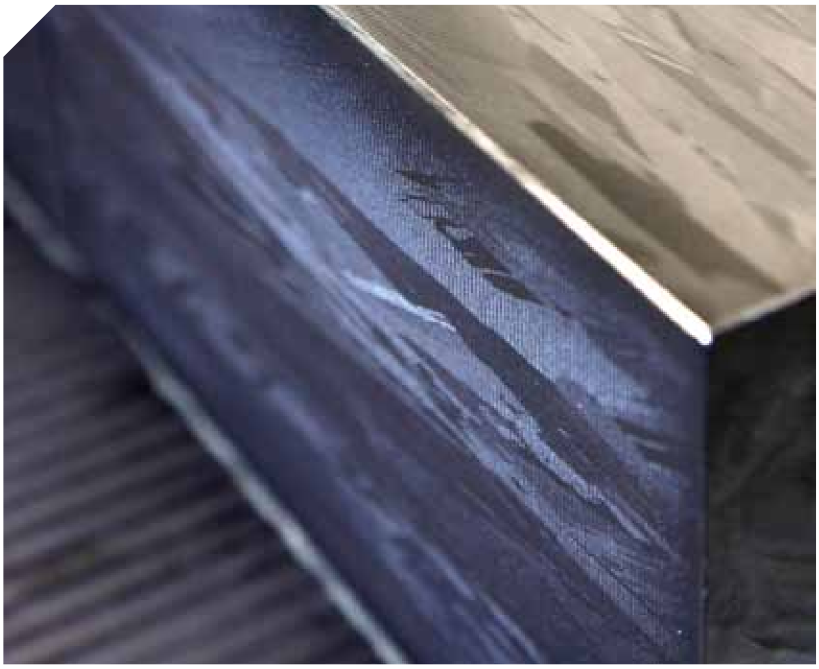


PHOTO: PV CRYSTALOX

Ingot

Manufacturing

The manufacture of modules from crystalline silicon cells requires a number of process steps and different production technologies, while the manufacture of thin-film modules is a continuous process in which physical deposition techniques (sputtering, vapor deposition) dominate.

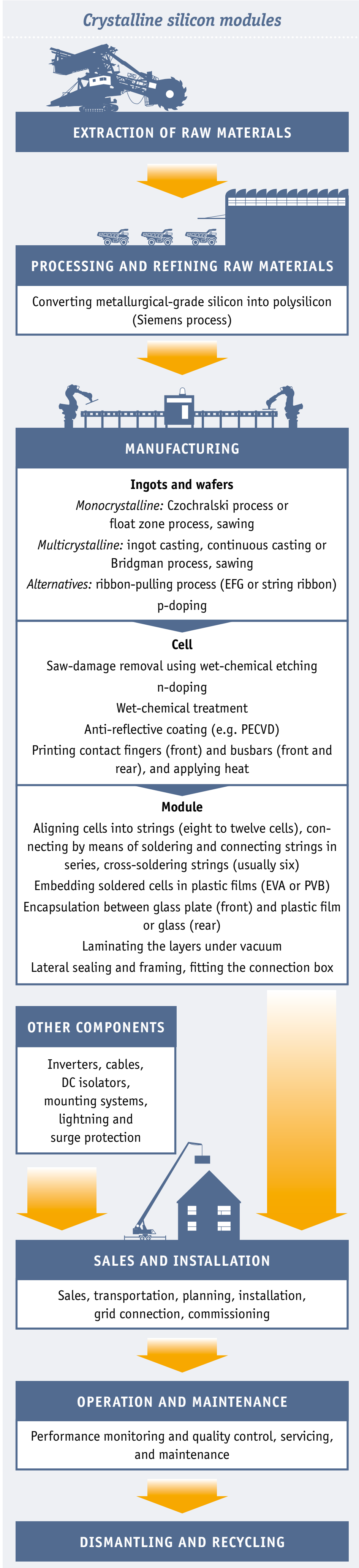
Crystalline silicon cells

Crystalline silicon cells are manufactured from razor-thin slices of silicon (wafers) that are either monocrystalline (c-Si) or multicrystalline (mc-Si, often also known as polycrystalline).

The manufacturing process comprises several steps. In a first step, the metallurgical-grade silicon (purity 98 to 99 percent) is converted into polysilicon (solar grade silicon) with a purity of up to 99.999999 percent. An even higher level of purity (99.9999999 percent) is needed for high-performance cells. The predominant production method is the Siemens process. In this process, the metallurgical-grade silicon is first converted into trichlorosilane using gaseous hydrogen chloride. After a number of distillation stages, the trichlorosilane is reduced thermally under hydrogen into polycrystalline silicon and gases containing chlorine by a CVD (Chemical Vapor Deposition) process. The silicon here deposits onto high-purity silicon rods that are held at approximately 1,500 °C. This leaves extra-pure polycrystalline silicon, which is cooled and crushed for further processing.

UPGRADED METALLURGICAL-GRADE (UMG) SILICON

UMG silicon is increasingly seen as a cost-effective alternative to the highly pure solar-grade silicon that is manufactured, for example, in the Siemens process. UMG technology is based on a purification process that starts with a molten silicon-aluminum solution. The silicon "flakes" that are fabricated in this process can be further processed into cost and energy efficient UMG silicon. The efficiency of the cell is just somewhat lower than that of regular polycrystalline solar cells. The lower breakdown voltage requires special attention.



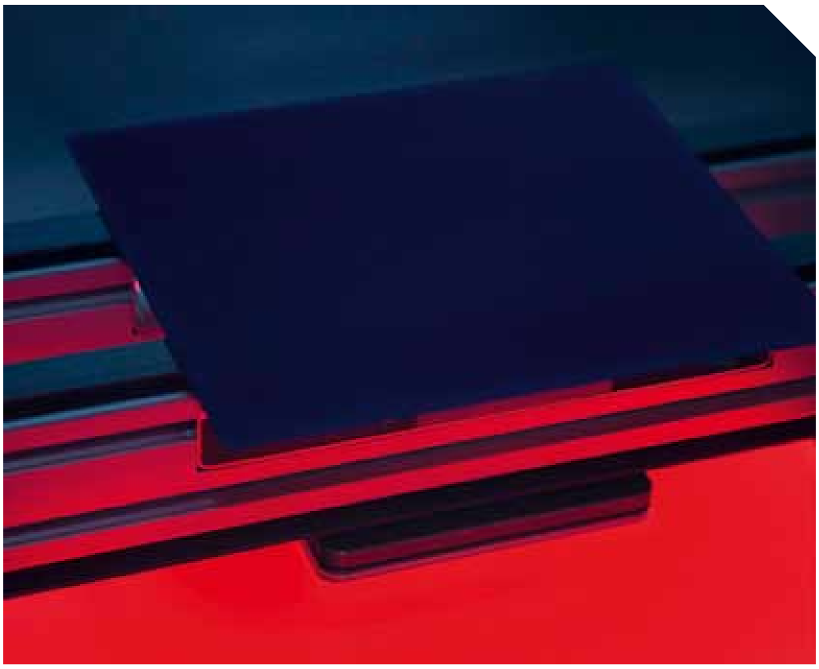
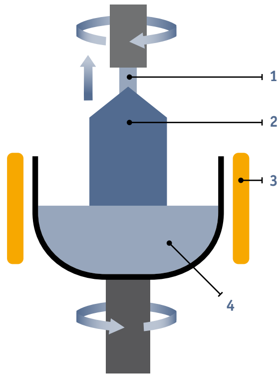


PHOTO: TOM BAERWALD / Q-CELLS INTERNATIONAL

Inspecting cell quality after application of an anti-reflective coating

Czochralski process



Source: Fraunhofer Technologiezentrum Halbleitermaterialien (THM)

Production of ingots

To permit the production of wafers, the solar grade silicon is first crystallized into blocks or ingots. Often boron is added to the silicon at this early processing stage, causing p-doping of the crystal structure.

Crystal growing, i.e. the synthetic production of monocrystals, is required for the production of monocrystalline ingots. Two methods have been proved in practice:

1. In the Czochralski process, the silicon crystal is pulled from a crucible containing molten polycrystalline silicon. The starting point for crystallization is a monocrystalline silicon seed crystal that is immersed in the melt and onto which the silicon atoms deposit themselves in a regular pattern. The seed's rod is slowly pulled upwards and rotated simultaneously so that a cylindrical monocrystal of around 30 cm diameter is extracted. This ingot can be several meters long.

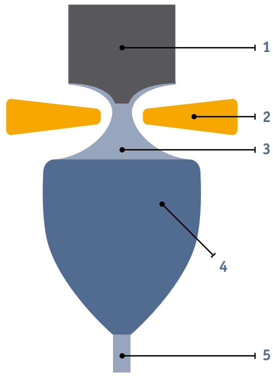
2. The zone melting process allows crystallization with simultaneous purification. A polycrystalline silicon rod is induction-heated to melting point at one end, i.e. a powerful current is induced in the inner core of the rod that heats the material to its melting point. The narrow melt zone travels along the length of the rod so that the material behind the molten zone resolidifies. As the melting point of the impurities differs from that of the silicon, the phase change from molten to solidified separates the impurities from the silicon. The impurities accumulate in the melt and are transported to the end of the rod as the molten zone travels through the rod so that they can be cut off after the end has solidified.

The process resolves the problem by slowly lowering a polycrystalline silicon rod with a monocrystalline silicon seed crystal at the tip through an annular coil. The coil generates a high-frequency electromagnetic field so that the rod heats up from the tip. As the rod cools down behind the molten zone, which travels slowly through the rod from the bottom to the top, a high-purity monocrystalline silicon structure is formed. This allows the production of extremely highly efficient solar cells from this ingot.

For the production of multicrystalline ingots, polysilicon is melted in the ingot casting process and poured into a cuboid crucible. The cast ingot solidifies uniformly in one direction because of this controlled heating and cooling. This directional solidification causes homogeneous silicon crystals to form. The grain sizes range from a few millimeters to several centimeters. Continuous casting, which permits a continuous production process, is an alternative to ingot casting. The Bridgman process is a further development. The lowest layer of the silicon is melted in the crucible. The heating zone then travels upwards while the material solidifies from the bottom upwards. This allows the production of larger multicrystalline ingots.

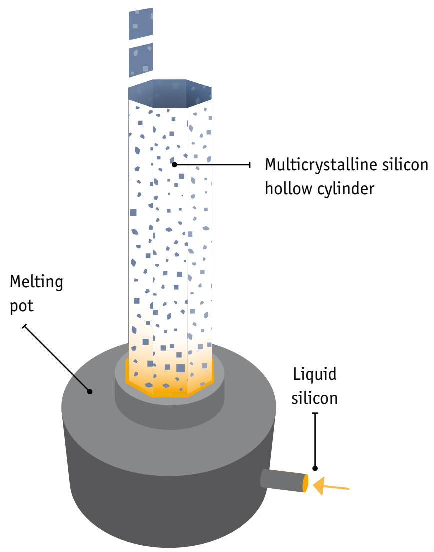
The ingots are then sliced into wafers with wire saws under a slurry which rinses the saw wire.

Floating zone process

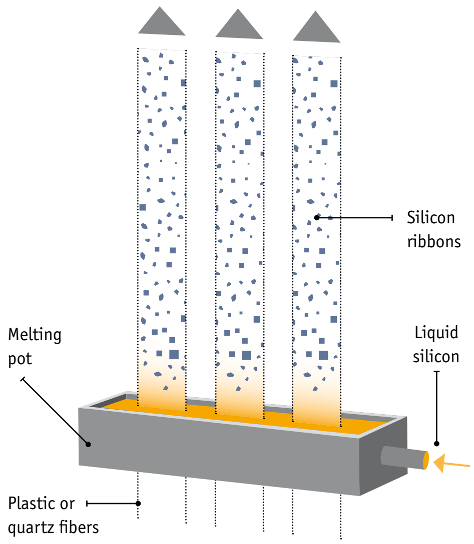


Source: Fraunhofer Technologiezentrum Halbleitermaterialien (THM)

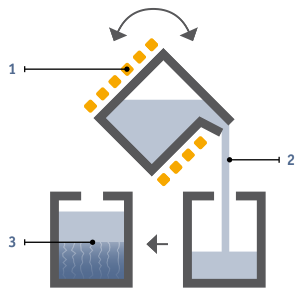
EFG process



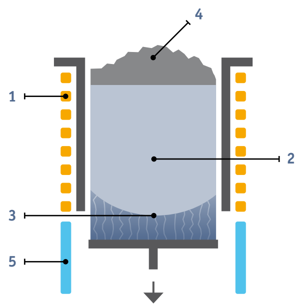
String-ribbon process



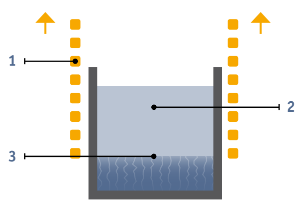
Directional solidification



Ingot casting



Continuous casting



Bridgman process

1 Heater
2 Silicon melt
3 Phase limit solid/liquid
4 Raw silicon
5 Cooler

Source: Fraunhofer Technologiezentrum Halbleitermaterialien (THM)

The silicon carbide particles in the slurry are actually responsible for the sawing process.

The ribbon-growing method was developed to eliminate the sawing step, which is associated with significant loss of material. Two methods may be used to produce multicrystalline silicon ribbons.

1. The EFG process (edge-defined film-fed growth process) generates an octagonal, hollow cylinder of multicrystalline silicon several meters long. An octagonal shaping graphite substrate is immersed in the silicon melt and slowly pulled upwards. The surface tension of the liquid silicon causes a skin to form on the underside of the substrate and slowly solidify. Growth is continuous. A laser then cuts the octagonal cylinder into slices which for their part are cut into eight wafers with an edge length of 10 to 13 cm each. The EFG process requires around 30 percent less silicon than the sawing method.

2. The string-ribbon process uses carbon or quartz fibers (strings) as seeds for crystallization. The strings are drawn from bottom to top through a flat crucible containing the silicon melt. Silicon is continuously added to the crucible while the rectangular wafers are continuously cut from the growing ribbon.

From wafer to solar cell

A multiple stage process is required to transform the 180 µm thick wafers into solar cells. First, the saw damage is removed by wet chemical etching. It is possible to roughen up the surface of the wafer at the same time in this step, to increase the absorption of sunlight. The wafers are cleaned in a wet chemical process after etching and then dried.

The silicon structure is then doped with phosphorus (n-doping). The wafers are exposed to a gas containing phosphorus in a diffusion furnace at around 900 °C in oxygen, which leads to the formation of an oxide with phosphorus on the surface. Phosphorus atoms diffuse from this layer into the silicon structure so that the front side of the wafer is formed into an emitter across its entire surface. The depth to which the phosphorus atoms penetrate depends in particular on the temperature and the duration of diffusion.

Then the phosphorus glass (phosphorus silicate) created on the surface is removed by a wet chemical treatment.

To increase sunlight absorption and to improve the electrical properties of the surfaces and the base material, an anti-reflection coating (silicon nitride) is applied to the front side of the wafer. Plasma enhanced chemical vapor deposition (PECVD) has proved itself the most effective method.

Extremely narrow conductors (contact fingers) are then screen-printed onto the front side of the wafer using a silver paste and two or three wider tracks (busbars) perpendicular to these

PHOTO: TOM BAERWALD / Q-CELLS INTERNATIONAL

Cell production

through which the charge carriers can be removed. Busbars are printed on the rear side with a silver/aluminum paste. A recently patented process allows silver to be replaced with inexpensive tin. The wafer is dried in a special furnace after each print process. Finally, the contacts are fired to create an electrical connection with the silicon.

The grid and the busbars inevitably cover a proportion of the cell surface, which reduces light absorption. For this reason, rear-side contacts are gaining in importance.

Eight to twelve solar cells are joined to form a string, connected with one another by soldered contact ribbons and thereby connected electrically in series. The strings are then soldered to one another. A number of strings (generally six) form a module which consequently consists of 48 to 96 cells, as a rule.

The soldered solar cells are embedded in plastic film – either of ethyl vinyl acetate (EVA) or of polyvinyl butyral (PVB) – and encased between a glass plate on the front side and a weather-resistant plastic film (usually Tedlar) on the rear side. The rear side may also consist of a glass plate. Only highly transparent, anti-reflection coated or structured glass is used for the front sheet of glass.

The complete sandwich is then baked in a laminator under vacuum at a temperature of around 140 °C. The important point here is to heat the entire module surface up uniformly and rapidly. The crystalline module is finally sealed at the edges with tape, an aluminum frame with silicon sealant and a junction box is fitted on the rear side.

Cast-monocrystalline cells

Thanks to a newly developed technique, it is now possible to manufacture wafers from ingots that are cast in crucibles yet have a high monocrystalline content. This production method combines the advantages of the Czochralski process and those of block casting. A monocrystalline silicon seed (seed crystal) is placed at the bottom of the crucible and partially melted to provide a starting point for crystallization. Because the solidifying ingot takes up the orientation of the seed crystal, it becomes almost a monocrystalline ingot as it grows. Monocrystalline crystals form in the ingot core while the proportion of multicrystalline crystals slowly increases around the periphery. It is possible to cut pure, monocrystalline wafers from the ingot, which can then be used to manufacture high efficiency cells. "Cast-monocrystalline growth" requires new process methods and special furnace technology.

Production of a multicrystalline cell (ingot casting)

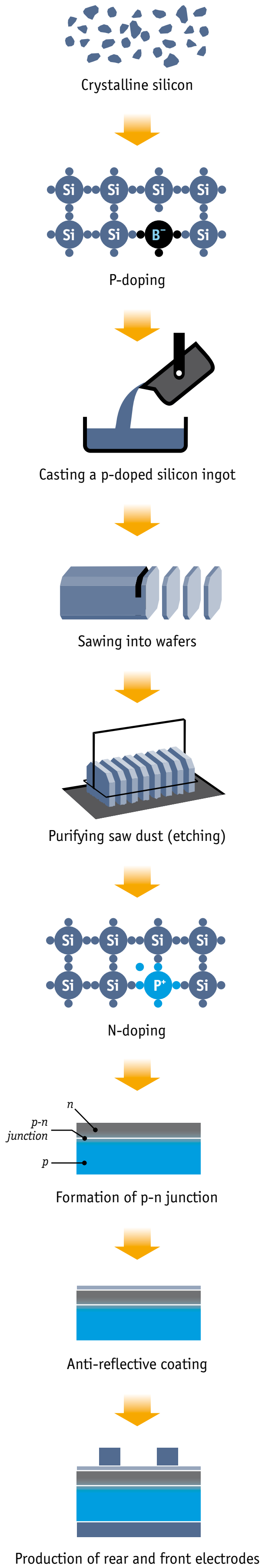


PHOTO: TOM BAERWALD / PARABEL

Large-scale PV plant with thin-film modules

Thin-film modules

There are several types of thin-film modules available in the market, principally differing by the photoelectrically active material. Once the films have been applied, the material is cut into individual cells by a laser beam. It is this monolithic connection which actually creates the module. The method is not expensive to automate and the production process is adaptable.

The front side of the thin-film modules consists of special highly transparent and anti-reflection-coated glass while the rear side is either glass or a weatherproof plastic. The production process is always completed by mounting the junction box on the rear side. The three most important thin-film technologies are described below.

Amorphous and microcrystalline silicon (a-Si/µ-Si): A transparent conductive film (transparent conductive oxide, TCO) is deposited on a substrate of glass, metal, or plastic by sputtering or by low pressure chemical vapor deposition (LPCVD). This film is generally zinc oxide doped with boron.

The amorphous (a-Si) and microcrystalline (µ-Si) silicon films are vapor-deposited in sequence. The method used is plasma-enhanced chemical vapor deposition (PECVD). Finally, a further TCO film is applied.

Cadmium telluride (CdTe): First, a TCO film is applied to the front glass plate, then cadmium sulfide (CdS) is vapor-deposited as a

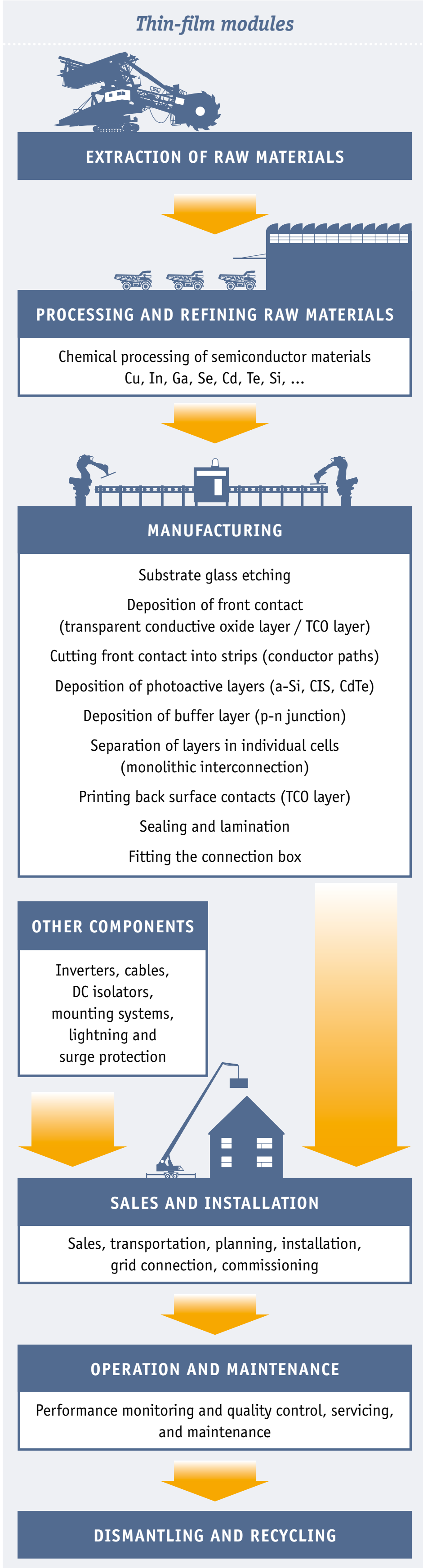



PHOTO: CALYXO

CdTe module with plug connector

buffer film, followed by cadmium telluride as the photoactive semiconductor. The quality of the CdTe absorber coating is enhanced by a wet chemical treatment with cadmium chloride ($CdCl_2$). The p-n junction is formed at the boundary layer between the CdS and the CdTe. A combination of antimony telluride (Sb_2Te_3) and molybdenum (Mo) is used as a metallic rear-side contact.

An integrated series circuit of individual cells is created by specific cuts following TCO, CdTe, and rear-side contact deposition. The CdTe module is laminated with a sealing film and a second glass plate.

CIS and CIGS: The production of thin-film modules from copper indium gallium selenide or copper indium gallium sulfite (CIGS) and from copper indium selenide or copper indium sulfite (CIS) begins by coating the glass substrate with molybdenum to create a rear-side contact. This is done by sputtering. The p-type CIS or CIGS absorber coating is produced either by vapor deposition onto the heated substrate or in a multistage process in which first copper and indium are deposited onto the unheated substrate. Selenization or sulfurization follows in a subsequent step known as baking.

A CdS buffer film and a ZnO film create the p-n junction. At the same time, the zinc oxide forms the transparent front contact (TCO film). The CdS buffer film is generally deposited in a chemical bath and the front contact is created by cathode evaporation (sputtering).

Approaches for improvements

The production technique employed in thin-film solar cells benefits hugely from the knowledge accumulated over the years in the application of coatings to architectural glass and in the production of displays. It is possible to coat glass plates measuring up to 3.2×6 m^2 = 19.2 m^2 within 35 seconds. This corresponds to a coating speed of 33 m^2/minute.

The larger the size of the unit produced, the lower the costs of industrial coating technologies. The aim is to exploit this scaling effect for photovoltaics. Coating methods have been developed for the photovoltaics industry that are capable of producing substrates of 5.7 m^2. The first production lines came on stream in 2008, but it has not yet been possible to achieve the hoped-for reductions in production costs.

The challenge is to achieve two improvements at once: First, to increase productivity by reducing material costs, increasing plant throughput (process speed) and improving plant availability (automation).

Secondly, to increase the conversion efficiency by minimizing optical losses (light traps), improving exploitation of the solar spectrum and finally by reducing the electrical losses.

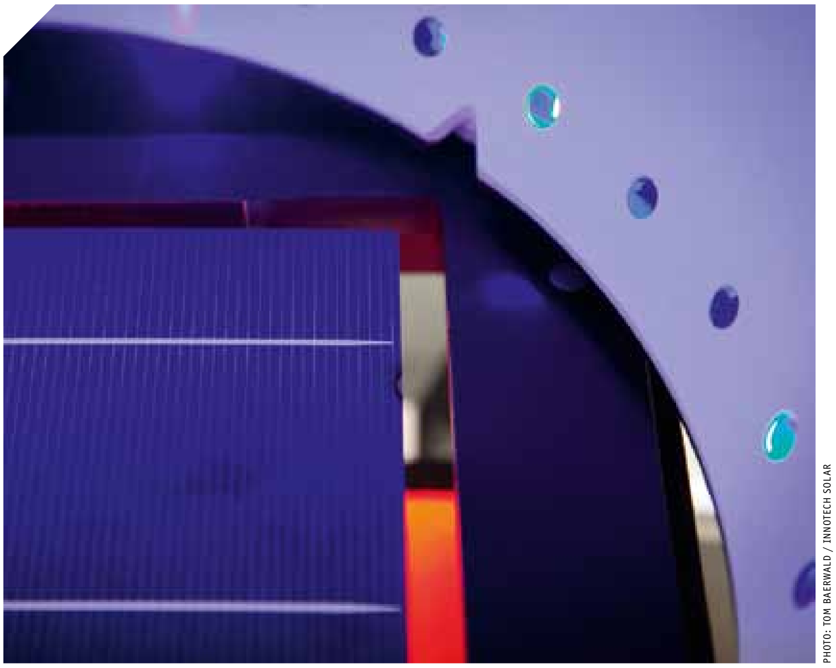
Only if the rate of learning in fundamental research is sustained over the long term will it be possible to push the ratio of minimum cost per unit of electrical output towards the target value of less than 1/W.


PHOTO: AVANCIS

CIS module


PHOTO: AVANCIS

Roof-mounted application



Front side inspection with multi-color analysis

Position control measurement within automated line

Roadmap for cost reductions

The learning curve resulting from empirical studies conducted over the past few decades shows that when cumulative production volumes double, PV module manufacturing costs drop by between 17 and 26 percent (learning rate).

Silicon is the most thoroughly investigated semiconductor, and crystalline silicon continues to hold sway in photovoltaics. Efforts to reduce costs therefore currently center on this material.

The success story of crystalline silicon photovoltaics is reflected in the fast pace at which module prices have plummeted. Over the past 34 years, the levelized costs of electricity have fallen by an average ten percent each year. Thanks to technological development, price reductions continue to occur and are accelerated where possible. Now, the manufacturing process must be simplified, material consumption decreased, and module efficiency must rise.

What this means for photovoltaics is that the development costs for new processes and machines must be shared among competitors, who all follow a widely recognized "roadmap". This roadmap stipulates a path for further development and favors the evolutionary development of technology typically employed in the successes achieved to date with crystalline silicon photovoltaics.

In its "International Technology Roadmap for Photovoltaics" (ITRPV), the association SEMI (Semiconductor Equipment and Materials International) sets out the most important steps towards the desired cost reductions over a period of ten years.

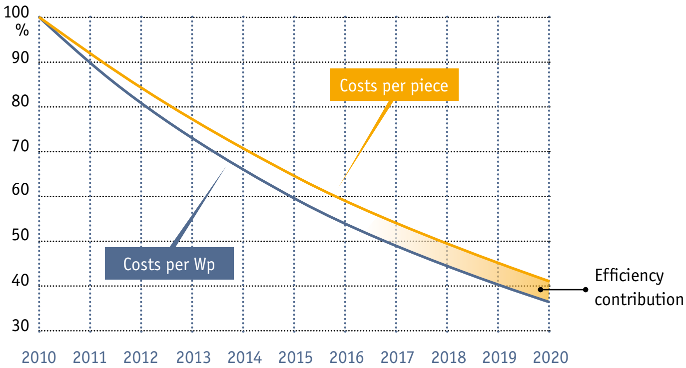
In a scenario for the period from 2010 to 2020, the ITRPV calculates an annual industrial growth rate of 35 percent and a learning rate of 20 percent. This yields a yearly cost reduction of between eight and nine percent, depending on the quantity of modules produced. If we look at this with regard to output, the reduction in costs is even greater (nine to ten percent), as module efficiency is set to increase.

Manufacturing costs and efficiency are the two factors which ensure that module costs fall dramatically. It is foreseeable, however, that manufacturing costs will be the dominating factor over the next decade and beyond.

Module manufacturing costs

Modeled module manufacturing costs based on an empirical learning curve with a learning rate of 20 percent. The cell efficiency gain is assumed to correspond to the values shown on page 34.

Scenario parameters:
learning rate = 20%
average CAGR = 35%
cell efficiency gain: according to ITRPV



Source: SEMI / PV Group

Conserving materials

The cost of materials is a crucial issue in module production which is why cost reductions here can have a huge knock-on effect. Polysilicon, in particular, needs to become considerably cheaper. The roadmap anticipates price cuts of 50 percent by 2020. In addition, the proportion of silicon required to generate one watt of power should drop in stages from 7 g/W today to 6 g/W in 2012 and 5.5 g/W in 2015.

Wafer thickness is another aspect which has a big influence on cost. In an effort to decrease material costs, ever thinner wafers are being sawed from the ingots. A wafer thickness of 180 mm is currently standard in mass production, and it is likely that thicknesses as low as 100 mm will be reached by 2020.

With increasing thinness, the wafers also become more sensitive. It is therefore important, when cutting ingots into increasingly thin wafers, to optimize the process steps that take these wafers to the finished module.

Conveyance, wiring, lamination, and all other production steps must be extremely swift, but at the same time so gentle that the thin silicon discs do not break. A high breakage rate can cancel out any advantage gained by conserving material.

The biggest cost component of sawing ingots into wafers is the fluid (slurry) which rinses the saw wire. Noticeable costs savings could be achieved if recycling the slurry could be made cheaper and thinner wires could be used for sawing.

The metallization pastes needed to apply the electrical contacts are also expensive, with silver and aluminum driving the costs highest. In order to lower the proportion of silver required per cell from the current quantity of 0.30 g to 0.02 g by 2020, the first step is to reduce the total amount of paste needed. Then, from around 2015 on, silver will be replaced by another metal (probably copper).

It is not only cost factors that are driving these changes, but also environmental concerns. For example, metallization pastes containing lead should be replaced by lead-free products. These must be available by mid 2012 in order for them to be introduced into mass production by 2013 at the latest.

Optimizing the manufacturing process

Some of the systems used to produce Si wafer solar cells originate from microelectronics manufacturing. They have already been adapted for markedly higher throughputs and the line cycle times last only seconds, making them 30 to 200 times faster than the line cycle times for thin-film solar cells which take minutes. However, there is still room to increase throughput and lower costs even further.

One option is to use larger ingots. The roadmap announced that the mass of a monocrystalline ingot will rise from around 150 kg at present to approximately 300 kg over the next ten years. The multicrystalline ingots that today weigh around 400 kg will then weigh more than one metric ton.

Within the same period, it will also be necessary to improve the productivity of tools by increasing the yield and throughput of production lines. This primarily affects the wafer sawing and wafer cleaning production steps where the throughput of each tool could be increased by around 50 percent.

Tool uptime as defined by SEMI standard E10 is another important factor that can be used to optimize production lines. The goal is to attain an uptime of over 96 percent. This is already achieved today in the chemical process steps of cell production, but will not be reached in metallization and classification until 2015.

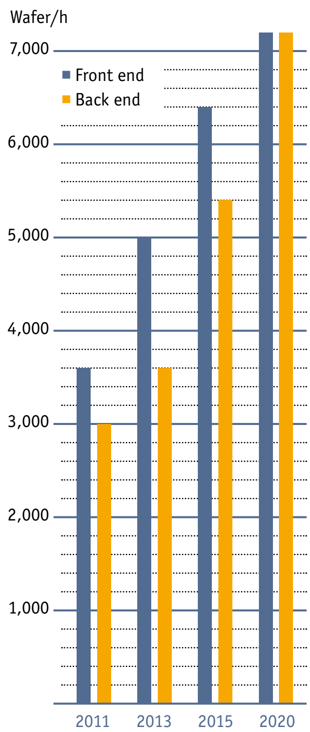
In order to increase the throughput of the entire production line, front-end (chemical and thermal) and back-end (metallization and classification) processes must be adapted to one another (synchronized).

Currently, the front end is rushing way ahead of the back end. The front end must process 3,600 wafers per hour as a minimum, but at the back end this total is just 3,000 wafers. In ten years, it is to be expected that front-end output will reach at least 7,200 wafers per hour. To close the gap, significantly faster metallization technologies will be employed to enable the back end to match this total.

In order to achieve the target cost reductions, production machinery should have a smaller footprint (45 percent less by 2020) and require fewer staff (minus 60 percent by 2020) while yielding a higher throughput. Moreover, the processes of interconnecting and encapsulating cells must be made quicker. Amongst other things, this will require encapsulation materials that permit shorter processing times.

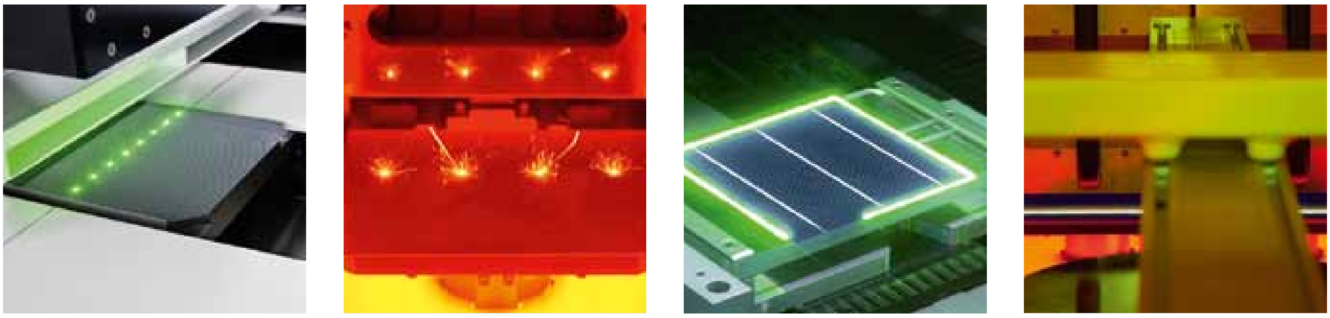
A surge in throughput rates is to be expected in around 2015 if new interconnection technologies and rear contacting are introduced into mass production.

Expected throughput of production tools



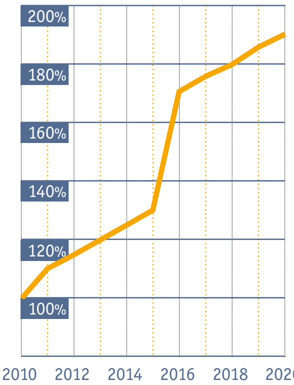
Front- and back-end tool throughput are expected to match 1:1 in 2020. All numbers are to be seen as minimum requirements for a high-end production environment.

Source: SEMI / PV Group



Use of laser technology in solar cell production PHOTOS: © MANZ / INNOLAS HOLDING / MANZ / Q-CELLS INTERNATIONAL (F. L. T. R.)

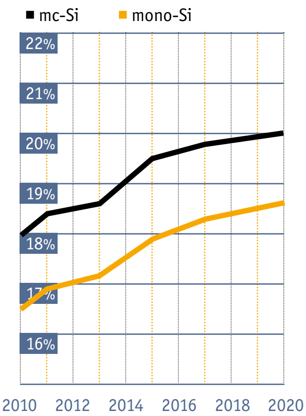
Throughput of module manufacturing equipment



Expected improvement in throughput of module manufacturing equipment

Source: SEMI / PV Group

Cell efficiency



Stabilized efficiency trend curve of p-type c-Si solar cells in mass production

Source: SEMI / PV Group

Increasing efficiency

Several measures are needed to improve the efficiency of cells. These include both reducing recombination losses and increasing emitter sheet resistance. By 2015, it will be possible to make the width of front contacts distinctly smaller by using new technology in the metallization process. At around the same time, silver printing will be superseded by copper plating, resulting in further cost reductions.

The key objective is to extract as much output as possible from the interconnected cells. A good yardstick for this is the module-to-cell power ratio. This value is currently 97.5 percent for multicrystalline, and 96 percent for monocrystalline silicon. By introducing anti-reflective glass into module production, it will be possible to improve these values by around 1.5 percentage points from 2013. Two years later, new interconnection and encapsulation technologies will increase them by a further percentage point, meaning that in principle a ratio of 100 percent will be achieved.

Over the next few years, the efficiency of multicrystalline cells is set to rise dramatically, allowing them to keep pace with developments in monocrystalline cells. It is anticipated that the 20-percent limit will be reached in 2020. This can be attributed in part to the fact that rear-contact cells will increasingly gain acceptance. The proportion of these cells on the market will soar from 2014 onward and will reach 40 percent by 2020.

Furthermore, statistical process control (SPC) is necessary to continually improve all manufacturing steps. This detects all the errors in individual process stages and assesses their impact on the subsequent process steps. Productivity can thus be increased even further by performing these checks.

The laser as an all-purpose tool

Laser processing plays an important role in PV production. As such, it has become an all-purpose tool: Today, cutting, labeling and marking, edge ablation and interconnection are all tasks assigned to the laser. Laser beams can create openings both directly from the rear side and through the substrate in order to interconnect (structure) the layers.

The first high-efficiency solar cell concept to be implemented on an industrial scale, the buried contact solar cell developed at UNSW, Sydney, uses grooves cut into the front side of the cell. They are formed by means of laser ablation (the process of removing material from a surface by irradiating it with a laser beam) followed by chemical etching of the silicon. The front-side metallization on the solar cells is then applied (or “buried”) by electroplating. The metal-filled grooves are so thin and deep that the light collection area is enlarged and the electrical resistance of the conductors is kept low.

PHOTO: INNOLAS HOLDING

CVD process: doping by means of laser irradiation

Special methods and processes

The successes achieved with laser technology in PV production have led to the development of many additional processes.

Laser-fired contacts: When connecting solar cells, there is always a tradeoff between applying metal contacts with low electrical resistance and minimizing the interface between the semiconductor and the metal, as this is where high losses are caused by the light-generated charge carriers. With conventional, full-area, screen-printed rear-side metallization, the full efficiency potential of the cell is not exploited owing to the large metallized area. The contact surface can be reduced without greatly increasing the electrical resistance. The metal-semiconductor interface can be neatly minimized using "laser-fired contacts" (LFC). Here, the metal is driven ("fired") through an insulating layer using a local laser pulse.

Drilling and surface structuring: In order to improve absorption, front-side metal contacts should be avoided although it is sensible to arrange the n-conducting emitter zone on the front side. To contact this zone via rear-side metal fingers, emitter-type connection channels between the front and rear sides are required, which are created by drilling fine holes through the solar cell. This is best done by laser drilling. Disk lasers can drill up to 3,000 holes through silicon wafers in just one second, allowing the preparation of these advantageous connection channels at a high throughput rate.

Doping: Lasers can also be used to dope the cells locally. This is necessary, for example, to selectively lower the contact resistance between the cell surface and the contact fingers, to allow the charge carriers to flow away without losses. The concentration of phosphorus atoms in the n-doped layer is therefore increased precisely where the contact fingers will later be printed (selective emitter). For this purpose, a liquid film containing phosphorus is applied to the silicon wafer and driven into the silicon by applying energy (a laser).

Removing insulating layers: In order to prevent the light-generated charge carriers from recombining, the surface of the cell is passivated. This can be done by means of depositing a dielectric layer onto it. Oxidized silicon surfaces and surfaces coated with silicon nitride have particularly good passivation properties. However, in both cases, the silicon is hidden under an insulating layer which must be removed in order to contact the solar cell. The use of "short pulse lasers" for this purpose is currently being trialed. If the insulating layer (silicon oxide / silicon nitride) is removed by short laser pulses, the substrate below has no time to heat up or conduct the heat down into the cell. The impact of the energy input, which results in material being blasted off the surface, is thus limited to the layers close to the surface, and damage to the deep levels of the silicon is avoided. This type of processing is particularly gentle and is ideally suited to producing local contact openings.

Soldering on laminating film: The process of connecting cells to form a complete module can also be improved by using lasers, and several complex handling steps can be eliminated. "On-laminate laser soldering", a recent technology, has the advantage that the cells are not soldered together until they are positioned on the module laminating film. The success of this method depends on precise process control in order to reduce the heat input of the laser to a minimum and avoid damage to the sensitive laminating films.

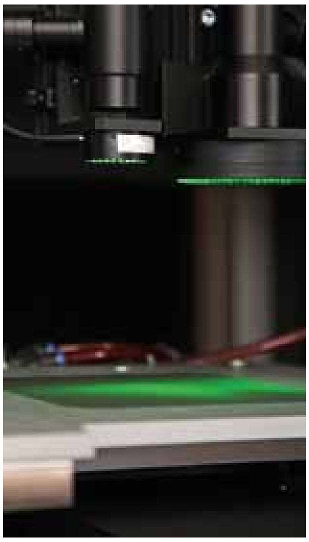
Laser technology advantages and outlook

The range of interesting possibilities offered by laser technology assists in developing new cell concepts. The most important advantages are:

- alternatives to photolithography that can be implemented on an industrial scale
- high speed (ten thousand holes can be made in wafers in seconds)
- contact-free wafer processing
- minimal heat input

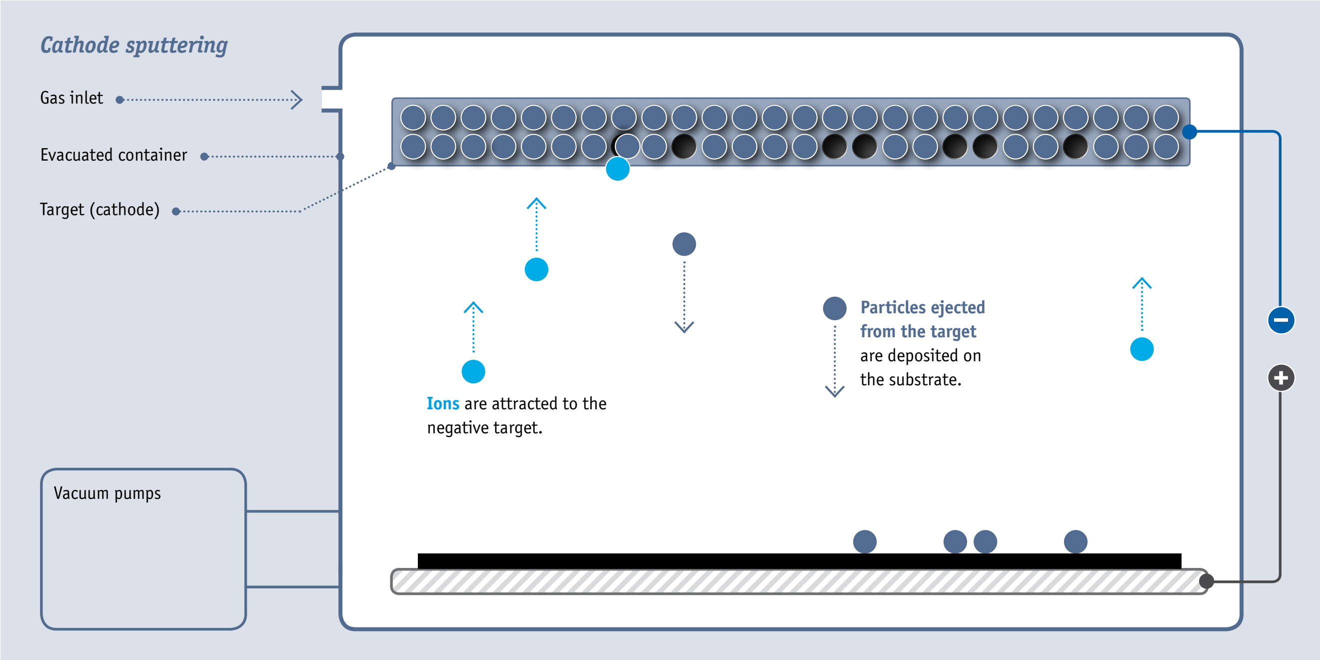
Processes where laser beams are applied to only a small proportion of the surface stand a particularly good chance of gaining wide acceptance in future.

New beam sources with ever higher repetition rates and capabilities are being launched onto the laser market. In addition, new possibilities for beam shaping and beam guidance are continually being created. This will enable the structuring of large solar cell surface areas to be performed cheaply in industrial-scale production.



PHOTOS: TOM BAERWALD / 3D MICROMAC

Camera-supported cell positioning in a laser application (above and below)



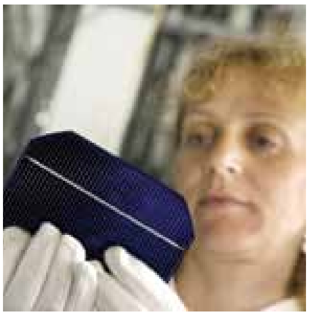


PHOTO: FRAUNHOFER IWS DRESDEN

Wafer processed using PECVD

Vacuum and deposition processes

Chemical vapor deposition (CVD) and physical vapor deposition (PVD) play an important role in PV production. Both processes are carried out under vacuum and are employed at various points during production.

CVD and PECVD

In chemical vapor deposition, layers are deposited on the substrate surface from the gas phase. For this to happen, the gaseous precursors chemically decompose on the substrate surface to allow a new coating to grow there. This method is used to manufacture polysilicon, which is employed as a source material in single crystal production. Decomposition of the precursors is usually thermal, and is achieved by heating the substrate to 500-850°C. In order to avoid competing gas phase reactions, the reaction chamber is evacuated (1 to 1,000 Pa) – in other words a vacuum is produced. The overriding advantage of the CVD process is the uniform layer deposition that it produces. This also makes it possible to coat irregularly-shaped surfaces and shallow depressions in wafers, for example.

In order to reduce the thermal stress on the substrate, it is also possible to trigger the chemical reaction by means of plasma discharge (plasma-enhanced CVD, PECVD). Here, a strong electrical field is applied between the substrate and a counter electrode to ignite the plasma. This destroys the bonds in the reactive gas and decomposes it to produce free radicals that deposit themselves on the substrate and react with one another there, allowing for higher deposition rates at lower deposition temperatures. In this process, it is sufficient to heat the substrate to 200-500°C, which is why PECVD systems are predominantly employed in PV production technology.

The PECVD process is hugely important for the production of thin-film silicon modules, as it allows amorphous silicon coatings to be deposited on large areas at high deposition rates and with great uniformity.

Producing tandem cells from amorphous and microcrystalline silicon (a-Si/µc-Si) is somewhat more complex, as it involves a two-stage procedure. Since the microcrystalline silicon film absorbs light much more poorly than the amorphous silicon film, it needs to be considerably thicker. Therefore, whilst the primary PECVD system deposits the amorphous film, six secondary PECVD systems work simultaneously to produce the microcrystalline layer.

PVD

In physical vapor deposition, the precursor is first converted into the gas phase with the aid of physical processes. The vapor then moves through the reaction chamber either balistically or guided through electric fields, and condenses onto the substrate to form the desired coating. This process allows virtually any metal to be deposited in an extremely pure form. Adding reactive gases to the process (e.g. oxygen or nitrogen) permits the deposition of thin oxide or nitride layers.

PHOTO: CENTROTHERM PHOTOVOLTAICS

Manually-loaded PECVD boat with cells

In order to avoid the accelerated vapor particles being dispersed with other gaseous molecules, it is necessary to evacuate the reaction chamber. A typical working pressure is anywhere between 10^{-4} and 10 Pa, which requires more sophisticated vacuum technology than with CVD. Because the vapor particles spread in a rectilinear fashion, it is not possible to homogenously coat irregularly-shaped surfaces without taking additional measures.

Cathode sputtering is a special variant of PVD. Here, the precursor is extracted from the solid (target) by means of bombardment with energy-rich ions (usually argon). The substrate is positioned close to the target so that the ejected atoms are deposited there and form a solid layer.

The ions can be accelerated using DC gas discharge (DC sputtering), whereby the target and the substrate form the negative and positive electrodes respectively. The plasma is created through impact ionization of the noble gas atoms, which are accelerated by the direct current. A continuous ion current hits the target as a result. The sputtering process can be improved further by incorporating plasma discharge, which is ignited using a magnetic field under argon atmosphere (magnetron sputtering technique).

The sputtering method can be applied almost universally. It is particularly well suited to depositing metal contact layers, transparent conductive oxide (TCO) and absorption coatings on thin-film modules, as well as depositing passivation layers on crystalline silicon wafers. It is possible to manufacture the front and rear contacts for all thin-film modules in sputtering processes, and in CIS and CIGS modules it is also possible to deposit the active photoelectric elements that will subsequently form the absorption layer.

A second, important PVD variant is the simultaneous evaporation (co-evaporation) of several elements from one electrically-heated target. This target contains the elements needed for the product in the desired stoichiometry. Higher evaporation rates are achieved if an electron beam is aimed directly at the target so that the atoms evaporate abruptly. Co-evaporation allows the active photoelectric layer in CIS and CIGS thin-film modules to be deposited in one processing step.

PHOTOS: CENTROTHERM PHOTOVOLTAICS

Direct plasma coating: an antireflective coating is applied to cells.


PHOTOS: TOM BAERWALD / SGS SOLARTEST HOUSE

Light aging test on crystalline modules

Quality Assurance

Despite the steep fall in prices over the past few years, a photovoltaic system remains a substantial investment for the plant operator. In order to ensure that a multi-kilowatt capacity system continues to be a lucrative asset in the longer term, the quality of the components is critical. The long-term behavior of these components plays a particularly significant role. A variety of tests and assessment methods are available to analyze the quality of different systems.

Laboratory or long-term testing? How to compare solar modules

The most common and most frequently employed method for comparing different solar modules with each other is performance testing under standard test conditions (STC). Standard test conditions can only be created in the laboratory so that the output results can only ever serve as guidance. They do not have much in common with the real yield of a roof-mounted or a free-standing module. The most common method for determining module output is the STC lab measurement using a flash solar simulator or a constant light solar simulator – outdoor measurements are taken less frequently.

While laboratory measurements can only provide a momentary assessment of module output, long-term tests in climatic chambers or outdoor tests under real conditions are much better suited to providing information about the quality of a PV system in the course of its life span. Tests in climatic chambers simulate the aging of solar modules as if taken with a time lapse camera. Outdoor tests submit modules to real environmental conditions for a certain duration. These results reveal the long-term, real operating behavior.

To keep costs at bay, only two or three sample modules per producer are tested. Obviously, the validity of such samples is limited in comparison with an annual production of several hundred thousand modules, even for mid-sized producers.

STANDARD TEST CONDITIONS

To allow for a comparison between solar modules from different producers, a uniform method for determining module output is needed. The output on the type plates is therefore asserted under set “standard test conditions”:

- 1,000 W/m^2 irradiance
- spectrum AM 1.5 (AM = air mass)
- 25°C cell temperature

These insolation conditions were chosen because they occur in reality – at an azimuth angle of 48.2°.

PHOTOS: TOM BAERWALD / SGS SOLARTEST HOUSE

Thin-film modules are also subjected to quality assurance tests.

Different test methods – different sources of errors

Even extensive performance testing under optimum scientific conditions is not completely error-free. The greatest sources of error are a strongly fluctuating temperature on the test sample, the homogeneity of the light sources and the deviations of the flasher spectrum from AM = 1.5. AM stands for "air mass". Light is attenuated as it passes through the atmosphere, changing its spectral power distribution.

Experts recommend not just looking at the yield in comparison with the system output, but also at the longevity and durability of a PV system. While the yield of a solar system depends on local factors, system-specific factors, and the module parameters, the life span is strongly influenced by the product design, the material used, and the fastening system. The most suitable method is the – relatively costly – climate chamber test. However, even this method is not entirely error-free. Frequently, this test only examines one form of exposure, but not a combination of different stress factors, such as UV radiation in combination with moisture and heat stress. It is not possible to put the residence time in a climate chamber in direct relation to the actual life span of a module.

The predictive power varies greatly

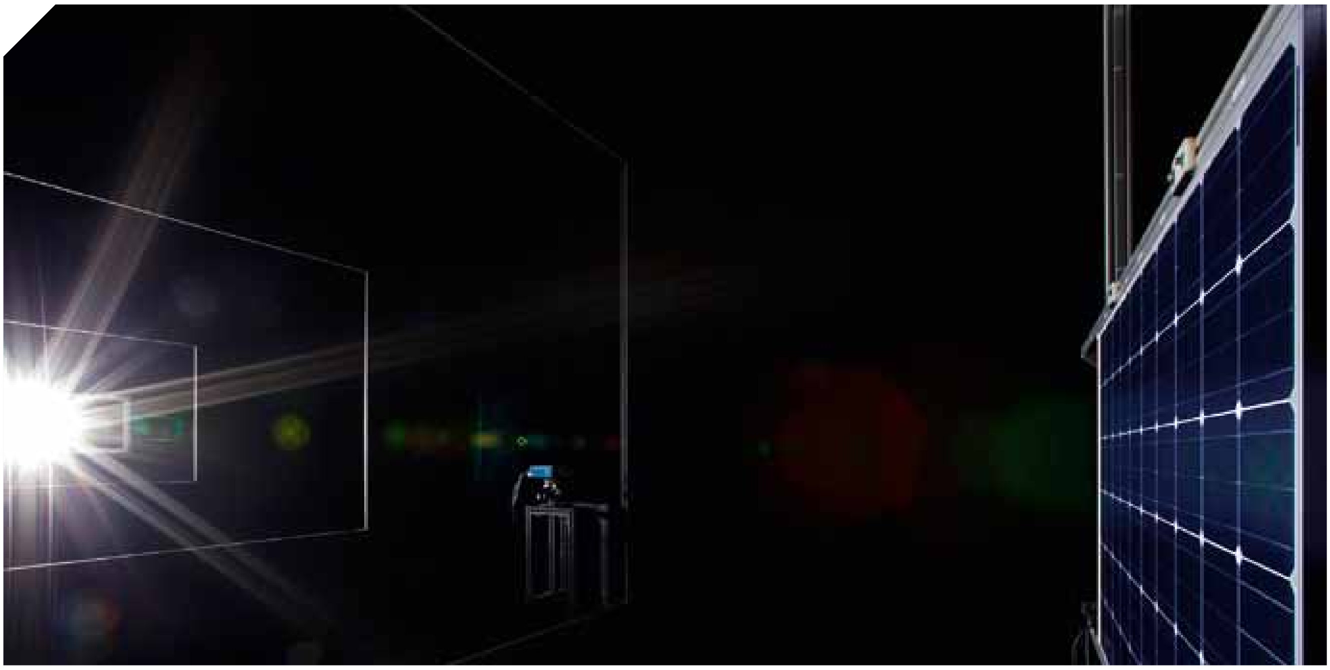
Climate chamber tests do provide a good idea of the module quality, ideally in combination with a prolonged yield measurement in the field. Such long-term tests are particularly suitable for determining the actual yield volume. Nevertheless, all procedures have two basic weaknesses: Testing just a few modules obviously has limited predictive power. Also, choosing samples is tricky in itself because there is always a risk of a producer selecting modules carefully when just two or three modules – the typical amount used in such tests – are ordered. This can be avoided by buying the modules anonymously in the free market. For the "PV test" introduced by Solarpraxis AG and TÜV Rheinland, samples are bought on the open market and the results published as high-score listings in the trade magazines "photovoltaik" and "pv magazine", as well as at www.pvtest.de.

Aspects of finishing, material testing, and the avoidance of transport damage and design errors have not yet been fully integrated into the common test procedures of the International Electrotechnical Commission (IEC). Today, independent institutes offer test procedures which go beyond this standard. For commercial customers and planners of large projects in particular, it is certainly worthwhile having the components tested as extensively as possible before the start of construction, followed by performance monitoring.

THE MOST FREQUENT SOURCES OF ERRORS

- strong deviation of flasher spectrum from AM 1.5
- fluctuating temperature of samples may lead to measurement errors of up to 0.5 percent per degree Celsius
- insufficient homogeneity of the light source may lead to measurement errors
- initial degradation of monocrystalline modules not yet concluded
- defective reference modules or microcracks in the modules
- spectral sensitivity of sample cell not sufficiently taken into account

Source: EuPD Research, 2011



PHOTOS: TOM BAERWALD / SGS SOLARTEST HOUSE

The rated capacity of solar modules is determined in a flash test.

Inspection and testing of received goods

In large projects, making spot checks from on-going deliveries is becoming common practice. The IEC 60410 sampling plan, an international standard regulating sampling procedures, provides a good basis for this. For solar parks of between two and seven megawatts, 125 modules are taken as samples at the lowest level of inspection.

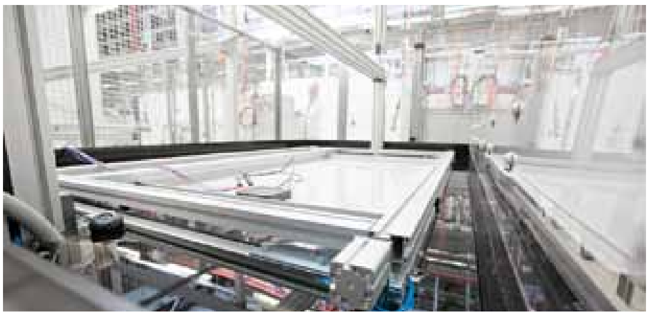
A typical inspection and testing procedure of received goods also includes output measurements, examination of efficiency in diffuse light, electroluminescence measurements, and insulation tests. These tests can generally be carried out during construction, but since they are mainly yield-oriented they do not predict the actual life span of the modules.

One of the few tests which can help to quickly uncover some sources of error in connection with life span is the EVA gel connect test. This test is relatively expensive, however, because the samples are destroyed during the test. Depending on the plant size, between eight and 20 modules will be tested. Despite its high costs, this test is highly recommended because products with low degrees of connection are relatively frequent.

Once again, the most conclusive test is the climate chamber test. Due to the time required for this type of test, however, it is only suitable for long-term projects.

Tests during production are another approach, which is carried out in the factory hall. Although this approach appears to be particularly effective at first glance, its success depends on a multitude of factors. In addition to the very large procurement volume necessary to facilitate tests during production, the supplier also has to agree to these tests being carried out. Running such a complex service program over an extended period also requires considerable persistence on the part of the importer.

PHOTO: Q-CELLS INTERNATIONAL



Measuring the resistance of the installation

PHOTOS: TOM BAERWALD / SGS SOLARTEST HOUSE

Modules are tested for potential induced degradation (PID). This is a drop in the performance of photovoltaic modules that can be caused by high levels of negative voltage.

Extra audit

When buying a large quantity of modules, it is always sensible to place the products, their manufacturers, as well as the components and materials used under closer scrutiny. An audit helps to validate the results of various module tests and estimate the risks of a project. If manufacturers subject their products and components to more stringent testing, and not simply to that specified in the standards, there is a reduced risk of damage at a later date, as certificates from different test institutes sometimes vary considerably.

There is no such thing as absolute security, but reasonable assessments can be made. Checklists can also prove useful in analyzing the risks of a product.

Quality control
PHOTO: Q-CELLS INTERNATIONAL

PHOTO: Q-CELLS INTERNATIONAL

Cold test

Ecology

Effective environmental management during manufacturing processes allows companies to reduce the time and money spent on fulfilling sustainability criteria, thereby lowering costs. Additionally, recycling lessens the effect of soaring raw material costs, which are predicted to rise significantly. The three mainstays of the Triple Green concept are green products, sustainable production methods and the avoidance of waste or the regular recycling of materials and products.

PHOTO: CENTROSOLAR

Sustainable production poses a challenge in the PV manufacturing industry, too.

Fewer materials, less energy

Leading manufacturers have started to construct large solar farms on the roofs and façades of their factories to keep their energy cycles green. Moreover, it is increasingly becoming standard practice to use waste heat in the manufacture of solar components or glass. In new factories, supply systems with cogeneration plants are being used to produce electricity and heat at the same time.

Attention is also being paid to water consumption: A modern solar glass factory requires around 1,000 cubic meters of cooling water an hour. It circulates in a closed cycle and only water lost through humidification needs to be compensated for by feeding in water from the network. Even solar cell manufacturers are feeling the effects of increased water costs. For example, acids and solutions are needed to etch the silicon wafers used for crystalline solar cells. Once the wafers have been processed, the acids are mixed with chemicals to neutralize and purify them, before they enter the waste water cycle. These processes are refined during the factory planning stage to ensure that up to 70 percent of the water used in the etching process can be fed in a closed cycle.

Dealing with materials, water and energy efficiently is the key to lowering production costs. Although solar cells are becoming increasingly thinner, the production of silicon still requires a considerable amount of energy. Semiconductors are produced by melting quartz sand at very high

PHOTO: TOM BAERWALD

The Triple Green concept comprises green products, sustainable production, and recycling or rather the avoidance of waste.

temperatures – a metallurgical process which uses a lot of energy. Following this, machines are used to saw the pure silicon into wafers in a process which results in around 40 percent of the precious silicon being lost as shavings. Reducing the amount of material lost by the wire saws and cooling emulsion (slurry) has become a focal point of research. New developments are key, as until now the Siemens process has dominated the manufacture of crystalline solar cells worldwide.

A new fluidized bed reactor has recently been developed to manufacture solar grade silicon. Here, the process gas silane flows continuously through a chamber containing pure silicon, lowering energy requirements by up to 80 percent. The process saves energy but causes a similar amount of material to be lost as the Siemens process. The string ribbon process, however, produces significantly less waste. Here, wafers are pulled directly out of a silicon melt between two wires, forming thin ribbons which are cut by a laser into rectangular cells.

The further processing of the wafers requires various wet chemical processes and gases. Cell doping and metallization are carried out in separate manufacturing stages which require temperatures of several hundred degrees Celsius. Engineers are also striving to lower these process temperatures.
When producing thin-film modules from silicon, around one fifth of the total manufacturing cost is taken up by process gases alone, including silane, nitrogen trifluoride and ammonia. By using silane more efficiently in deposition procedures, manufacturers of modules made using extremely thin coatings of amorphous silicon were able to reduce their consumption of the process gas by three quarters during the course of one year.

Particular issue: process materials

Rising metal prices are prompting manufacturers to use aluminum or copper in their metallization pastes instead of expensive silver. New contacting processes (copper plating on the front of the cell or using aluminum to form a reflective layer on the rear of the cell) have also reduced the amount spent on metallization. A further example is silicon-based thin-layer modules, which require special gases in order to clean unwanted deposits from the process chambers used to deposit extremely thin silicon layers. Nitrogen trifluoride or sulfur hexafluoride are used as sources of activated fluorine. Releasing one kilogram of nitrogen trifluoride into the atmosphere is equivalent to emitting 17.5 tonnes of carbon dioxide, while one kilogram of sulfur hexafluoride has the same environmental impact as 23 tonnes of carbon dioxide. The standard procedure is to discharge these gases from the process chambers through an airtight pipe system after the cleaning process and chemically neutralize them. A new technique that uses hydrofluoric acid renders hazardous cleaning gases superfluous. This does, however, demand additional investment. Because fluorine is classified as extremely volatile and corrosive, it requires double-walled pipes for security reasons.

PHOTOS: CENTROSOLAR

Eco-certified production (above and below)

PHOTO: SAPERATEC

Eco-certified production

PHOTOS: SAPERATEC

Developing liquids to separate semiconductor coatings from discarded thin-film modules

Extensive recycling

The solar industry is almost unique in having developed a closed-loop recycling system for its products at an early stage. Members of the PV CYCLE recycling initiative cover around 90 percent of the European market for solar cells and solar modules. Companies from Asia and the USA also rank among its 240 members. By 2015, a Europe-wide network for the recycling of solar modules will come into existence. PV Cycle currently uses old modules and production waste to make recycled glass, meaning the recyclable materials are not directly reused by the solar industry. The recycling association Ceres was established in France in 2011.

In January 2012, the European Parliament in Brussels decided to include solar modules in Directive 2002/96/EC (waste electrical and electronic equipment), meaning that the same take-back and recycling procedures apply as for refrigerators, radios and computers.

The directive stipulates that in 17 member states of the European Union at least 75 percent of disused solar modules must be collected and a minimum of 65 percent must be recycled by 2015. By 2018, 80 percent must be collected and 70 percent of old modules must be recycled. After this date, the quotas will rise to 85 and 80 percent. Bulgaria, the Czech Republic, the Baltic states, Hungary, Poland, Malta, Romania, Slovakia and Slovenia have been given smaller initial quotas: By 2016 around 40 percent of their old modules need to be recycled. In nine years they will be subject to the same regulations as the other member states.

Solar module and inverter manufacturers are solely responsible for ensuring the directive is fulfilled. They must be able to prove to the national authorities in each EU member state that their products meet the required cycles and quotas. The EU member states have until July 2013 to incorporate the new directive into their national law.

In Germany, an extensive system has been in place since the end of 2009 ensuring that old modules are taken back. A pilot line in which crystalline solar modules were dismantled and recycled ran in Freiberg, Saxony until the end of 2010. The modules were removed from their frames and the junction boxes were disconnected. The glass-glass laminates were then heated for several hours to burn the composite plastics, after which the glass, string connectors and silicon were separated and recycled. Etching processes were among those used to remove cell metallization and doped films. The silicon was chemically purified and the silicon produced by breaking up the wafers was remelted into ingots.

This pilot line was closed, however, because the process did not take off as a business concept. There are plans for the technology to be used in a larger automated plant in Bitterfeld. Germany currently has no industrial capacity for module recycling.

PHOTO: SAPERATEC

Thin-film modules during the recycling process

The growing quantity of old modules is opening up a recycling market which has developed its own technology and is independent of research conducted by module manufacturers. Around 5,000 metric tons are collected in Europe each year and experts predict a sharp rise in this from 2020. Two new technology suppliers have appeared in the area of thin-film module recycling since 2011 and are testing their processes in pilot lines. A supplier in Saxony is using highly concentrated acid baths, while a company from Bielefeld has developed an innovative surfactant mixture to gently loosen and separate semiconductor films, sheets and metallic components from glass. This process can be adapted to all thin-film and crystalline solar modules. With the increasing number of old modules, solar module recycling will develop into an independent economic sector, even for suppliers of plant technology.

CIS and CIGS still at an early stage

The recycling of solar modules made from compound semiconductors with copper and indium (CIS or CIGS) remains highly underdeveloped, as the mass production of these generators is still at an early stage. In terms of recycling, everything revolves around indium, as the solar industry will require around 580 metric tons of this material per year by 2050. Indium is rare, and to add to this, the solar industry competes for this much sought-after material with manufacturers of displays and flat screens. It is currently difficult to recover indium and the growing demand must be fulfilled by new deposits, the majority of which are located in Asia. The same is true of gallium, which is also used in CIGS solar modules. The demand for gallium is set see an approximate six-fold increase by 2020 in comparison to the amount used today.

PHOTO: SAPERATEC

Dissolved semiconductor coatings: a recyclable product

MARKET SEGMENT RECYCLING

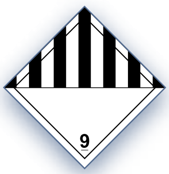
The market for module recycling is slowly becoming established with an increasing number of independent technology providers entering the scene, all searching for economic module recycling solutions. At present, research focuses on a special material that allows EVA films and other reusable materials to be removed and recycled without the need for heat or manual work. Another method uses acids to dismantle old modules.

At the Brandenburg University of Technology (BTU) in Cottbus/Germany, one area of research focuses on the disposal of hazardous waste in environmental technology. The German Federation of Industrial Research Associations (AiF) recently sponsored a project at the BTU where a test facility was built that enables semiconductors and contact materials to be fully recovered from thin-film modules. This method uses vacuum ejector technology. In addition, a new type of high-performance blasting lance has been developed that allows the recyclable materials to be removed layer by layer.

At the German Federal Institute for Materials Research and Testing (BAM), systematic tests on the concentration of recyclable materials were performed using a physico-chemical flotation technique. This technique can now also be applied in practice.

PHOTO: TOM BAERWALD / INNOTECH SOLAR

Rear side inspection: multi-color analysis



Cadmium telluride

A manufacturer-specific take-back system for thin-film modules made from cadmium telluride has been in place for several years. Disused modules are firstly shredded in a hammer mill and ground into pieces a centimeter long. This breaks the lamination bond. A weak sulfuric acid dissolves and washes out the semiconductor layers before the solid matter is separated from the process liquid. The metalliferous liquid is filtered several times and concentrated. The resulting filter cake provides cadmium telluride for new modules. A recycling quota of almost 95 percent has been achieved with cadmium telluride.

The continued expansion of cadmium telluride solar modules should trigger a surge in demand of up to almost 700 metric tons by 2050. The demand for tellurium will increase to around 300 metric tons by 2030. The limited amount available (132 metric tons in 2006) highlights the economic importance of recycling.

Heavy metals in components

Amendments to the EU's "Restriction of the use of certain hazardous substances" (RoHS) environmental protection Directive 2002/95/EU were debated in Brussels in the fall of 2010. It prohibits the use of heavy metals such as cadmium or lead in portable electronic devices. Solar modules will continue to be exempted until 2014 because power plant engineering is generally not covered by RoHS. Nevertheless, the debate made one thing clear: The solar industry will increasingly be expected to reconcile economics with ecology. This is why many module manufacturers are opting to replace leaded solder pastes for stringers with lead-free technologies. In the case of inverters, which contain a lot of electronics, new devices from some suppliers already use lead-free solder throughout. Cadmium is currently used as a buffer layer in CIS and CIGS modules and as a semiconductor in modules containing cadmium telluride.

Health care costs should not be underestimated. Companies need to pay particular attention to how they work with cadmium, as it is a toxic heavy metal which poses a risk to both humans and the environment. Although cadmium telluride (cell material) and cadmium sulfide (buffer layer and contacts) do not pose a danger comparable to the heavy metal in its pure form, solar module manufacturers must be extremely careful during the production stage and when dealing with industrial effluent.

In addition, the manufacture of solar technology requires various auxiliary chemicals, the use of which is regulated in the EU's Reach ordinance (Registration, Evaluation, Authorization and Restriction of Chemicals). The photovoltaic industry is yet to be heavily affected but it is only a matter of time until this changes. Discussions are currently taking place in Brussels as to whether RoHS and Reach should be combined into one ordinance in the medium term.

Toxic waste nevertheless accumulates during the production of solar cells, solar modules and components. Its disposal costs a lot of money, making production more expensive. For ex-

PHOTO: TOM BAERWALD / INNOTECH SOLAR

Fair working conditions also form part of sustainable production.

ample, only two percent of the potassium hydroxide solution utilized in the wet chemical etching of solar cells is fully exploited before it is removed from the process as waste. Explosive or poisonous gases, such as silane and phosphine, are produced when manufacturing solar modules from thin layers of silicon. It is important that here, too, the chemicals be put to better use and fed in a closed circuit, as the amount spent on operating safety, redundant systems and purifying waste gas (abatement) is a crucial factor in the overall module manufacturing cost.

Environmental management

Introducing an environmental management system is an integrated approach to identifying specific manufacturing costs and systematically looking for potential improvements. Most manufacturers apply international DIN EN ISO 14001 or EMAS standards. DIN stands for "Deutsche Industrienorm" (German Institute for Standardization), EN stands for "European Standard", ISO stands for "International Organization for Standardization", and EMAS stands for "Eco Management and Audit Scheme". DIN EN ISO 14001 lays down the requirements placed on an environmental management system. The main emphasis is on the continuous improvement of environmental targets, specified by the company itself. The DIN EN ISO 14001:2005-06 standard applies in Germany. EMAS is also referred to as "eco-audit". The scheme was developed by the European Union and is used for eco-auditing and environmental management. Independent experts scrutinize the environmental statements made by participating firms at regular intervals. EMAS II incorporates additional specifications from ISO 14001 and enables manufacturers who have various plants to be validated in a single procedure. EMAS III came into force in early 2010 and essentially concerns concessions for small and medium-sized enterprises.

Social standards

Renewable energy currently enjoys a strong position of trust. This is why the public is particularly concerned with the situation of factory workers. The solar industry would therefore be well advised to insist on high levels of social responsibility from producers and their suppliers – all over the world. In Germany, the industry's task is to achieve levels of pay and worker participation that are at least equivalent to those in the automotive industry. Many companies are moving in this direction, setting up works councils and negotiating collective wage agreements. Only then will the solar industry be able to exploit its full potential and push ahead with the social and ecological transformation of industrial society in exemplary fashion.

Summaries

Approx. 150,000 people were employed in the German solar industry at the end of 2011.

Summary

Market

Photovoltaics was able to achieve an important milestone in 2011: It is now no longer an expensive means of generating electricity. Systems technology as a whole has become ever cheaper, primarily as a result of the unprecedented drop in PV module prices during 2011. This is causing demand to grow, even in countries that cannot afford costly subsidy programs. Step by step, photovoltaics is gaining independence from both direct and indirect subsidization and is taking great strides toward profitability.

This generally positive development also has its downsides, however, that are now being felt by the PV manufacturing industry. The reason for this is that the slump in prices is not only the result of innovation but also stems from the surplus capacities that have been created in all areas of production over the past few years. These capacities are so far from being exhausted that ever more companies are sustaining losses. The industry is therefore now undergoing a process of consolidation that many manufacturers will be unable to survive.

PV components have become mass-produced goods, and several of the larger manufacturers are single-mindedly continuing to expand their capacities in the belief that size alone will ensure their survival. This is true of the four largest polysilicon producers and six of the ten largest cell manufacturers. Surplus capacities will therefore persist for some time yet, even as smaller manufacturers disappear from the market and the prices of PV systems continue to fall.

Thin-film technology now occupies a tangibly smaller share of the market and an end to this development is not yet in sight, as the falling prices for silicon technology are increasing its dominance. Manufacturers of thin-film modules are attempting to improve throughput rates and lower production costs to compensate for the disadvantage of this technology's lower efficiency.

How the market will develop can only be predicted to a limited extent, as the political frameworks are extremely diverse and are also subject to change at a moment's notice, as demonstrated in Germany. The drastic cuts to the German feed-in tariff in spring 2012 indicate that the particularly favorable political framework provided in recent years will very soon come to an end. Similar developments are to be expected in Italy. Both countries dominated the PV market during 2011.

The heavy dependence of worldwide market developments on just two national markets will diminish as demand increases in other countries. If the persistent fall in prices also leads to the creation of sustainable growth in China, India, and the USA, photovoltaics will be able to continue its incredible progression.

PHOTO: TOM BAERWALD / MIKRON BERLIN

Applying contacts to thin-film cells

Technology

In order to set themselves apart from fierce competition, manufacturers are focusing increasingly on developing high-performance solar cells. It is possible to increase the efficiency of mono- and multicrystalline silicon cells by moving the contacting from the front to the rear of the cells, leaving a larger active surface area to absorb sunlight. A variety of technical concepts are available here. The best back contact cells now achieve efficiencies of over 24 percent (i.e. some six percentage points more than standard cells), though they require ultra-pure silicon and more intricate – and therefore expensive – production technology.

Efficiency can also be increased by reducing the recombination of charge carriers, which in turn increases yields. This can be achieved by passivating the cell rear, for example. N-type cells represent another fundamentally different approach. Here, the base material of the silicon wafer is not p-doped, as is customary, but rather n-doped, giving it a noticeably smaller capture cross section – meaning that less recombination of charge carriers takes place and that yields are higher as a result.

Thin-film module efficiency is distinctly lower, ranging from just under 10 percent (micromorph silicon) to 12 percent (copper indium diselenide). Efficiencies of 20 percent have been achieved with this technology in lab conditions, though it will be some time until thin-film modules with such high efficiencies are available on the market. Cadmium telluride modules (CdTe modules), which have an efficiency of 11 percent, can be manufactured at relatively low expense, meaning that kilowatt hours of electricity can be produced very cheaply. Now that crystalline silicon technology is increasingly catching up, however, the competitive advantage enjoyed by CdTe technology has melted away over the past year.

Next generation PV technology has not yet reached a commercial stage. Both organic and dye-sensitized solar cells are not yet suitable for series production due to low efficiencies and product lifespans that are still far too short.

Metal contacts are applied with extreme precision.

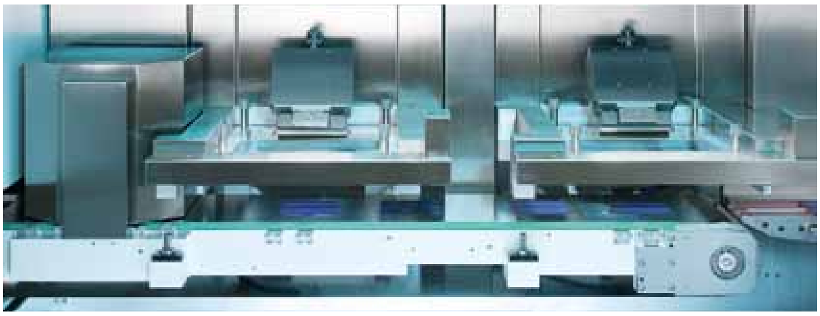


PHOTO: MANZ

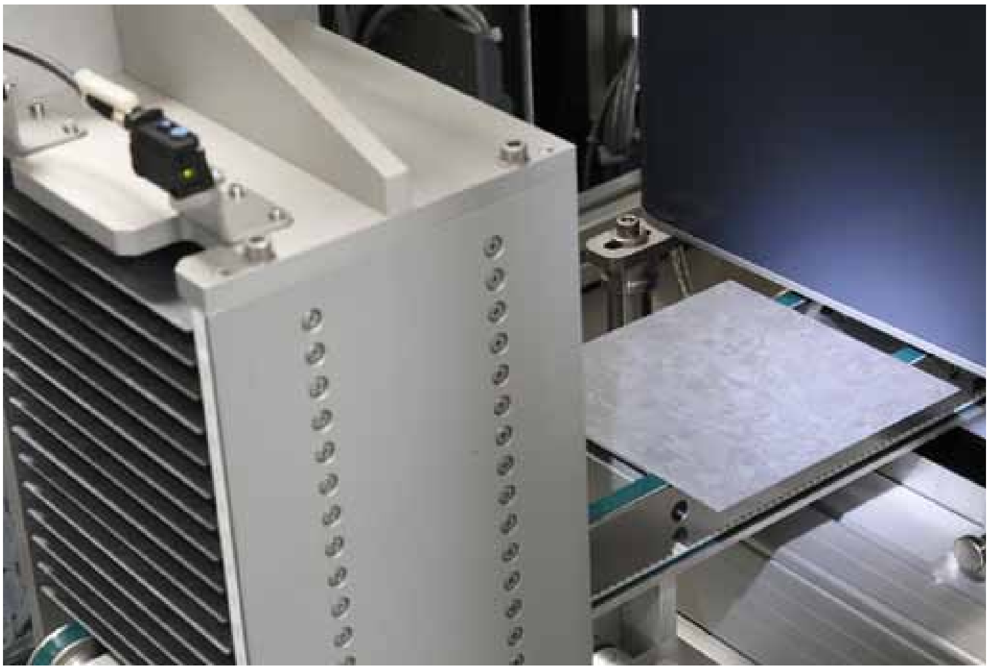


PHOTO: BAUMANN

Stacking wafers

Production

PHOTO: HÜTTINGER ELEKTRONIK

Crystalline cells dominate the world market.

Photovoltaics can only continue to grow if the costs of generating power from solar energy visibly decrease year on year. Cost reduction is therefore the primary aim of production technology.

Numerous process steps and various manufacturing procedures are necessary, first to produce cells from crystalline silicon and then to construct modules. For this reason, it is necessary to optimize every single step of each process.

In view of this demanding task, the PV manufacturing industry has developed a joint roadmap to help take the strain off individual manufacturers, allowing them to share the development costs for new processes and machinery. The ultimate goal is to continue the evolutionary technological development typical of the successes achieved to date with crystalline silicon technology.

Conserving materials, increasing throughput and enhancing efficiency are the roadmap's three most critical objectives in its drive to reduce costs by 9-10 percent annually until 2020.

Conserving silicon is the top priority. This means that the wafers used to manufacture cells need to become increasingly thinner. Despite being carried out at extremely high speeds, all subsequent processing steps must be extremely gentle to ensure the thin wafers do not break. This places stringent requirements on the production technology.

Throughput can be increased by using larger ingots from which the wafers are cut. Productivity and tool operating life can also be improved. A marked increase in throughput rates can be expected in around 2015 if new interconnection technologies such as back contact cells are introduced into mass production.

Thin-film modules are manufactured in continuous processes in which physical deposition techniques dominate. Production line cycle times here last just minutes.

Developments within production technology are currently centered on increasing process speed and improving system availability. Enhancing efficiency (chiefly by minimizing optical losses and improving utilization of the solar spectrum) is also an important step toward lowering the cost per kilowatt hour for power generated using thin-film modules.

Two vacuum techniques, chemical vapor deposition (CVD) and physical vapor deposition (PVD) are key to PV module production. Lasers have also become established as universal production technology tools. They are used to drill vias connecting the front and rear sides of cells to produce back contact cells, they are employed to create locally-doped regions and they are also used to remove insulating layers from surfaces. Lasers are also indispensible when developing new cell concepts.

PHOTO: HÜTTINGER ELEKTRONIK

Stacking wafers

Quality Assurance

PV modules should generate a reliable supply of electricity for at least 20 years, meaning that quality assurance is of critical importance. Performance measurements and long-term testing take top priority here. Several test methods are combined in order to be able to assess quality as comprehensively as possible.

Measurements performed under laboratory conditions that provide snapshots of module efficiency are supplemented by long-term tests under extreme conditions in climate chambers. Such tests simulate how modules age at greatly accelerated speeds. However, it is not possible to calculate the actual lifespan of a module by converting the time spent in the climate chamber into a real time equivalent. Outdoor tests are therefore necessary to obtain conclusive information about module lifespan under real conditions. The results of these three test methods allow statements to be made on the actual long-term performance of modules.

In order to keep costs as low as possible, only a few modules of each type undergo testing. Sample testing in this way offers only limited reliability, particularly since manufacturers generally supply the modules to test institutes themselves. This is one reason why several test institutes have now begun purchasing modules on the open market.

When large-scale plants comprising thousands of modules are installed, it is wise to test samples from each new delivery. In-process inspections go a step further, as they allow test institutes to take individual modules from ongoing production processes.

Ecology

The success of photovoltaics is largely dependent on its environmentally-friendly image, which results in strict requirements on PV module production. Conserving materials and energy, avoiding waste, and careful recycling are key to ensuring that production is sustainable.

The products themselves can contribute to improving the energy supply for production if PV modules are installed on the roofs and façades of solar factories. The utilization of waste heat and cogeneration have become standard practice for exploiting the energy used as effectively as possible. In addition, water use is reduced to a minimum – also when producing the process materials required for production. If the properties of such materials do not meet the demands placed on sustainable production they are gradually replaced with environmentally-friendly equivalents.

The PV manufacturing industry developed closed-loop systems for its products at an early stage to ensure that products are recycled to the greatest possible extent. Special attention is paid to heavy metals in particular: The recycling quota for cadmium telluride thin-film modules is almost 95 percent.

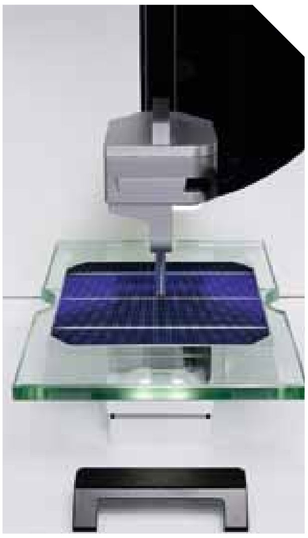


PHOTO: CENTROTHERM PHOTOVOLTAICS

The bowing of cells is measured in a bow test.

PHOTOS: TOM BAERWALD / MIKRON BERLIN

薄膜光伏电池组件的生产

Thin-film module production

综述

市场

2011年对光伏产业来说是一个重要的里程碑。这一年，它不再被视为一种昂贵的发电方式。2011年光伏组件的降价，使整个光伏系统技术变得经济实惠。即使在那些不能承担庞大支出的国家中，对光伏的需求也大大增长。光伏正在逐步抛开直接或间接的补贴扶持而大步前进，并与经济紧密关联。

在光伏工业普遍积极发展的同时，其隐晦的一面也逐渐显露。价格下降不仅仅是因为技术革新，还因为近年来在各个生产阶段过剩的产能。设备的闲置使越来越多的厂家陷入亏损的境地。而在行业整合的过程中，很多厂商将不能度过难关。

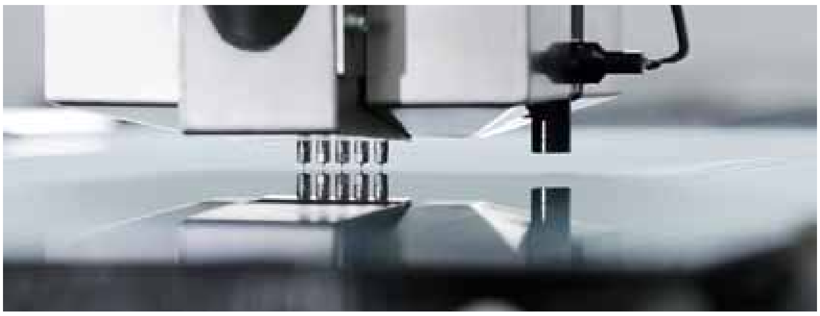
在光伏组件已经开始大批生产的同时，一些大厂商仍然扩大规模，以期规模大到足以渡过难关。就像四大多晶硅生产商以及十大电池制造商一样。因此产能过剩仍将持续一段时间，小厂家从市场消失，光伏发电系统的价格将继续下跌。

薄膜技术的市场份额已经大幅度减少，但是它的发展还没有到尽头，因为硅技术仍占有价格优势。薄膜模块的生产厂家正努力提高生产合格率，降低生产成本，以弥补效率低的缺点。

因为迅速变化的不同政策，使市场发展的可预见性变得极其有限。比如在德国，2011年春的上网电价大幅减免政策立即使之前的政策失去了优势。类似的情况也发生在意大利。而在2011年，这两个国家在光伏市场中占据了主导地位。

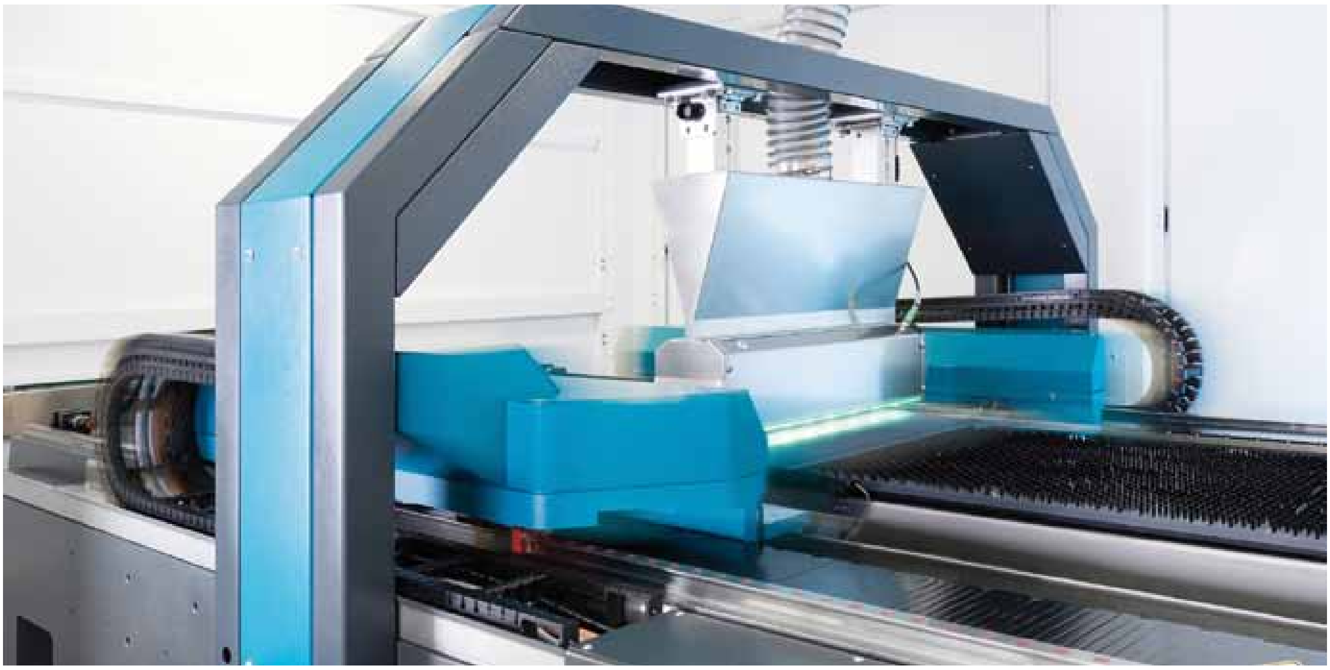
如果其他国家的需求增长，那么全球市场的发展在极大程度上只依靠两个国家市场的情况将会削弱。如果价格持续走低，那么在中国、美国及印度将持续发展，光伏发电可以继续其惊人的增长。

PHOTO: MANZ



薄膜光伏电池组件的机械结构处理 | *Mechanical patterning of a thin-film module*

PHOTO: MANZ



用于划分薄膜光伏电池组件导线中导体层和半导体层的激光结构处理

Laser patterning of a thin-film module to subdivide the conducting and semiconducting layers into cell strips

技术

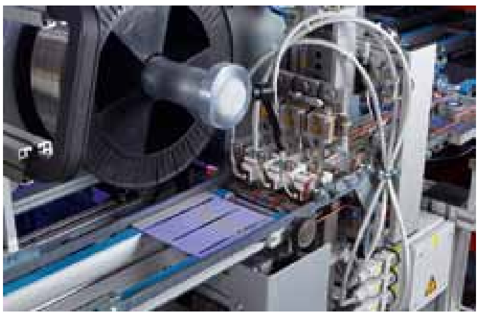
为了在日趋激烈的竞争中脱颖而出，越来越多的厂商加紧开发更高效的太阳能电池。通过将前面的接触点向背面移动，增大了吸收阳光的有效面积，提高了单晶硅和多晶硅太阳能电池板的效率。对此有不同的技术性概念。最好的背接式单元(Back contactcells)的效率超过了24%(比当前的标准单元高出了大约六个百分点)，但是其要求硅的纯度相当高，并要求更复杂、更昂贵的制造技术。

更有效的方法是通过减少电荷载体的重组，来提高产量。例如可以通过钝化单元格背面来达到此种效果。N型单元格体现了一种全新的方法。晶圆的基本材料不但包含n型单元格，还有p型单元格，从而显著降低捕获横截面，这就意味着电荷载体的重组较低而产量较高。

薄膜模块的效率要低得多，从不到10%(微晶硅)到12%(铜铟硒)。实验室中已经达到了20%的高效，但是到实用阶段还有相当长的时间。碲化镉模块(CdTe-Module)实现了以较低的生产成本达到11%效率的目标，更加低廉地生产每度电力。碲化镉技术的竞争优势得益于过去一年获得的结晶硅技术。

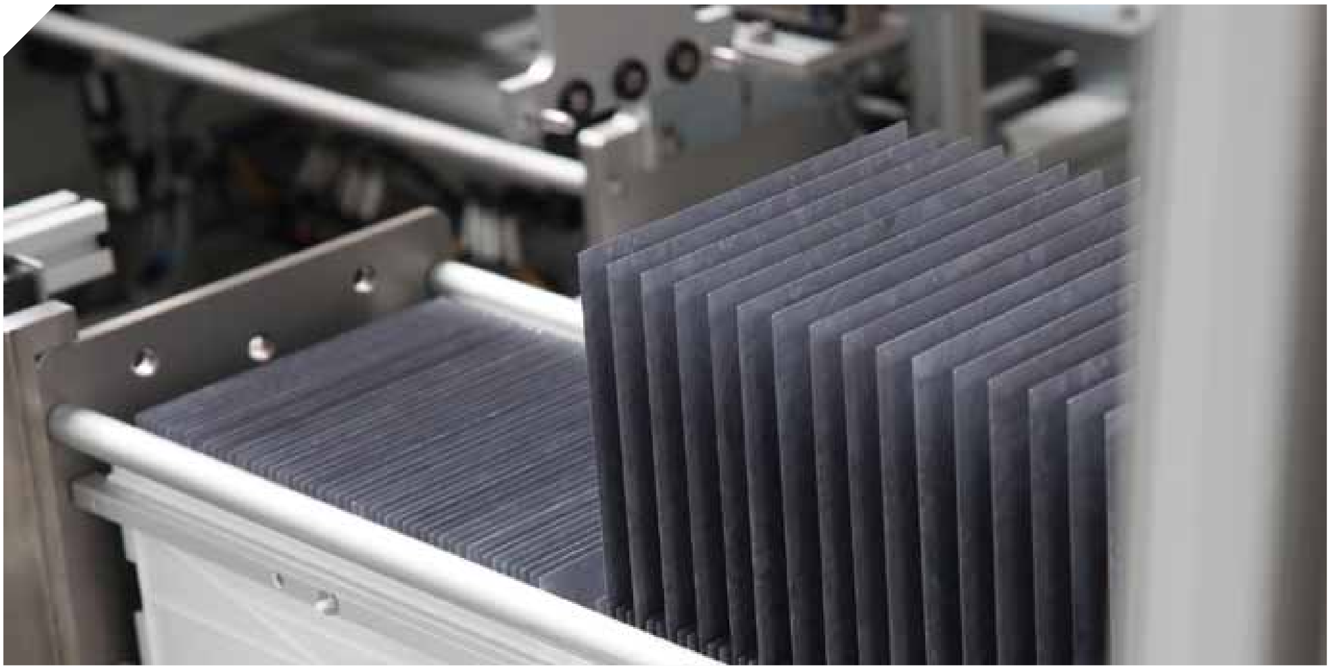
下一代光伏发电技术尚未达到商业化阶段。有机太阳能电池和着色材料单元因为较低的效率和过短的寿命还不能形成系列产品。

PHOTO: SCHMID GROUP



新近获得专利的工艺在光伏电池背接触处理中可利用成本较低的锡替代银

A recently patented process allows silver to be replaced with inexpensive tin in the rear side contacts.



PHOTOS: BAUMANN

晶片处理

Wafer handling

PHOTO: SCHMID GROUP

锡作为背面材料

Tin as a rear side material

生产

如果光伏太阳能发电的成本逐年显著降低，那么光伏发电系统将持续发展。因此降低成本成为生产技术的首要目标。

晶体硅经过众多的处理步骤和不同的生产工艺成为光伏单元，最后生产出光伏模块。因此有必要对每一步生产步骤进行优化。

为了完成这个对每个厂商而言都很艰巨的任务，光伏行业制定了一个共同发展蓝图，以共同承担开发新工艺和新设备的研发费用。目的就是继续创新研发，典型的就是迄今取得成就的结晶硅技术。

节省材料、提高合格率和提高效率是这个蓝图的三个最重要的目标，以期在2020年之前，每年降低成本9%–10%。

首先要节省硅的使用，这就意味着，从制造单元格开始，晶圆就必须变得更薄。在其后的加工过程中，必须谨慎保持高速，不能打破晶圆。这就提高了对生产技术的要求。

从较大的硅锭上切割晶圆，不仅能提高合格率，而且提高了产能和工具的使用寿命。预计到2015年，随着背接晶圆这样的新电路技术的应用，合格率将大幅提高。

薄膜模块生产是一个连续的过程，物理分离技术在其中起到主导作用。周期时间因此是以分钟为单位。

目前生产技术进一步发展的重点是提高处理速度和提高系统的可用性。此外提高效率(特别通过减少光损失和改进利用太阳光谱)是重要的步骤，以减少千瓦时薄膜模块的生产成本。

化学气相沉积法(CVD)和物理气相沉积法(PVD)这两个真空方法对光伏组件生产有十分重要的意义。激光已经成为生产技术中的普遍工具。它在单元上钻出连接孔，以便使单元前后连接，实现背接单元，产生区域优势并清除表面的绝缘层。

PHOTO: MANZ

高速捡料装置能够显著提升产量

High-speed pickers are able to significantly increase throughput.

PHOTO: CENTROTHERM PHOTOVOLTAICS

扩散系统

Diffusion system

质量保证

光伏组件应该可靠供电至少20年。因此，质量保证是非常重要的。重点进行性能测量和长期的测试。几种测试方法相结合，以便尽可能充分评估质量。

实验室测量：能够提供模块的瞬间功率，可以模拟极端气候条件进行长期测试，模拟硅模块随时间老化的情况。计算转换：在一种气候条件下得到的模块寿命是不可能计算出模块的实际寿命的。因此要获得现实中模块的寿命，有必要进行现场试验。用这三种测试方法得到的结果可以用来证明现实中的长期运行状况。

考虑到费用问题，只对少数几种模块进行测试。这样，样本的说服力变得非常有限，特别是当厂家自行提供模块样品给测试机构的时候。因此，一些测试机构选择那些在普通市面上找到的模块。

当安装由成千上万的模块组成的大型系统时，可以从供货中抽取样本。甚至为了更进一步地进行生产相关的测试，允许测试机构抽取已经安装并运行的模块。

生态

光伏发电系统的成功在相当程度上取决于它们的环保形象，由此促进了对光伏模块的生产需求。节约材料和能源,减少制造垃圾，循环再造，这些措施都保证了其持续的生产。

在太阳能工厂的屋顶和外墙上安装光伏模块，可以提高能源的生产。为了尽可能有效地使用能源，余热利用以及热电联产已成为理所当然的事情。此外，水以及其它必要生产辅助材料的耗费也降到最低限度。假如其属性不能满足持续生产的需求，它将逐渐被环保辅助材料取代。

光伏产业早就发展了封闭的循环体系，以便尽可能的回收自己的产品。特别是对重金属，比如碲化镉薄膜模块的回收利用率几乎达到95%。

PHOTO: REIS ROBOTICS

光伏产业中自动化程度不断升高

The degree of automation within the PV manufacturing industry is continuously growing.


PHOTO: MANZ

Zelltester | *Cell tester*

Zusammenfassung

Markt

2011 konnte die Photovoltaik einen wichtigen Meilenstein erreichen. Sie gilt nun nicht mehr als eine kostspielige Methode der Stromerzeugung. Vor allem durch den beispiellosen Preissturz der PV-Module im Jahr 2011 ist die gesamte Systemtechnik immer preisgünstiger geworden. Dadurch wächst die Nachfrage auch in denjenigen Ländern, die sich kostspielige Förderprogramme nicht leisten können. Die Photovoltaik verliert Schritt für Schritt die Abhängigkeit von direkten oder indirekten Subventionen und kommt der Wirtschaftlichkeit in großen Schritten näher.

Die Schattenseiten dieser grundsätzlich positiven Entwicklung bekommt die PV-Industrie zu spüren. Denn der Preissturz ist nicht nur auf Innovationen zurückzuführen, sondern auch auf Überkapazitäten, die in den vergangenen Jahren in allen Fertigungsstufen aufgebaut wurden. Die Auslastung ist so gering, dass immer mehr Firmen in die Verlustzone geraten. Die Branche befindet sich in einem Konsolidierungsprozess, den viele Hersteller nicht überleben werden.

PV-Komponenten sind zu Massenprodukten geworden, und einige der großen Hersteller setzen den Kapazitätsausbau unbeirrt fort in der Überzeugung, dass nur Größe allein das Überleben sichert. Das gilt für die vier größten Polysilizium-Produzenten ebenso wie für sechs der zehn größten Zellenhersteller. Deshalb werden die Überkapazitäten noch eine Weile fortdauern, auch wenn kleinere Hersteller vom Markt verschwinden, und die Preise für PV-Systeme werden weiter fallen.

Der Marktanteil der Dünnschicht-Technologie ist deutlich geringer geworden und ein Ende dieser Entwicklung ist noch nicht in Sicht, weil die Dominanz der Silizium-Technologie aufgrund des Preisverfalls noch zunimmt. Die Hersteller von Dünnschichtmodulen versuchen, den Durchsatz der Fertigung zu verbessern und die Produktionskosten zu senken, um den Nachteil des geringen Wirkungsgrades zu kompensieren.

Die Berechenbarkeit der Marktentwicklung ist begrenzt, weil die politischen Rahmenbedingungen sehr unterschiedlich sind und sich außerdem schnell ändern können, wie das Beispiel Deutschland zeigt. Die drastische Kürzung der deutschen Einspeisevergütung im Frühjahr 2012 deutet auf ein baldiges Ende der bisher besonders günstigen Rahmenbedingungen hin. Mit einer ähnlichen Entwicklung ist in Italien zu rechnen. Beide Länder haben im Jahr 2011 den PV-Markt dominiert.

Die starke Abhängigkeit der weltweiten Marktentwicklung von nur zwei nationalen Märkten wird sich dann abschwächen, wenn in anderen Ländern die Nachfrage wächst. Wenn aufgrund des anhaltenden Preisverfalls auch in China, Indien und den USA ein nachhaltiges Wachstum entsteht, könnte die Photovoltaik ihren erstaunlichen Erfolg fortsetzen.

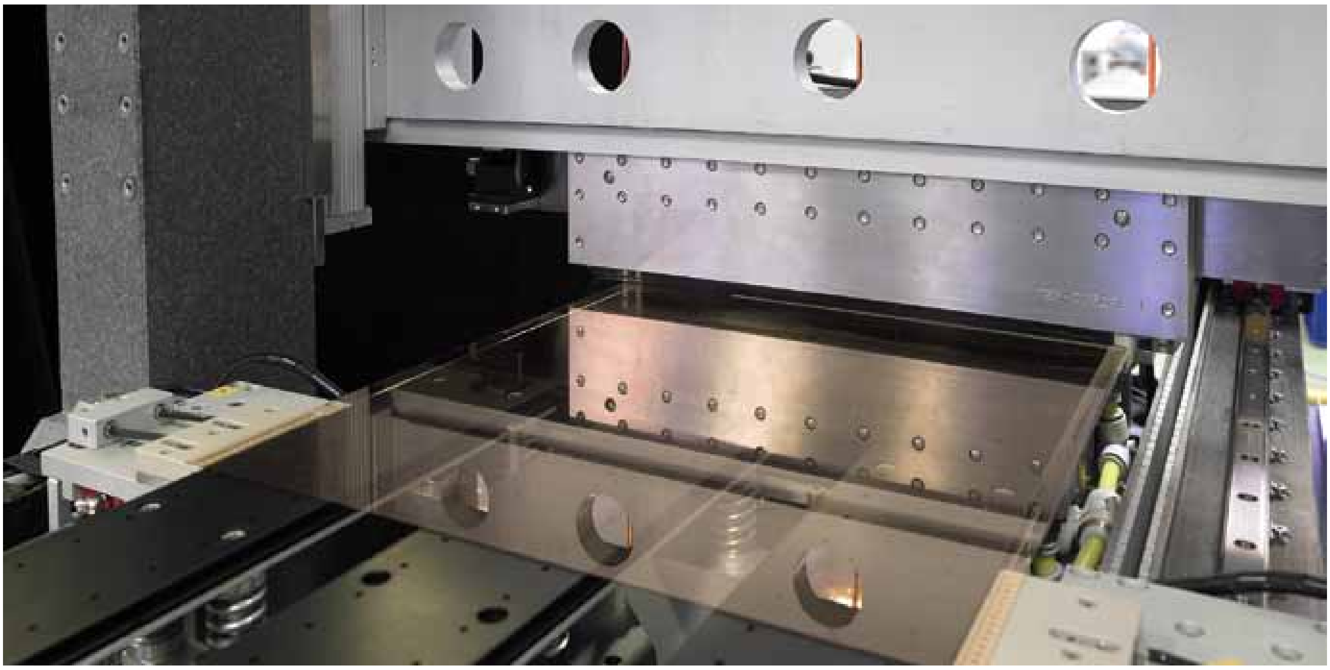


PHOTO: MANZ

Sogenannte Slit Coater ermöglichen die Herstellung großflächiger Paneele. | *Slit coaters facilitate the production of large-area modules.*

Technologie

Um sich im verschärften Wettbewerb zu profilieren, verstärken immer mehr Hersteller die Entwicklung leistungsfähiger Solarzellen. Der Wirkungsgrad mono- und multikristalliner Silizium-Solarzellen lässt sich steigern, indem die Kontaktierung der Vorderseite auf die Rückseite verlegt wird, sodass mehr aktive Fläche für die Absorption des Sonnenlichtes zur Verfügung steht. Dafür gibt es unterschiedliche technische Konzepte. Die besten Rückkontaktzellen (Back contact cells) erreichen inzwischen einen Wirkungsgrad von über 24 % (also rund sechs Prozentpunkte mehr als die Standardzelle), doch sie benötigen Silizium höchster Reinheit und setzen eine aufwendigere – und damit teurere – Fertigungstechnik voraus.

Der Wirkungsgrad kann ebenfalls gesteigert werden, indem die Rekombination der Ladungsträger vermindert und dadurch die Ausbeute erhöht wird. Dies geschieht zum Beispiel durch die Passivierung der Zellenrückseite. Einen grundsätzlich anderen Ansatz verkörpert die n-Typ-Zelle. Das Basismaterial des Siliziumwafers ist nicht wie üblich p-dotiert, sondern n-dotiert und weist dadurch deutlich geringere Einfangquerschnitte auf – das bedeutet, dass die Rekombination der Ladungsträger geringer und die Ausbeute höher ist.

Die Wirkungsgrade der Dünnschichtmodule sind deutlich geringer, sie reichen von knapp 10 % (mikromorphes Silizium) bis 12 % (Kupferindiumdiselenid). Im Labor wurden schon 20 % erreicht, doch es wird noch dauern, bis Dünnschichtmodule mit so hohem Wirkungsgrad lieferbar sind. Cadmiumtelluridmodule (CdTe-Module) mit 11 % Wirkungsgrad sind mit relativ geringem Fertigungsaufwand realisierbar, sodass die Kilowattstunde Strom sehr günstig produziert werden kann. Dieser Wettbewerbsvorteil der CdTe-Technologie ist aufgrund der Aufholjagd der kristallinen Silizium-Technologie allerdings im vergangenen Jahr zusammengeschmolzen.

Die PV-Technologie der nächsten Generation hat das kommerzielle Stadium noch nicht erreicht. Sowohl die organischen Solarzellen als auch die Farbstoffzellen eignen sich aufgrund ihres geringen Wirkungsgrades und der noch viel zu kurzen Lebensdauer bisher nicht für die Serienproduktion.

PHOTO: REIS ROBOTICS

Schon während der Produktion wird die Belastbarkeit von Modulen kontrolliert.

The load capacity of modules is tested during production.

PHOTO: GP SOLAR

Belastungstest Dünnschichtmodule

Thin-film module load testing

Produktion

Die Photovoltaik kann nur dann weiter wachsen, wenn die Kosten der Stromerzeugung aus Solarenergie von Jahr zu Jahr deutlich sinken. Kostensenkung ist also das vorrangige Ziel der Produktionstechnik.

Zahlreiche Prozessschritte und unterschiedliche Fertigungsverfahren sind erforderlich, um aus kristallinem Silizium zunächst Zellen und anschließend Module herzustellen. Deshalb ist es erforderlich, jeden einzelnen Schritt zu optimieren.

Um angesichts dieser anspruchsvollen Aufgabe die einzelnen Hersteller zu entlasten, hat die PV-Industrie eine gemeinsame Roadmap entwickelt, sodass Entwicklungskosten für neue Prozesse und neue Maschinen geteilt werden können. Das Ziel ist die Fortsetzung der evolutionären Technologieentwicklung, die für die bisher erreichten Erfolge der kristallinen Silizium-Technologie typisch ist.

Die Einsparung von Material, die Steigerung des Durchsatzes und die Erhöhung des Wirkungsgrades sind die drei wichtigsten Ziele der Roadmap, die eine jährliche Kostensenkung um 9 bis 10 % bis 2020 anstrebt.

Die Einsparung von Silizium steht an erster Stelle. Das bedeutet, dass die Wafer, aus denen die Zellen gefertigt werden, immer dünner werden müssen. Die folgenden Fertigungsschritte müssen trotz hoher Geschwindigkeit sehr behutsam ablaufen, damit die dünnen Scheiben nicht brechen. Dies stellt erhöhte Anforderungen an die Fertigungstechnik.

Die Steigerung des Durchsatzes ist möglich durch die Verwendung größerer Ingots, aus denen die Wafer geschnitten werden. Auch die Produktivität und die Standzeit der Werkzeuge können noch verbessert werden. Ein deutlicher Anstieg des Durchsatzes ist um 2015 zu erwarten, wenn neue Verschaltungstechnologien sowie die Back contact cells in die Massenproduktion eingeführt werden.

Die Fertigung von Dünnschichtmodulen geschieht im Durchlaufverfahren, in dem physikalische Abscheidetechniken dominieren. Die Linientaktzeiten liegen daher im Minutenbereich.

Die Weiterentwicklung der Produktionstechnik konzentriert sich zurzeit darauf, die Prozessgeschwindigkeit zu steigern und die Anlagenverfügbarkeit zu verbessern. Auch die Steigerung des Wirkungsgrades (vor allem durch Minimierung der optischen Verluste und verbesserte Nutzung des Sonnenspektrums) sind wichtige Schritte, um die Kosten der mit Dünnschichtmodulen erzeugten Kilowattstunde zu senken.

Zwei Vakuumverfahren, die Chemical Vapour Deposition (CVD) und die Physical Vapour Deposition (PVD), sind für die Fertigung von PV-Modulen von großer Bedeutung. Als Universalwerkzeug der Produktionstechnik hat sich der Laser etabliert. Er bohrt Verbindungskanäle durch die Zelle, um Vorder- und Rückseite zu verbinden und dadurch eine Back contact cell zu realisieren, erzeugt lokale Dotierungen und trägt Isolatorschichten von der Oberfläche ab. Auch für die Entwicklung neuer Zellkonzepte ist der Laser unverzichtbar.

PHOTO: TOM BAERWALD / SGS SOLARTEST HOUSE

Lichtungstest: Justierung des Pyranometers | *Exposure test: aligning the pyranometer*

Qualitätssicherung

PV-Module sollen mindestens 20 Jahre lang zuverlässig Strom liefern. Deshalb ist die Qualitätssicherung von großer Bedeutung. Im Vordergrund stehen Leistungsmessungen und Langzeitprüfungen. Mehrere Testmethoden werden kombiniert, um die Qualität möglichst vollständig beurteilen zu können.

Labormessungen, die eine Momentaufnahme der Leistungsfähigkeit eines Moduls liefern, werden durch Langzeitprüfungen unter extremen Bedingungen in Klimakammern ergänzt. Diese simulieren die Alterung der Module wie im Zeitraffer. Eine Umrechnung der Verweilzeit in einer Klimakammer in die tatsächliche Lebensdauer eines Moduls ist jedoch nicht möglich. Deshalb sind Freilandversuche erforderlich, um Aufschluss über die Lebensdauer unter realen Bedingungen zu erhalten. Die Ergebnisse dieser drei Testmethoden erlauben Aussagen über das langfristige reale Betriebsverhalten.

Um die Kosten im Rahmen zu halten, werden jeweils nur wenige Module eines Typs getestet. Die Aussagekraft dieser Stichproben ist begrenzt, zumal in der Regel die Hersteller selbst die Module an die Testinstitute liefern. Deshalb sind einige Institute dazu übergegangen, die Module auf dem freien Markt zu erwerben.

Wenn Großanlagen installiert werden, die aus Tausenden von Modulen bestehen, ist es sinnvoll, aus den laufenden Anlieferungen Stichproben zu ziehen. Noch einen Schritt weiter geht die produktionsbegleitende Prüfung, die es den Testinstituten erlaubt, aus der laufenden Fertigung einzelne Module zu entnehmen.

Ökologie

Der Erfolg der Photovoltaik ist in hohem Maße von ihrem umweltfreundlichen Image abhängig. Daraus ergeben sich erhöhte Ansprüche an die Produktion der PV-Module. Einsparung von Material und Energie, Vermeidung von Abfällen und sorgfältiges Recycling sind die wichtigsten Maßnahmen, um eine nachhaltige Produktion sicherzustellen.

Die Energieversorgung der Produktion kann durch das Produkt selbst verbessert werden, indem PV-Module an den Dächern und Fassaden der Solarfabriken installiert werden. Die Nutzung von Abwärme sowie der Einsatz von Kraft-Wärme-Kopplung sind selbstverständlich geworden, um die eingesetzte Energie so effektiv wie möglich zu nutzen. Außerdem wird der Wasserverbrauch auf ein Minimum reduziert, ebenso wie die für die Produktion erforderlichen Hilfsstoffe. Falls deren Eigenschaften den Ansprüchen an eine nachhaltige Produktion nicht genügen, werden sie nach und nach durch umweltverträgliche Hilfsstoffe ersetzt.

Schon frühzeitig hat die PV-Industrie geschlossene Kreisläufe entwickelt, um ihre Produkte so weit wie möglich wiederverwerten zu können. Besonderes Augenmerk gilt den Schwermetallen. Die Recycling-Quote der Cadmiumtellurid-Dünnschichtmodule erreicht fast 95 %.

PHOTO: TOM BAERWALD / SOLARPRAXIS

Photovoltaik kann Energiegewinnung und Umweltschutz miteinander versöhnen

Photovoltaics reconciles energy production with environmental protection.

Companies

Overview

Companies presented
at a glance
(in order of appearance)

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Business Areas

Page	Companies (in alphabetical order)	Silicon production				Glass production					Wafer production				Cell production														Module production					Thin-film technology				
		Polysilicon production	Crystal growing	Crystal growth furnaces	Other equipment	Solar glass production concepts	Glass handling	Glass melting furnace	Coating facilities	Other equipment	PV grinding/polishing machinery	PV sawing machines	Wet chemistry equipment	Other equipment	Cleaning	Diffusion	Passivation	Metallization	Other process technologies	Furnaces	PECVD equipment	Sputtering equipment	Screen printing equipment	Wet chemistry equipment	Other process equipment	Gases and dopants	Metallization pastes	Other process materials	Design and concept	Stringers/tabbers/laminators	Other equipment	Test equipment	(Process) materials	Deposition equipment	Evaporation equipment	Sputtering equipment	PECVD equipment	Gases and dopants
102	3S Modultec and 3S Photovoltaics																												●	●	●							
72	ACI ecoTec GmbH													●															●	●	●							
98	AIS Automation Dresden GmbH																																					
73	APPLIED MATERIALS											●						●	●				●															
74	baumann Automation															●																						
75	Beckhoff Automation GmbH																																					
76	Bürkle Process Technologies						●		●																					●	●							
77	Carl Zeiss Microscopy GmbH																																					
78	centrotherm photovoltaics AG	●		●	●						●	●				●	●	●	●	●	●	●		●	●		●	●	●	●	●	●		●	●	●	●	
80	Dow Corning Corporation																									●							●					●
81	GPP Vision				●					●				●									●									●						
82	Grenzebach						●			●																			●		●	●						
83	Heraeus Precious Metals																	●									●											
84	HÜTTINGER Elektronik				●																													●	●	●	●	
85	INFICON																																					
86	Komax Solar																													●	●	●						
87	Konica Minolta Sensing Europe B.V.																																					
88	KREMPEL-GROUP																																					
89	KUKA Systems						●																						●		●	●						
90	Kurt J. Lesker Company®																			●	●	●											●	●	●	●	●	

	Storage technology				Vacuum technology				Automation and automation solutions					Laser technology				Environmental technology			Metrology				Testing and analysis systems				Further production materials							Facilities											
	Lead-acid batteries	Lead-gel batteries	Lithium-ion batteries	Control technology	Vacuum components	Vacuum pumps	Turbomolecular pumps	Vacuum measurement	Mechanical handling	Non-contact handling systems	Transport systems	Process control for cell/module production	Software solutions	Lasers	Laser equipment	Laser scribing	Optical components	Waste gas treatment technology	Water management	Recycling equipment	Metrology systems	Precision measuring systems	Temperature measurement and analysis	Other measuring techniques	Test equipment	Test methods	Mass spectrometers	Other systems	Cell and string connectors	Backsheets	Sealants, adhesives and pottants	Encapsulants	Electrical insulators	Sputtering targets	Other materials	Turnkey projects	FAB design	FAB construction	FAB operation	Facility management	Operation and maintenance	Suppliers (piping systems)	**Consulting and project management**	**IT services and products**	**PV plants and system components**	**Logistics**	**Association**
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Business Areas

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		Polysilicon production	Crystal growing	Crystal growth furnaces	Other equipment	Solar glass production concepts	Glass handling	Glass melting furnace	Coating facilities	Other equipment	PV grinding/polishing machinery	PV sawing machines	Wet chemistry equipment	Other equipment
91	Lohmann GmbH & Co. KG													
92	Luvata													
94	Madico, Inc.													
95	Manz AG													
96	Meyer Burger Technology AG										●	●		●
104	MIKRON													
106	MONDRAGON ASSEMBLY													
105	Rehm Thermal Systems GmbH													
108	REIS ROBOTICS						●							
99	Roth & Rau AG													
109	SCHMID Group | Gebr. SCHMID GmbH	●	●	●	●		●		●	●	●	●	●	●
110	Schunk Group				●									●
118	SEMI PV Group													
112	SENTECH Instruments GmbH			●										
113	Siemens Industry Sector					●								
100	Somont													
114	Spire Corporation													
115	TRUMPF Business Field Laser Technology													
116	VAT		●						●					●
119	VDMA Photovoltaic Equipment													

Page	Companies (in alphabetical order)	Cell production													
		Cleaning	Diffusion	Passivation	Metallization	Other process technologies	Furnaces	PECVD equipment	Sputtering equipment	Screen printing equipment	Wet chemistry equipment	Other process equipment	Gases and dopants	Metallization pastes	Other process materials
91	Lohmann GmbH & Co. KG														
92	Luvata														
94	Madico, Inc.														
95	Manz AG	●		●	●			●		●	●	●			
96	Meyer Burger Technology AG	●	●	●	●	●	●	●	●	●					
104	MIKRON														
106	MONDRAGON ASSEMBLY														
105	Rehm Thermal Systems GmbH				●		●								
108	REIS ROBOTICS														
99	Roth & Rau AG		●	●		●	●	●							
109	SCHMID Group | Gebr. SCHMID GmbH	●	●	●	●	●	●	●	●		●	●			
110	Schunk Group							●							
118	SEMI PV Group														
112	SENTECH Instruments GmbH			●											
113	Siemens Industry Sector					●									
100	Somont														
114	Spire Corporation														
115	TRUMPF Business Field Laser Technology														
116	VAT							●	●						
119	VDMA Photovoltaic Equipment														

Page	Companies (in alphabetical order)	Module production					Thin-film technology				
		Design and concept	Stringers/tabbers/laminators	Other equipment	Test equipment	(Process) materials	Deposition equipment	Evaporation equipment	Sputtering equipment	PECVD equipment	Gases and dopants
91	Lohmann GmbH & Co. KG					●					
92	Luvata										
94	Madico, Inc.										
95	Manz AG							●	●		
96	Meyer Burger Technology AG	●	●	●	●						
104	MIKRON	●	●	●							
106	MONDRAGON ASSEMBLY	●	●	●		●					
105	Rehm Thermal Systems GmbH										
108	REIS ROBOTICS	●		●							
99	Roth & Rau AG										
109	SCHMID Group | Gebr. SCHMID GmbH	●	●	●	●	●	●	●	●	●	
110	Schunk Group						●		●	●	
118	SEMI PV Group										
112	SENTECH Instruments GmbH						●			●	
113	Siemens Industry Sector										
100	Somont		●		●						
114	Spire Corporation	●	●	●	●	●					
115	TRUMPF Business Field Laser Technology										
116	VAT						●	●	●	●	
119	VDMA Photovoltaic Equipment										

	Storage technology				Vacuum technology				Automation and automation solutions					Laser technology				Environmental technology			Metrology				Testing and analysis systems				Further production materials							Facilities							Consulting and project management	IT services and products	PV plants and system components	Logistics	Association
	Lead-acid batteries	Lead-gel batteries	Lithium-ion batteries	Control technology	Vacuum components	Vacuum pumps	Turbomolecular pumps	Vacuum measurement	Mechanical handling	Non-contact handling systems	Transport systems	Process control for cell/module production	Software solutions	Lasers	Laser equipment	Laser scribing	Optical components	Waste gas treatment technology	Water management	Recycling equipment	Metrology systems	Precision measuring systems	Temperature measurement and analysis	Other measuring techniques	Test equipment	Test methods	Mass spectrometers	Other systems	Cell and string connectors	Backsheets	Sealants, adhesives and pottants	Encapsulants	Electrical insulators	Sputtering targets	Other materials	Turnkey projects	FAB design	FAB construction	FAB operation	Facility management	Operation and maintenance	Suppliers (piping systems)					
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State-of-the-art dispensing technology for different applications; here: backrail assembly

ecoSplit-C Lite – the world's smallest automatic wafer separator

New Duo-Carrier for wet-chemical batch processing of solar cells

ACI ecoTec GmbH

ACI ecoTec GmbH
Albring 18
78658 Zimmern ob Rottweil
Germany

Phone
+49 (0)741 175 115-0

Fax
+49 (0)741 175 115-170

Email
info@aci-ecotec.com

Web
www.aci-ecotec.com

Year founded
2004

Sales volume
15 million euros

Employees
80

Innovative process and automation technology for wafer, cell and PV module production

State-of-the-art quality, precision and reliability are the hallmarks of the machines and systems built by ACI ecoTec GmbH. As an honored member of the "TOP 100 Innovation" for small to medium enterprises, ACI ecoTec specializes in process and automation engineering where we develop and manufacture machines and customized production lines involving precision robotics, turnkey systems for assembly, microassembly, measurement and testing for the automotive industry. We secured our debut in the photovoltaic industry with up to 20 patented processes for wafer-to-cell production and module technology for crystalline and thin-film.

Thanks to quick commissioning, high up-times and our easy-to-integrate modular design, these systems have achieved an excellent reputation throughout the world, as can be seen from the high export share of over 75%. Our machines and systems are supplied to all key markets in the photovoltaic industry on a global scale.

Our main products currently are in wafer/cell separation and handling for wet-chemical batch and inline processes through to complete back-end assembly lines for thin-film technology.

ACI ecoTec has extensive existing execution capabilities and a solid market reputation combined with the unique ability to rapidly roll out state-of-the-art technology beyond manufacturing, offered across a wide range of PV technologies in a number of key markets.

With a management team strong in both science and business, we offer leading-edge technology and project management capability to enable access to clean, boundless solar energy.

Applied HCT™ Wafering Systems

Applied Solion® Ion Implanter

Applied Baccini® Cell Systems

APPLIED MATERIALS

POWERING THE c-Si ROADMAP

Applied Materials is the world's #1 provider of solar PV manufacturing equipment offering a holistic solutions approach focused on state-of-the-art equipment, qualified consumables, process know-how and advanced automation.

As PV manufacturers push for aggressive cost reduction, the need of the hour is higher yield, higher efficiency, thinner wafers and advanced automation. Delivering equipment solutions that advance all these four critical elements in parallel requires competency across the entire PV manufacturing value chain. It also warrants that PV equipment manufacturers understand process-tool interaction and offer complete, multi-dimensional solutions that include qualified consumables and process consulting. This enables PV manufacturers to get the most out of their investments, reduce risk, lower costs and get to market faster in an increasingly competitive market place.

Applied Materials offers solutions that cover almost all the key steps in c-Si PV manufacturing, from wafering to cell manufacturing. We are process experts in the solar industry today, thanks to 40 years of technology and market leadership in the semiconductor and flat panel display industries. And we are continually working with leading edge suppliers from around the world to develop consumables that are designed to fit our customers' needs, optimized to deliver best results and fully qualified on our equipment. Our expertise and experience in commercializing technology, global reach and R&D infrastructure make us truly distinct in being able to deliver both scale and technology differentiation.

The ever increasing need for cleaner, more sustainable forms of energy is fuelling the expansion of the solar industry. As solar PV strives to become competitive with the more traditional forms of energy, it is critical to drive down costs per watt. Applied Materials is uniquely positioned to meet this goal by delivering technological advancements to increase cell efficiency and manufacturing scale to boost factory productivity.

APPLIED MATERIALS®

APPLIED MATERIALS
3050 Bowers Ave.
PO BOX 58039
Santa Clara 95052
USA

Phone
+1 408 727-5555

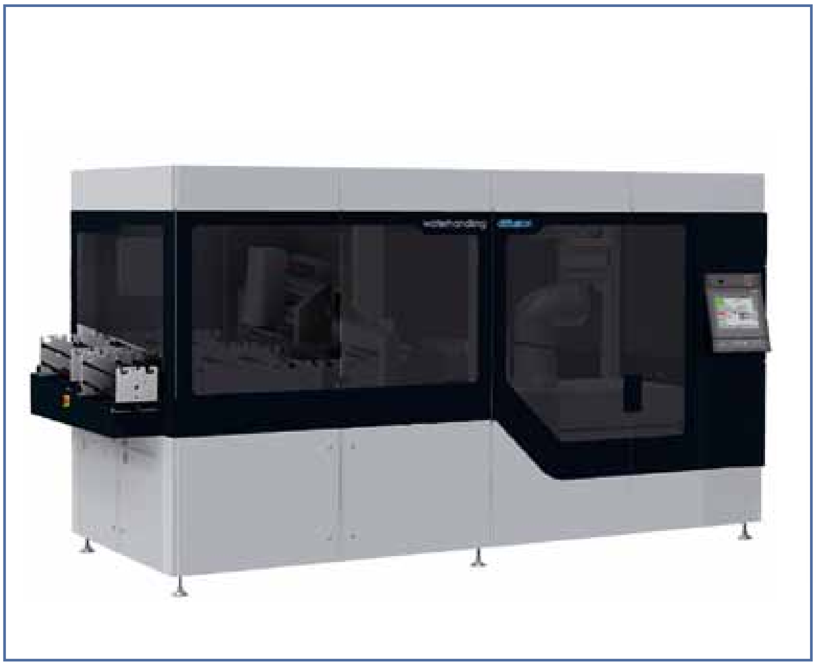
Email
solar_marketing@amat.com

Web
www.appliedmaterials.com/solar

Year founded
1967

Employees
Approx. 14,600 (worldwide)

Xi'an Global Solar Technology Center



Waferhandling Diffusion

baumann vacuum gripper

baumann Automation

We Can Handle It!

AUTOMATION
baumann

baumann GmbH
Oskar-von-Miller-Straße 7
92224 Amberg
Germany

Phone
+49 (0)9621 6754-0

Fax
+49 (0)9621 6754-922

Email
info@baumann-automation.com

Web
www.baumann-automation.com

Year founded
1984

Employees
> 320

1 Waferhandling Plasma
2 Waferhandling Wetbench
3 Waferhandling Quality

Automation solutions for solar cell manufacturing

For over 25 years, baumann has developed and produced turnkey automation systems for customers in various industries, such as international automotive suppliers, electronics, domestic appliances, telecommunications, medical technology, photovoltaic and solar technologies. Everything one-stop – from the single robot cell up to the completely automated production line.

Automation, rationalization and quality improvement are the most important criteria used by baumann to develop flexible system solutions. Our focus is to offer innovative solutions that point the way ahead for the tasks of our customers.

Solar cell manufacturing is comprised of numerous sophisticated processes, making complex demands on systems technology. baumann is a reliable and competent partner in the photovoltaic market, producing reliable and high-quality turnkey automation solutions.

In the field of solar cell manufacturing, baumann focuses on plants for loading/unloading processing machines and quality control.

Our products:

- Waferhandling Diffusion Inline/Offline
- Waferhandling Plasma Inline/Offline
- Waferhandling Wetbench
- Waferhandling Quality
- Waferhandling Laser

All baumann Waferhandling systems employ a specially developed technology, which ensures high handling reliability with minimum wafer breakage. All are designed using standard components, leveraging their inherent reliability, while ensuring flexibility and short delivery times.

baumann applies the proven processes and extensive knowledge of its experienced engineering department to the unique challenges of processing solar cells. The result: efficient technology for world-class photovoltaic production solutions.

1

2

3

Robotics, motion control, PLC on one PC platform

Universal PC- and EtherCAT-based control solution

Beckhoff Automation GmbH

PC-based control for photovoltaic production

With an extensive portfolio of robust and powerful industrial PCs, fieldbus components, drive technology and TwinCAT automation software, as well as the high-speed EtherCAT communication system and XFC, the high-speed machine control system, Beckhoff offers a scalable, modular control concept that provides an ideal solution for every task in the creation of photovoltaic products: wafer cutting technology and inspection, saw damage etching, texture etching, diffusion, phosphor glass etching, anti-reflective coating, metallization, classification, transport and storage systems, as well as stringer and lamination lines.

The basis for process communication is the Ethernet-based fieldbus system, EtherCAT, which is ideally suited for use in photovoltaic plants due to its flexible topology. Direct communication between the controller and the I/O signals – without special hardware – offers machine manufacturers, for example, the possibility of realizing high-precision motion control with many axes, synchronized by means of EtherCAT distributed clocks. This leads to better control quality and faster machine processes.

Robotics as an integral component of the controller

By extending TwinCAT automation software with the “TwinCAT Kinematic Transformation” library, robots can now also be integrated seamlessly into the PC Control system, which means that PLC, motion control, HMI and robotics run on just one industrial PC. TwinCAT supports various parallel and serial kinematics, such as those used for pick-and-place tasks. Application examples in photovoltaic production are loading and unloading in automatic production lines for solar cells. The integration of robotics into the PC Control concept provides the user with a series of advantages. Not only are costs and engineering efforts reduced, but friction losses caused by the interaction of various CPUs are eliminated, as a result of which the performance and accuracy of the machine are increased.

BECKHOFF

Beckhoff Automation GmbH
Eiserstraße 5
33415 Verl
Germany

Phone
+49 (0)5246 963-0

Fax
+49 (0)5246 963-198

Email
info@beckhoff.com

Web
www.beckhoff.com

Year founded
1980

Sales volume
465 million euros (2011)

Employees
2,100 (worldwide)

Intensive trials in the Bürkle Innovation Center in Freudenstadt, Germany

Bürkle Process Technologies

A Global Leader in Innovation

BÜRKLE
PROCESS TECHNOLOGIES

Robert Bürkle GmbH
Stuttgarter Straße 123
72250 Freudenstadt
Germany

Phone
+49 (0)7441 580

Fax
+49 (0)7441 7813

Email
pv@buerkle-gmbh.de

Web
www.buerkle-gmbh.de

Year founded
1920

Employees
720

System solutions for the PV industry

Effective, efficient and reliable lamination and coating technologies as well as back ends for thin-film modules and standard modules with crystalline cells – all this is offered by Bürkle from one source. As one of the technology leaders in the photovoltaic industry, Bürkle has quickly gained an excellent reputation and in only five years has supplied more than 200 single- and multi-opening lamination lines, coating lines and complete back ends to customers in America, Europe and Asia.

The Ypsator – the first high-performance multi-opening lamination line for the manufacture of solar modules – proved that Bürkle meets the demands of the market through innovative system solutions. To continue being a driving force in the market in innovative technology matters, Bürkle has intensified development activities from the very first day at its innovation center in Freudenstadt, Germany, constantly improving the process for the manufacture and lamination of solar modules.

These efforts have resulted in the revolutionary SL lamination technology, which is used for the production of crystalline solar modules and is characterized by:

- 100% capacity increase
- lowest cost of ownership (TCO)
- 50% space requirements
- 50% process time reduction

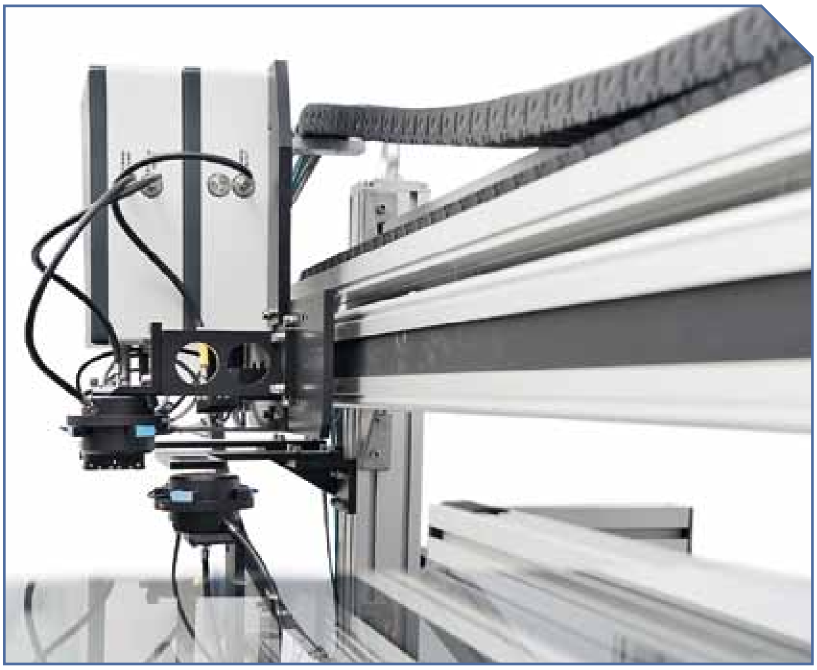
Leading solar glass suppliers around the world rely on Bürkle's process experience and high-quality roller coating machines for applying anti-light reflective (AR) coating materials to glass used as front glass in solar modules. AR coating reduces the reflection of the incoming light and increases light transmission through the glass. Since more light will come into contact with the solar cells, this additional energy improves the overall efficiency of the solar modules.

Thanks to different manufacturing locations in Germany and China and a tight service and sales network, Bürkle can act as a competent partner – directly and worldwide. Since the beginning of 2011, Bürkle has supported its customers around the clock with the 24/7 e.a.sy-Service.

Bürkle's innovative technologies are bringing us closer to the target of "grid parity".

System for process control of coatings

OPTOPLEX P for in-line measurements



OPTOPLEX NG Q for at-line measurements

Carl Zeiss Microscopy GmbH — *Optical Sensor Systems*
Solutions for the Glass and Solar Industries

In-line and at-line measuring systems for quality and process control

Founded as a workshop for precision mechanics and optics in the German city of Jena in 1846, Carl Zeiss is today a global leader in the optical and opto-electronic industries. There are currently approx. 24,000 employees in the Group. We have offices in over 30 countries and are represented in more than 100 countries.

Carl Zeiss Microscopy GmbH is a 100% subsidiary of Carl Zeiss AG. The Optical Sensor Systems business unit is part of this and offers solutions for a wide variety of applications in the solar industry.

Precise and fast in-line and at-line measurements are required in order to control the complex process stages involved in glass and solar cell production. Our systems are designed for quality and process control for coating processes in the solar and glass industries.

Carl Zeiss Optical Sensor Systems offers complete instrument systems which allow the non-contact and non-destructive measurements of spectral transmittance/reflectance and the determination of color values, layer thickness, haze and sheet resistance. High quality and safety are also guaranteed under extreme ambient conditions or in vacuum. The measured results are provided immediately and are available for process optimization and archiving.

The ZEISS spectrometers from the proven line of MCS 600 or CORONA PLUS systems combine modern UV-VIS-NIR diode array technology with precise optical design and fast, high-resolution electronics. Speed, robustness and reliability number among their outstanding features. The diode array spectrometers offer high measuring accuracy, very good wavelength stability and excellent reproducibility of the measured results. Their modular design also permits the systems to be expanded with further measuring points. Via standard interfaces and appropriate protocols, the software allows communication with other systems and databases or integration into existing solutions.

We offer solutions for e.g.

- in-line measurement of glass coatings
- in-line process control of coatings
- quality control of coated glass
- at-line measurement and mapping of coated glass

We make it visible.

Carl Zeiss Microscopy GmbH
Optical Sensor Systems
Carl-Zeiss-Promenade 10
07745 Jena
Germany

Phone
+49 (0)3641 64 2838

Fax
+49 (0)3641 64 2485

Email
info.spektralsensorik@zeiss.de

Web
www.inline-metrology.com
www.zeiss.de/spektral

The SIC closes the gap between R&D and mass production.

centrotherm photovoltaics AG

Comprehensive Expertise at All Stages of PV Production

centrotherm Solar Innovation Center (SIC) in Constance

centrotherm photovoltaics

centrotherm photovoltaics AG
Johannes-Schmid-Straße 8
89143 Blaubeuren
Germany

Phone
+49 (0)7344 918-0

Fax
+49 (0)7344 918-8388

Email
info@centrotherm.de

Web
www.centrotherm.de

Year founded
1976

Sales volume
Approx. 700 million euros (2011)

Employees
1,747 (Q1 2012)

Technology, equipment and integrated solutions along the entire PV value chain

With its innovative strength and numerous groundbreaking technology developments and implementations, centrotherm photovoltaics has set standards in the PV industry for more than 30 years. Its product and service portfolio covers technology and manufacturing solutions for metallurgical grade silicon and polysilicon as well as for ingots and wafers. Further, centrotherm offers technology, key equipment and turnkey lines for the production of crystalline solar cells and modules. In the field of CIGS thin-film modules, centrotherm supplies technology and key equipment, such as vacuum plasma coating systems and selenization systems for deposition and thermal conversion to CIGS. In addition centrotherm provides manufacturing solutions to the semiconductor and microelectronics industry.
The group is headquartered in Blaubeuren (Germany) and has further German sites in Constance, Dresden, Burghausen and Abensberg as well as international service and sales subsidiaries in Asia, Europe, and the USA. centrotherm photovoltaics AG is listed in the Prime Standard at the Frankfurt Securities Exchange and achieved a revenue of around 700 million euros in the 2011 financial year.

Silicon & wafer
Within the group, centrotherm SiTec operates in the silicon & wafer segment, providing technology, key process equipment, engineering and services for the manufacture of solar grade and higher-purity electronic grade polysilicon.
For the manufacture of polysilicon, the portfolio covers CVD reactors, STC-TCS converters, vent gas recovery (VGR) systems and lab CVD reactors for quality assurance, training and R&D. centrotherm also supplies process systems, quality management and all engineering services for the production and optimization of advanced mg-Si material. Engineering and project management services for the planning and realization of integrated ingot and wafer production lines complete the portfolio.
Our subsidiary, GP Solar, is one of the leading providers of inline inspection systems and laboratory characterization tools for the production

centrotherm SiTec

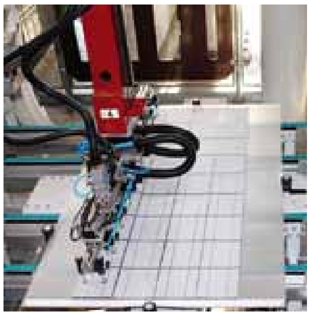
centrotherm SiTec GmbH
Johannes-Schmid-Straße 8 | 89143 Blaubeuren | Germany
Email info@sitec.centrotherm.de
Web www.sitec.centrotherm.de

centrotherm cell & module

centrotherm cell & module GmbH
Johannes-Schmid-Straße 8 | 89143 Blaubeuren | Germany
Email info@centrotherm.de
Web www.centrotherm.de

c.FIRE for the metallization of front and rear contacts of solar cells

1



2

of wafers, cells and modules. The systems are designed for precise monitoring and ensure reliable quality control.

Solar cell & module

The core business of centrotherm's cell & module segment covers technology, key equipment and turnkey solutions for the manufacture of crystalline solar cells and modules, including engineering, process technology and after sales service. The development and continuous optimization of production equipment, such as diffusion and fast firing furnaces as well as PECVD and laser process systems, is one of the company's strengths. For module certification, centrotherm supports its customers during the whole process phase – from the selection of appropriate raw materials through to the certified solar module rolling off the production line.
As development of the company's own high-efficiency solar cell technologies enjoys particular priority, production concepts and line setups are reconciled with R&D activities in such way that scientific progress can easily be transferred into mass production. Technology upgrades can be integrated via equipment bundles that are installed into existing production lines. This concept enables our customers to meet increasing market and capacity demands and to deploy state-of-the-art production technology over the long-term.
Besides inspection systems, the subsidiary GP Solar provides process specific materials for texturing and metallization processes. Technological consulting, from planning to tailored optimization of PV projects, rounds off the portfolio of GP Solar.

Thin-film

For CIGS module manufacturing, centrotherm employs its proprietary atmospheric pressure deposition and annealing process as well as the appropriate key equipment for selenization and thermal conversion into the CIGS crystal phase. FHR Anlagenbau offers technology and compatible equipment for magnetron sputtering, thermal evaporation and PECVD, such as roll-to-roll coating systems for the production of flexible solar cells or organic display films. Furthermore, the portfolio covers advanced etching technologies, atomic layer deposition (ALD) and the engineering, manufacturing and bonding of sputter targets. GP Solar completes the portfolio in the thin-film segment with process inspection systems for integrated thin-film lines and stand-alone use.

3

4

1 Deposition of high purity polysilicon in the CVD reactor

2 String layup within a centrotherm turnkey module line

3 Inline inspection system by GP Solar

4 Roll-to-roll coating system by FHR Anlagenbau

.GPsolar
centrotherm photovoltaics group

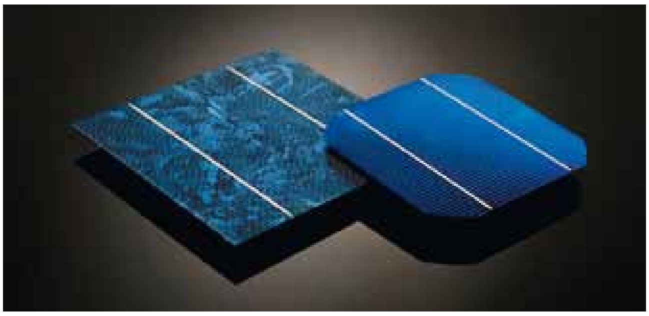
GP Solar GmbH
Reichenaustraße 21 | 78467 Konstanz | Germany

Email info@gpsolar.de
Web www.gpsolar.de

FHR
centrotherm photovoltaics group

FHR Anlagenbau GmbH
Am Hügel 2 |01458 Ottendorf-Okrilla | Germany

Email postbox@fhr.de
Web www.fhr.de



Dow Corning Corporation

Leading the Way in Material Solutions

DOW CORNING

Dow Corning Corporation
Corporate Center
P.O. Box 994
Midland, MI 48686
USA

Phone
+1 989 496-7881

Fax
+1 989 496-6731

Email
solar.solutions@dowcorning.com

Web
www.dowcorning.com/solar

Year founded
1943

Sales volume
6.43 billion USD

Employees
12,000 (worldwide)

Unleash the solar power of silicon

As the photovoltaic industry assumes an increasingly important role in meeting the world's energy needs, Dow Corning Corporation is committed to helping PV producers grow and succeed by unleashing the power of silicon.

Dow Corning Corporation has the capability to provide silicon-based solutions across the PV value chain, including feedstocks and a wide range of other options that improve the performance and durability of finished solar modules.

A growing portfolio of solutions

At Dow Corning, we are continuing to invest to make a difference in solar by expanding our portfolio of total solution packages for cell manufacturing, module assembly and installation. Solution packages include high-performance encapsulants, adhesives, coatings, potting agents and sealants, as well as feedstock options.

Investing in the success of the PV industry

Our long-term commitment to sustainability and to providing solutions to the PV industry is demonstrated by major investments in Solar Solutions Application Centers around the world and by our continuous support, as a majority shareholder, of the expansion of polycrystalline silicon capacities at Hemlock Semiconductor in the USA. Dow Corning has opened Solar Solutions Application Centers in Freeland, Michigan, Newark, California, Jincheon, Korea, and Seneffe, Belgium. These state-of-the-art PV module and solar cell applications centers enable close collaboration with customers and test applications on site.

Dow Corning is leading the way in material solutions.

You can learn more about Dow Corning Solar Solutions and view our Virtual Trade Show at dowcorning.com/solar or email solar.solutions@dowcorning.com

1

2

GPP Vision

Trust Our Eyes — Safeguarding Your Excellent Quality

Errors must be identified to be eliminated – and to boost your profits!

GPP plans, develops, manufactures, installs and supports high-tech inspection systems for the products and production processes of renowned customers and clients.

GPP Vision image processing solutions, and their integration within processes, take on a central role here. Inspection technology is implemented as an automated or semi-automated system solution in production lines. To this end, it is planned as an inline system in plants and machines, or as a stand-alone system.

GPP Vision for quality control

- **SolarCellInspect** – inspection and measurement of solar wafers and cells, electroluminescence testing
- **SolarModuleInspect** – inspection and measurement of solar modules, electroluminescence testing
- **SurfaceInspect** – surface inspection of round and flat surfaces, such as solar glass and thin-film solar modules

GPP also enables the inspection of material properties, e.g. using electroluminescence, for solar cells, solar strings and solar modules. The mobile electroluminescence inspection device is used for checking solar modules during the construction of solar power plants.

GPP Vision for process control

- **RobotVision** – optical measurements for robot control
- **ProcessControl** – process and robot control
- **LaserControl** – triggering laser systems and scanners

For more than twenty years, the company has been a technological system provider for inspection and automation technology. Highly qualified engineers and IT experts develop innovative, top-quality, high-tech solutions for the photovoltaic industry. For many years, we have served many renowned companies around the world.

GPP – implementing inspection technology for tomorrow's projects, today!

GPP

GPP Chemnitz Gesellschaft für Prozeßrechnerprogrammierung mbH
Annaberger Straße 73–77
09111 Chemnitz
Germany

Phone
+49 (0)371 523620

Fax
+49 (0)371 52362390

Email
info@gppc.de

Web
www.gppc.de

Year founded
1990

1 SolarModuleInspect – GPP Vision system for automated panel inspection

2 SolarCellInspect.EL – manual system for electroluminescence testing

Robot with lens plate

Buffer station

Grenzebach

Expert Partnership for Solar Technology

Conveying a thin-film module

GRENZEBACH

Grenzebach Maschinenbau GmbH
Albanusstraße 1
86663 Asbach-Bäumenheim
Germany

Phone
+49 (0)906 982-2000

Fax
+49 (0)906 982-2108

Email
info@grenzebach.com

Web
www.grenzebach.com

Year founded
1960

Employees
1,500

Intelligent solutions for complex tasks

For more than 40 years, Grenzebach has supplied solutions and machinery for manufacturing and processing to the glass industry.

Grenzebach has become the world's largest supplier for automation and process technology for the thin-film industry. Except for coating technology and chemical processing, all equipment units can be supplied by Grenzebach.

At the front end these are: loading, edge processing, transport, metrology, cleaning and laser processing (P1-P3). The typical back end technologies are laser edge removal, electric tests, contacting, foil handling and lamination, installation of outlets, flash testing, Hipot testing, and sorting and packing. All production steps are monitored by Grenzebach optical inspection systems.

Production lines with an annual output of nearly 3 GWp are supported by Grenzebach machinery. Project solutions have been successfully engineered across the spectrum, including for a-Si/µ-Si, CdTe and CI(G)S modules. A simulation program allows for optimization of the line concept from the beginning to the end, including optimized availability to increase production yield.

Grenzebach has opened up a new business market with lines for CPV. Grenzebach was one of the first companies to supply a fully automated module assembly line for this purpose. In addition to module assembly, Grenzebach also offers solutions and machinery for bottom plate assembly and automation for lens plate manufacturing.
Grenzebach supplies semi- and fully automated assembly lines for Fresnel mirrors to the CSP sector, as well as concepts for mirror and bending lines.

A special highlight of the Grenzebach thin-film solar line is the continuous control system concept. This is an intelligent system uniting all necessary functions from the overriding MES to the drive system. Planning of production (resources, maintenance, simulation, recipe management) and analysis of all production data is a significant strength of the Grenzebach MES system.
Back end concepts for c-Si are offered as well.

Grenzebach attaches great importance to close partnerships and cooperation with its customers. Service at Grenzebach means service around the clock and all over the globe. With 1,500 employees in five manufacturing facilities in Germany, the USA and China, as well as its representative offices all over the world, service is always nearby.

Heraeus metallization paste


Heraeus scientist testing cell for performance


R&D scientist performing screen printing

Heraeus Precious Metals
Business Unit Photovoltaics

Innovation and competence in metallization for lower costs per watt

Heraeus manufactures high volumes of thick film pastes for some of the most prominent companies within a variety of industries. For over 40 years, we have built a reputation of innovation, extensive research and new product development. The Heraeus Photovoltaics Business Unit is an industry-leading metallization paste manufacturer for c-Si solar cells. We formulate and supply paste to increase the efficiency, performance and output of solar cells – while reducing the cell's cost per watt. We are addressing the rising cost of silver with new formulations that use less per cell – without sacrificing efficiency. Heraeus develops and provides pastes for conventional and novel cell designs, and for thin-film solar cells.

Heraeus' front-side silver pastes for conventional solar cells provide high efficiencies and wide processing windows, resulting in better yields and higher output. We offer pastes that allow for finer line resolution during screen printing. Our newest products, with a reduced silver content per cell, help customers lower their cost per watt.

Heraeus offers a broad line of pastes for novel cell designs, which can be customized to meet our customers' individual requirements. We introduce several new formulations each year for different cell designs, such as N-type, new passivation layer, selective emitter, metal wrap through (MWT) and high sheet resistance applications. These designs, and combinations of them, all serve the goal of improving cell efficiencies.

For thin-film and other advanced cell designs, Heraeus has developed the SOL500 series, a set of low temperature processing pastes. These pastes can be screen printed and are fast curing at temperatures of 125 to 280°C.

Our low silver backside pastes help reduce costs and show optimized adhesion characteristics. In the second quarter of 2012, we released a new paste with a reduced solid content of about 55% and we continue to lower the silver content while maintaining excellent performance.

Heraeus' staff is the foundation of our success, supporting our customers and our product performance. You can expect a fast response from our competent sales team, on-site manufacturing support from our technical service engineers, and innovative product customization from our R&D scientist. With full-service, staffed facilities in Shanghai, Taiwan, Singapore, Germany and the USA, Heraeus is capable of supplying your needs – whenever and wherever you need us.

Heraeus

Heraeus Precious Metals GmbH & Co. KG – Business Unit Photovoltaics
Heraeusstraße 12–14
63450 Hanau
Germany

Phone
+49 (0)6181 35-3544

Fax
+49 (0)6181 35-3002

Email
pv-info@heraeus.com

Web
www.pvsilverpaste.com

Year founded
1851

Employees
13,300

Process power for stable film deposition processes in solar cell production

HÜTTINGER power supplies enable highly-efficient solar cells.

HÜTTINGER Elektronik

Power for Stable Processes in Solar Cell Production

TRUMPF

HÜTTINGER Elektronik
generating confidence

HÜTTINGER Elektronik GmbH + Co.KG
Bötzinger Straße 80
79111 Freiburg
Germany

Phone
+49 (0)761 8971-0

Fax
+49 (0)761 8971-1150

Email
info@de.huettinger.com

Web
www.huettinger.com

Year founded
1922

Sales volume
152 million euros

Employees
700

The right solution for highly demanding sputtering processes: TruPlasma DC Series 3000 NEW

Customized process energy for all types of solar cells

Reliable and precise process energy is one of the most important factors in solar cell production. This is exactly what the power supplies offered by HÜTTINGER Elektronik provide. They meet energy requirements during the production process perfectly – be it for silicon crystal growing or the plasma-based application of extremely thin material layers.

HÜTTINGER Elektronik offers a large selection of direct current (DC), medium frequency (MF) and high frequency (RF) power supplies for induction heating and plasma excitation. Our induction generators are key to providing energy for melting and heating silicon in zone floating and crystal-pulling applications. At high power and high efficiency, solar-grade silicon wafers can be produced at new cost levels.

HÜTTINGER also offers the right products for the main production steps in manufacturing thin-film solar cells – such as PECVD processes for photo-active a-Si/µc-Si layers and magnetron sputtering processes for TCO layers.

Full control in plasma-based film deposition processes

Best suited to PECVD and etching processes is the TruPlasma RF 3012. This RF power supply was introduced to the market in 2012 and provides 12 kW of RF power at 13.56 MHz. The TruPlasma RF 3012 combines the advantages of HÜTTINGER's unique power coupling technology, CombineLine, with an optimized power converter topology for the best energy conversion efficiency. Thanks to its energy efficiency factor of more than 80% and an exceptional level of robustness, this power supply provides new potential for reduced production costs and continuous production at the highest throughput in solar cell manufacturing lines.

For highly demanding sputtering processes, the TruPlasma DC Series 3000 NEW is the right solution. This product family contains the highly sophisticated arc management system CompensateLine. It allows for a dramatic reduction of the residual arc energy and ensures optimum results with regards to layer quality and deposition rate. Consequently, CompensateLine enables the production of exceptionally high quality and homogeneous films, even in highly arcing processes such as TCO processes.

High quality and globally renowned customer care play a fundamental role for HÜTTINGER. As a member of the TRUMPF Group and with subsidiaries in Europe, Asia and the USA, HÜTTINGER offers a worldwide sales and service network.

PORTER – New CDG020D (more details at www.porter-inficon.com)

Helium leak detector UL1000 Fab for maintenance on PV production tools

INFICON

Bringing proven experience to the most complex manufacturing processes

INFICON provides world-class instruments for gas analysis, measurement and control. These products are vital to equipment manufacturers and end users in the complex fabrication of semiconductors and thin-film coatings for solar cells, optics, flat panel displays and industrial vacuum coating applications.

INFICON has almost six decades of thin-film experience to apply to the manufacture of photovoltaic products. For processes of solar cell and thin-film module production, we provide market-leading thin-film deposition controllers and monitors with unique enabling technology for CIGS solar cells, residual gas analyzers (mass spectrometers), helium leak detectors and sensor integration and analysis systems. Pressure measurement products include vacuum gauges for total pressure measurement, valves, fittings and feedthroughs.

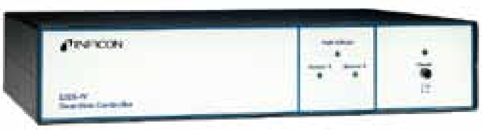
Meeting your needs through responsive manufacturing

We employ flexible manufacturing lines that are designed and staffed to meet our customers' demands. Furthermore, our Total Quality Management, involving SixSigma methodology and ISO registration programs, places emphasis on team-driven, continuous improvement and continuous attention to process and product specifications. Due to the design of the lines, the accuracy of the documentation, and the flexibility of our employees, we manufacture more rapidly and efficiently to meet your specific demands. Combined with advanced supply chain management, we are able to reduce manufacturing cycle times to offer you on-time delivery of high-quality products.

INFICON is ISO9001 and ISO14001 certified. These certifications allow us to consistently manufacture high-quality products while closely monitoring our environmental impact and the use of natural resources in our processes. Many of our instruments are RoHS/WEEE compliant.

Committed to worldwide customer support

Our customer support centers, strategically located around the world, ensure you have global access to comprehensive sales, installation, training, application support and repair services. Experienced teams and modern systems work together to handle your requests in an accurate and timely manner. Our technical support personnel understand your process and operational requirements and can translate this knowledge into a competitive advantage for your business.



INFICON
Alte Landstraße 6
9496 Balzers
Liechtenstein

Phone
+423 (0)388 3111

Fax
+423 (0)388 3700

Email
reachus@inficon.com

Web
www.inficon.com

Year founded
2000

Employees
909

www.porter-inficon.com

The Guardian™ controls simultaneous co-deposition of up to eight materials.

Xcell X2 with GX6 layup

XLam 17/34, Xinspect 4000ic, Xcell X2

Komax Solar

THE WAY TO MAKE IT | TO GRID PARITY

komax SOLAR

Komax Solar Inc.
20 Innovation Drive
York, PA 17402
USA

Phone
+1 717 755 6800

Fax
+1 717 757 6470

Email
info.YOK@komaxsolar.com

Web
www.komaxsolar.com

Year founded
2001

Company profile

Komax Solar is a global supplier of state-of-the-art photovoltaic module assembly equipment for both crystalline and thin-film technologies. We have developed a full line of equipment for crystalline module manufacturing, from string assembly through to lamination and testing. Additionally we offer custom automation solutions for new emerging solar technologies.

About us

With sales and service personnel in 50 countries and manufacturing sites in North America, Europe and Asia, we offer a true global footprint.

Changing industry requirements

As the solar industry matures, module manufacturers are focusing on lowering cost per watt. Competitive equipment prices, short delivery cycles, high yields and low breakage of process equipment are not just expected, they are taken as commonplace.

What matters to the module manufacturer in the end are the watts per day out the door. To facilitate this, we dramatically increased the output of our stringing machines while lowering costs. We also developed a new high speed, high-precision layup solution as well as a family of low cost EL inspection systems. Our new line of lamination products combines a competitive price with advanced features and options.

New machines for new requirements

Ownership

Our Xcell stringer platform was modernized from an Xcell X2 to an Xcell X2 Plus that produces up to 25% more output per year, yielding an industry leading, consistent 36 MW per unit.

The GX6 layup family offers best-in-class string placement accuracy by achieving a string gap tolerance of ±0.2 mm at a (measured/proven) 3 sigma process capability level, capable of offloading two Xcell X2 Plus machines.

Komax Solar is also introducing a new high-value lamination product, the XLam 21/34E, which can be configured with pins as well as a cooling press for optimized cycle rates.

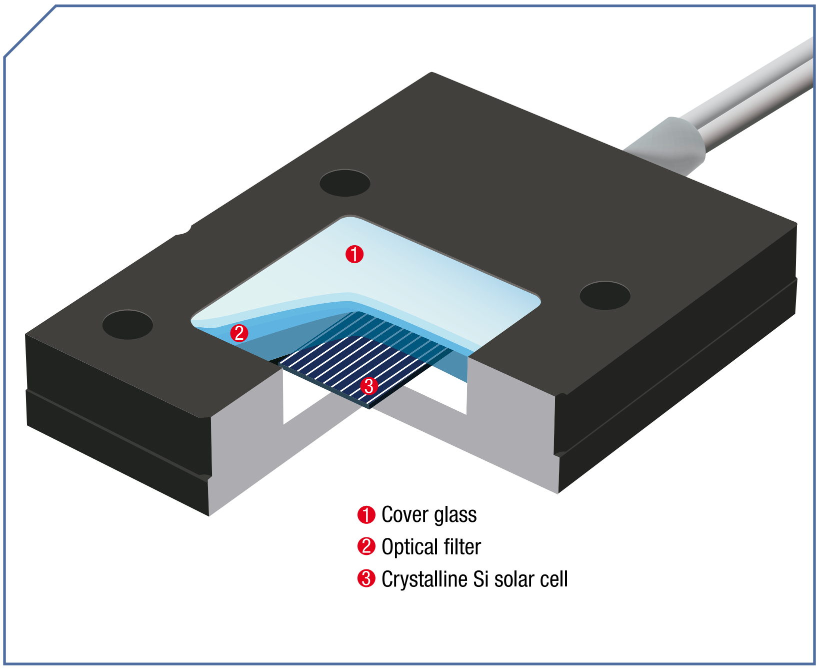
In addition, we have supplemented our full family of EL inspection equipment with a new, attractively priced module tester offering extremely high image resolution. Our testers are configured for both in-line and stand-alone applications.

Technical features and benefits

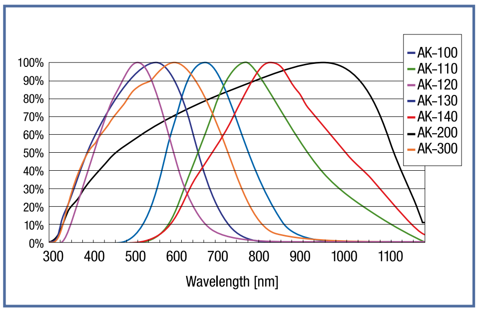
All our equipment is designed to provide the best-in-class value/performance features such as:

cell interconnect process equipment with closed loop control induction soldering technology

high throughput, gentle cell/string handling for high yield/low breakage, full line of critical process equipment, equipment flexible to handle multiple product sizes and types, low cost of ownership and reduction of floor space requirements, innovative solutions for new cell and module technologies, SCADA and MES capability



Cross-section of reference PV cells



Relative spectral responses of reference PV cells (AK series)

Konica Minolta Sensing Europe B.V.

PV Reference Cells Meet New Material Characteristics of Solar Cells

New materials require new solutions for reference cells

Konica Minolta Optics, Inc., a leader in radiometric instruments and optical filter technology, offers a new range of PV reference cells to perfectly match the spectral sensitivity characteristics of solar cells. In close cooperation with the renowned National Institute of Advanced Industrial Science (AIST), a line-up of seven reference cells for precise performance evaluation of thin-film silicon PV cells such as multi-junction are offered.

The challenge

Photovoltaic (PV) reference cells are required to adjust the irradiance of a Solar Simulator, which measures output characteristics of PV cells (IEC60904-3).

The output of PV cells strongly depends on the spectral distribution of the irradiated light. Unless the reference cell used has a similar relative spectral response to the PV cell to be tested, the solar simulator cannot be adjusted accurately and an I-V characteristic for the PV cell being tested cannot be calculated correctly. An optimum spectral match of the reference cell is therefore necessary for adequate measurement of the irradiance output under standard test conditions.

The solution

Konica Minolta's reference cells consist of two stable single-crystal PV cells and a newly designed glass filter combined with a specially-manufactured window frame in a WPVS (World Photovoltaic Scale) body.

The main features of these PV reference cells are:

- improvement of spectral match with measured cells
- reduced error due to multi-reflection in the use of a solar simulator
- long-term photo stability of the glass filter

In 2010 Konica Minolta Sensing introduced their first three reference cells, one for crystalline solar cells (AK-200) and two for 2-junction solar cells, the a-Si top layer type (AK-100) and μc-Si bottom layer type.

This year, the range was further extended with the addition of the world's first commercially available PV reference cells for 3-junction type solar cells for bottom-, top- and middle-layer (AK-120, AK-130 and AK-140) types.

The new AK-300 is the world's first reference cell type for dye-sensitized N719 materials.

To obtain the traceability certification to national and international standards, it is essential to use a reference PV cell which can be calibrated at organizations or institutes accredited by ISO/IEC17025 and designated in the ILAC/APLAC MRA, which is important from the viewpoint of conformity assessment. For the AK series, calibration certificates traceable to AIST are available as an option.

KONICA MINOLTA

Konica Minolta Sensing Europe B.V.
Edisonbaan 14F
NM 3439 Nieuwegein
The Netherlands

Phone
+31 (0)30 248-1193

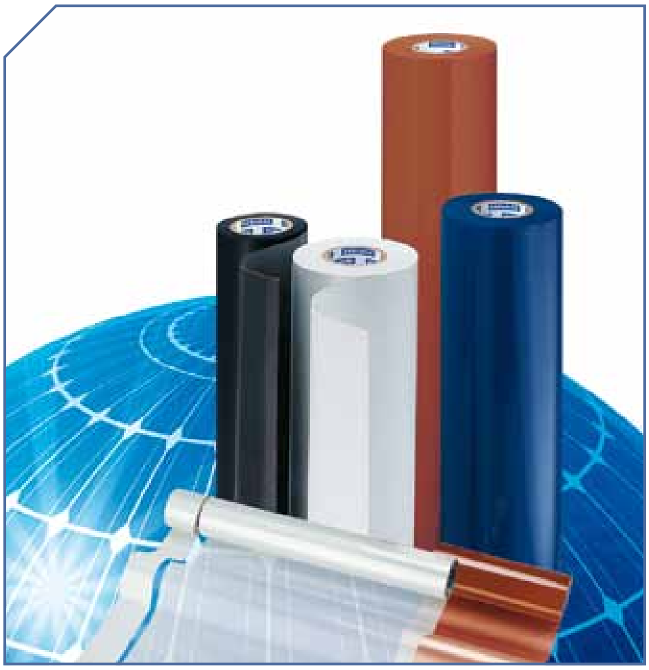
Fax
+31(0)30 248-1280

Email
info.sensing@seu.konicaminolta.eu

Web
www.konicaminolta.eu

Year founded
2006

Employees
80



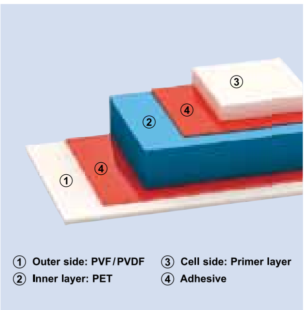
1

2

3

1 Backsheet laminate AKASOL® – durable and adjustable
2 Laminating system
3 Finished laminate
4 Structure of the backsheet laminate

KREMPEL-GROUP – *The Comprehensive Backsheet Product Range: Economically Efficient Solutions for Different Requirements*



4

KREMPEL GROUP

KREMPEL GmbH
Papierfabrikstrasse 4
71665 Vaihingen/Enz
Germany

Phone
+49 (0)7042 9150

Fax
+49 (0)7042 15985

Email
info@krempel-group.com

Web
www.krempel-group.com

Year founded
1871

Sales volume
215 million euros

Employees
1,200

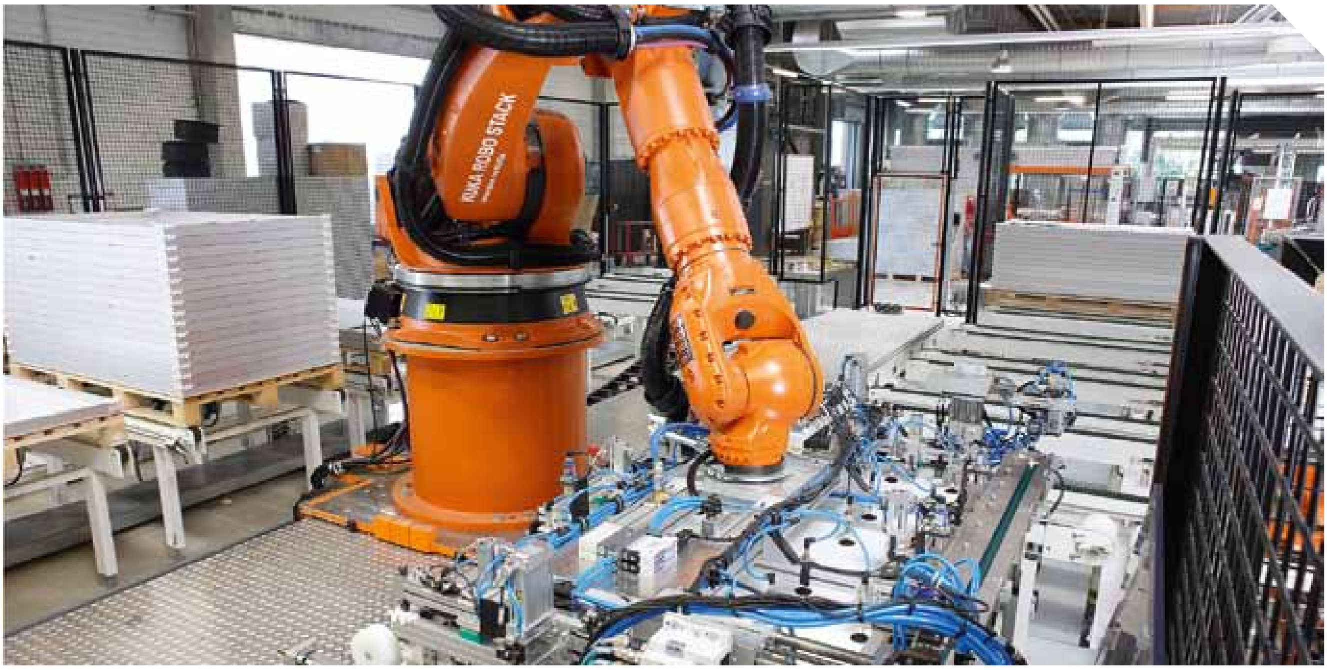
Backsheet laminates for PV modules

The KREMPEL-GROUP is a leading global system supplier established in the world of materials. With electrical insulations, solar materials, composites, electronic materials and special laminates, we belong to the world market leaders in many areas. Our production facilities operate in Germany, England, Poland, Brazil as well as in China. As a family-owned enterprise, we are an independent producer of high-grade semi-finished products: High-tech made by the KREMPEL-GROUP.

Solar modules convert sunlight into electrical energy and should do so efficiently and continuously. Having made a name for itself on a global scale in this field, the KREMPEL-GROUP is and should be your first-choice partner. Our diverse backsheet portfolio offers proven quality for all requirements at market price. To help you make the most effective and strategic choice of materials suitable for your application, our solar material specialists provide you with advice based on more than 20 years of practical experience.

The quality of our classical AKASOL® PTL & AKASOL® PVL products with fluoropolymer film used for the cell side and outer layers has been proven in many years of use all over the world. AKASOL® PTL 2 & AKASOL® PVL 2 were developed as a more cost-effective solution. The cell side is designed as a primer layer with high-quality UV absorbers and is characterized as a whole by its optimum ratio of polyester film thickness to bonding agent. The least expensive new development, AKALIGHT® ECS, combines the tried-and-tested cell side layers of this second generation with a special film that is unaffected by UV radiation and was designed for reliable use in the outer layer in accordance with the highly demanding standards that KREMPEL has set itself. The layer for the cell side is a high-quality film with UV absorbers that has already proven its worth in AKASOL® products.

Our PV backsheet laminates made in Germany reliably protect your solar modules against harmful outside influences, while ensuring outstanding electrical insulation at the same time. Quality from KREMPEL pays off and gives you an advantage over your competitors.



KUKA Systems Energy solutions

KUKA Systems

Our technology

KUKA Systems is an international supplier of flexible production systems to the automotive, aerospace, energy and other industries in which highly automated processes are required. A workforce of around 3,600 across the world develops ideas, concepts and solutions for automated production, as well as supplying products and services for virtually all tasks in the industrial processing of metallic and non-metallic materials. The company's range of products and services are presented and marketed around the globe by subsidiaries and sales offices in Europe, the Americas and Asia.

KUKA Systems Energy specializes in the supply of tailor-made systems. The core competencies are the analysis, modeling and optimization of complex production processes that are integrated and supported on-site. All automation solutions can be flexibly scaled – from the robotic cell as an automated production island right up to complete production lines.

Our products

- automated module manufacturing
- planning and engineering
- turnkey supplier
- testing and inspection equipment
- automated process stations
- thermal collector solutions
- liquid encapsulation process for PV modules

KUKA Systems Robo X – cross-tie soldering

KUKA

KUKA Systems GmbH
Blücherstraße 144
86165 Augsburg
Germany

Phone
+49 (0)821 797-0

Fax
+49 (0)821 797-1991

Email
energy@kuka.de

Web
www.kuka-systems.com

Year founded
1898

Sales volume
850.7 million euros (2011)

Employees
3,600

Cluster deposition tools provided to the world's leading institutes

Industry leading quality standards and practices

Repeatable component production no matter the size

Kurt J. Lesker Company®

Serving Research, Pilot Line, and Production Applications

Kurt J. Lesker Company
1925 Route 51
Pittsburgh, PA 15025
USA

Phone
+1 412 387-9200
+1 800 245-1656

Fax
+1 412 384-2745

Email
sales@lesker.com

EUROPEAN HEADQUARTERS
Hastings, United Kingdom

Phone
+44 1424 458100

Email
saleseu@lesker.com

ASIAN HEADQUARTERS
Shanghai, China

Phone
+86 21 50115900

Email
saleschina@lesker.com

Web
www.lesker.com

Year founded
1954

Employees
355

Experts in all things vacuum

Founded in 1954, the Kurt J. Lesker Company offers a full range of vacuum products, parts, systems, design technologies, innovative thinking, and responsive customer service. We serve the academic and industrial R&D communities by providing vacuum products and services on a global scale, working with an eye toward quality, environmental stewardship, and customer satisfaction. KJLC has strategically positioned sales and warehouse facilities around the globe, highlighted by our newest location in Shanghai, China.

Engineering and manufacturing

KJLC offers expertise in electrical, mechanical, and software engineering. This strength provides the versatility to be a partner in projects ranging from contract manufacturing to pilot line production systems. Our engineering and manufacturing divisions collaborate to produce quality and cost effective solutions to satisfy the demands of the PV market segment.

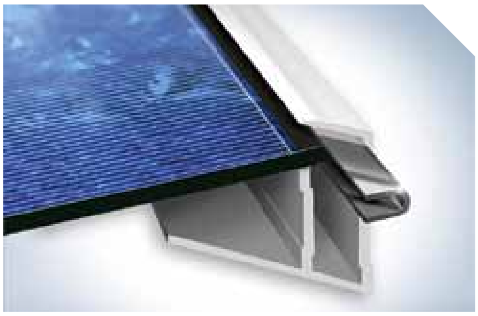
Process and application expertise

KJLC's technology arm — the Process Equipment Division (PED) — has been a premier manufacturer of purpose built thin-film deposition equipment since the early 1980s. With more than 1,500 installations worldwide, PED's significant experience in thin-film technology provides a natural extension as thin-film PV technologies evolve. We are proud to be a preferred equipment supplier to the world's leading materials discovery and molecular engineering institutes. Our applications and process development centers in North America, Europe, and Asia enable close collaboration with our customers to deliver thin-film technology solutions.

Next generation process materials

The Materials Division's chemical and powder synthesis techniques are utilized to manufacture custom stoichiometries for the most challenging R&D and production requirements in the evolving PV materials domain. Proprietary processes yield homogeneous, high density products to enhance thin-film processes. Expert technical support linked with global distribution and target bonding yield a complete, high quality product to meet the most demanding PV requirements.

1



2

3

Lohmann GmbH & Co. KG *Looking into the Future – with High-Class Adhesive Tapes from Lohmann*

In order to fulfill its customers' needs, Lohmann offers individual and efficient bonding solutions for the photovoltaic solar energy industry.

The challenge for manufacturers within the photovoltaic industry nowadays is to increase efficiency and productivity. This is where adhesive solutions from Lohmann's Bonding Engineers come in. The more reliably and efficiently different components are connected, the more long-lasting and cost-effective the technical solutions will be. Lohmann satisfies all the requirements expected from a sustainable adhesive tape solution. As a primary provider, Lohmann has been developing adhesive tape solutions for the solar sector since 1992. At that time, the "Bonding Engineers" used heat/humidity storage requirement standards and the climate change test to check the quality of the products.

The company's customized adhesive solutions for the photovoltaic solar energy industry include several products in the DuploCOLL range: high-end adhesive tapes to frame photovoltaic modules. These tapes guarantee highly reliable processing when bonding frame profiles to solar laminates, even in fully automated processes.
Self-adhesive die-cut parts to bond junction boxes to photovoltaic modules. Their tailor-made geometry ensures highly efficient processing.
Double-sided adhesive tapes to fix and insulate busbars. These tapes are most suitable for preventing contact between the voltage-conducting busbar and the cells.

Lohmann has also developed a double coated, pressure sensitive tape for the "back rail" bonding of thin-film solar modules. Using this tape to bond the metal back rails enables thin-film solar modules to be installed quickly.

A new product is the patented single-sided adhesive laminating "Invisible Tape" for fixing cells within crystalline solar modules. One of the features that makes this DuploCOLL adhesive tape unique is its tremendous adaptability. Owing to its compatibility with all other components, it remains invisible following lamination – no inclusions or discoloration! Taken as a whole, the innovative "Invisible Tape" optimizes the manufacturing process for crystalline solar modules and helps reduce cycle times.

With a long history stretching back over 161 years, Lohmann is one of the pioneering forces in adhesive tape technology. The Adhesive Tape Group is headquartered in Neuwied, Germany. With approximately 1,600 employees worldwide and state-of-the-art coating plants at six sites in Europe, Asia and the USA, Lohmann provides high-end adhesive solutions worldwide.

Lohmann
The Bonding Engineers.

Lohmann GmbH & Co. KG
Irlicher Straße 55
56567 Neuwied
Germany

Phone
+49 (0)2631 34-0

Fax
+49 (0)2631 34-6661

Email
building-construction@lohmann-tapes.com

Web
www.lohmann-tapes.com

Year founded
1851

Employees
1,600

1 Adhesives are coated on to flexible web materials for the solar industry.
2 Lohmann high-end adhesive tapes to frame photovoltaic modules
3 Temperature resistance of the adhesive solutions is tested in the climate chamber.

Luvata

Going Beyond Expectations to Make Things Better

All over the world companies are finding better ways to do more for more people and waste less in the process. All over the world Luvata is helping them.

LUVATA
Partnerships beyond metals

LUVATA OY
Kuparitie 2
28101 Pori
Finland

Phone
+358 (2) 6266111

Email
info@luvata.com

Web
www.luvata.com

Employees
6,400

SUNWIRE MANUFACTURING LOCATIONS
Pori, Finland
Pasir Gudang, Malaysia
Appleton, Wisconsin, USA
Suzhou, China

Luvata Sunwire® on spools

Photovoltaic wire

Customer needs are continually evolving and business requirements are forever changing. Nowhere is this more apparent than in the renewable energy industry. Luvata, an early pioneer in the photovoltaic industry, manufactures solar ribbon branded Sunwire®. Sunwire is compatible with both thin-film technology and crystalline silicon and is used as both an interconnecting ribbon and a cross-connecting ribbon.

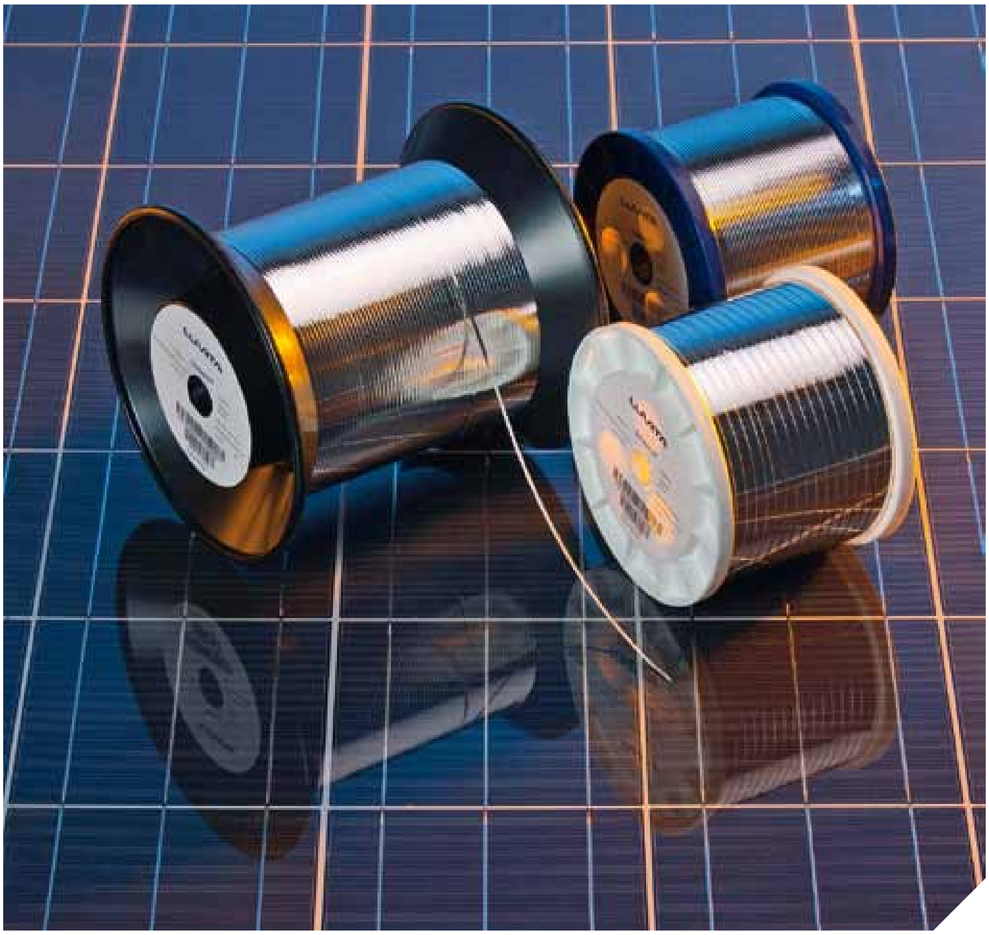
In recent years, silicon cell thicknesses have been reduced to save material costs. This can make the cells extremely fragile and therefore Sunwire must be softer to prevent them from cracking during manufacture. Increased electrical efficiency of the cells requires a greater copper cross section, but not at the expense of width, which shadows the cell. Sunwire has been made thicker, which requires even greater material softness. Luvata continues to work on yield strength to make Sunwire ultrasoft, perhaps the softest solar ribbon on the market today.

In addition, as the automation and efficiency of PV module manufacturing have improved, there has been demand for larger spools. Historically spools of Sunwire have been 4–5 kg and now they have doubled to 10–15 kg. Larger biconical spools help improve production efficiency and reduce manufacturing costs. With our Sunwire proprietary technology, we are able to deliver all three: softer, thicker Sunwire on bigger spools.

With dedicated Sunwire manufacturing facilities and staff in Europe, Asia (China and Malaysia) and North America, Luvata has more than tripled its solar ribbon production capacity. By implementing identical processes at all four facilities, Luvata is able to manufacture exactly the same product with the same consistent quality, while this close proximity to customers provides the responsiveness of local customer service and technical support.

Luvata's Sunwire proprietary manufacturing technology is extremely energy efficient, chemical free and amazingly compact in design. Sunwire is made from materials that are 100% recyclable and its innovative reusable packaging design ensures safe transport while eliminating metric tons of landfill – all of which contribute to clean solar energy.

Luvata continues to research new types of solder and alloys in addition to helping customers with the development of other technologies. This may involve running trials, testing and certification, or simply offering new ideas or solutions to overcome a production or transportation challenge. Luvata recognizes that additional cost and oper-



Luvata Sunwire® on discs

Luvata Sunwire® cut to length

ating efficiencies in the manufacture of PV modules must be achieved before we finally reach grid parity. And we are here to help make this happen.

Photovoltaic connectors

In addition to making Sunwire® branded solar ribbon for PV modules, Luvata also offers machined, cold formed and specialty connectors in a wide variety of shapes and sizes. These connectors are used in junction boxes on the back of the module to transfer electricity to the power grid. Manufactured from high purity copper, Luvata connectors provide 100% conductivity and high reliability and performance for both thin-film and crystalline technologies.

Luvata delivers cost-saving solutions by taking products previously manufactured from bar and re-engineering them to be cold formed. The net result is a product with exceptional performance, quality and reliability along with savings from a reduction in material costs.

Luvata

Throughout Luvata's numerous markets, there is a huge demand for solutions that make the modern lifestyle more sustainable: supporting high efficiency, low-emission products and processes that conserve energy, water or food. Luvata uses its experience, innovative spirit and willingness to listen, solve problems and create added value to help customers bring improvement to their products and processes.

Creating lasting partnerships has always been Luvata's strategy. It is about commitment, collaboration and continually exceeding expectations: www.luvata.com

Luvata Sunwire® on spools

LUVATA
Partnerships beyond metals

SUNWIRE GERMAN CONTACT
Luvata Espoo Oy
POB 340128
45073 Essen
Germany

Phone
+49 (0)201 79917859

Mobile
+49 (0)172 6902257

Email
norbert.weidehoff@luvata.com

Web
www.luvata.com

PV CONNECTOR CONTACT
Luvata Welwyn Garden Ltd.
Centrapark, Bessemer Road
Welwyn Garden City,
Hertfordshire AL7 1HT
United Kingdom

Phone
+44 (0)1707 379789

PV CONNECTOR MANUFACTURING LOCATIONS
Welwyn Garden City, United Kingdom
Delaware, Ohio, USA
Suzhou, China

Protekt® HD with our patented Bright White Power Boosting Technology

100+ years of manufacturing excellence

Madico, Inc.

Madico Backsheets Offer the Ultimate in Cost Performance

High performing solar panels are built with Madico PV backsheets

Madico, Inc.
64 Industrial Parkway
Woburn, Ma 01801
USA

Phone
+1 781 935-7850

Fax
+1 781 935-6841

Email
infoSF@madico.com

Web
www.madico.com

Year founded
1903

Employees
270

Madico, Inc. has been developing innovative materials for more than a century. An unrivaled commitment to research and development has enabled the company to pioneer a number of industry-first products and processes for emerging safety and energy markets. The company's award winning specialty film products have been proven to increase reliability and energy generation in the growing renewable energy sectors. Madico's corporate headquarters and one of its manufacturing centers are located in Woburn, Massachusetts.

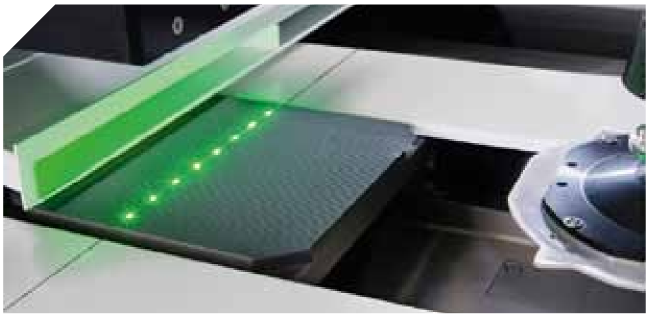
Madico offers a full line of backsheet solutions allowing module manufacturers to choose backsheets based on the cost performance. Solar panels available on the market are designed around a varying cost performance structure. The Madico backsheet portfolio is designed to support this model; Madico understands that materials matter and that it is important to use the right materials for the best cost performance results.

As a premier manufacturer of coated and laminated PV backsheets, Madico is an award winning material supplier and 20+ year technology innovator in PV.

Madico is committed to manufacturing excellence in producing high quality, high performing PV backsheets. The company believes in solar power, sustainability and lean practices; it is this belief that drives the company's growth and contribution to technical advancements.

Madico's fluoro-coated backsheet product portfolio

- Protekt® – our classic fluoro-coated design
- Hytek™ – an advanced fluoro-coated material coupled with Madico's latest advancements in process technology
- Reflekt™ – an innovative process design based on extrusion technology
- All new materials are available in a "prime" (enhanced RTI) version.



Manz's selective emitter technology for increased solar cell efficiency

Manz's thin-film technology: highest level of precision for every scribing process

Manz AG's headquarters in Reutlingen

Manz AG

25 Years of High-Tech Engineering for a Green Future

Enabling the future with Manz high-tech engineering

Manz AG, based in Reutlingen, Germany, is a leading global high-tech equipment manufacturer. Over the past few years, the company has developed from an automation specialist into a provider of integrated system solutions for the production of crystalline silicon solar cells and thin-film solar modules.
The group, established in 1987, is headed by company founder Dieter Manz and has been publicly listed in Germany since 2006. Manz operates production facilities in Germany, China, Taiwan, Slovakia and Hungary.
In addition, it has sales and service branches in the USA, South Korea and India. At the beginning of 2012, Manz AG had approximately 2,000 employees, 900 of whom work in Asia.

High-tech for growth markets
With over 25 years of experience in the fields of automation, laser processing and vacuum coating technology, wet-chemical processes, control technology, image processing and quality assurance systems, Manz AG is primarily active in the world's high-tech growth markets. An interdivisional research & development department provides the technological synergies that make it possible to further widen the company's technological lead.

Manz's core competencies include:

- System solutions for manufacturing crystalline solar cells with a focus on laser processing technology, vacuum technology, wet chemical processing and automation, as well as metallization, measurement and testing technology.
- Single equipment for manufacturing thin-film solar modules with a focus on laser and mechanical scribing, automation, glass cleaning and etching, measurement and testing technology, laser edge isolation, laser cutting and vacuum technology.
- Fully integrated production line for the manufacture of CIGS modules, the Manz CIGSfab.

Driven by the company's slogan, "passion for efficiency", Manz engineers promise to provide their customers from various future key industries with ever more efficient manufacturing systems. As a result, Manz continuously optimizes its product portfolio. The aim is to achieve highly reliable production processes on the customer side while steadily improving performance parameters for products manufactured on Manz equipment.

Manz SpeedPicker for fast and safe wafer or cell handling

manz
passion for efficiency

Manz AG
Steigaeckerstrasse 5
72768 Reutlingen
Germany

Phone
+49 (0)7121 9000-0

Fax
+49 (0)7121 9000-99

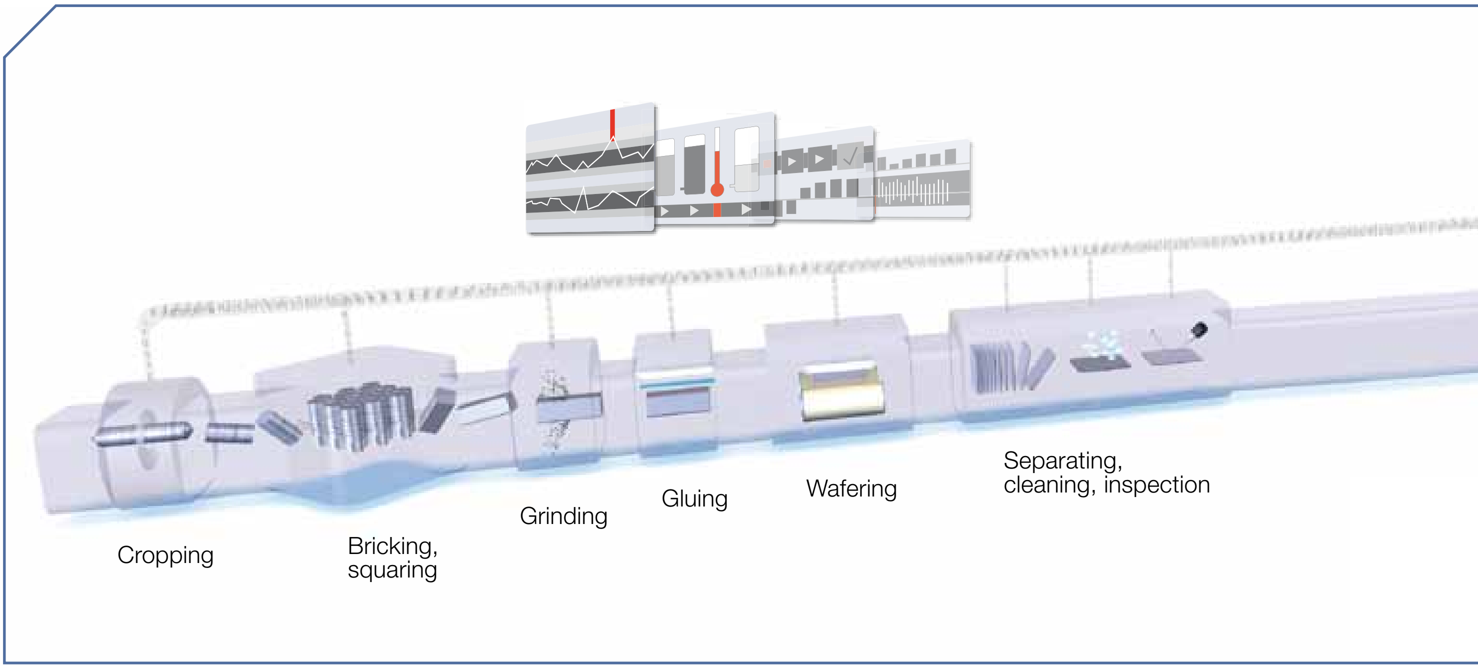
Email
info@manz.com

Web
www.manz.com

Year founded
1987

Sales volume
240.5 million euros (2011)

Employees
Approx. 2,000



Processes and systems from the Meyer Burger Group – from wafer to module

Meyer Burger Technology AG

Passionate about PV – Committed to Systems and Processes

Pioneering system solutions for the solar industry – providing optimum material flows and processes along the entire value chain

The new Monte Rosa Hut, Swiss Alps. Outstanding architecture and resource efficiency.

Meyer Burger Technology Ltd is the technology leader at every stage of the photovoltaic value chain. Our technology group's established core expertise encompasses all important production processes, systems and equipment for solar production – from wafers to building-integrated PV systems. Our system solutions are distinguished by a high level of integration leading to new applications and groundbreaking system designs – for quantum leaps in system efficiency as a whole with a simultaneous reduction in production costs.

System performance and cost reduction

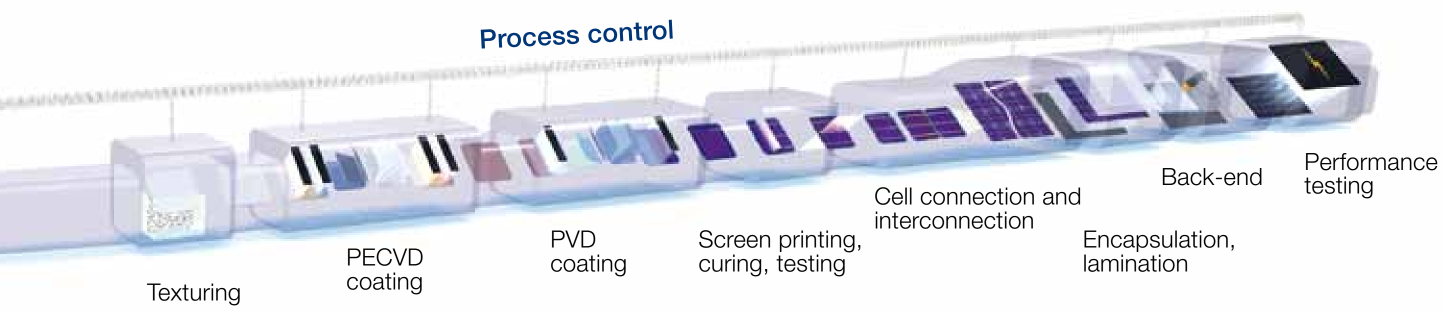
Processes and systems from the Meyer Burger Group play a vital role in increasing overall performance and efficiency throughout the value chain. We are continuously developing the crucial key factors further within all processes – for optimum material utilisation, lowest possible production costs and maximum availability.

Cross-process innovations for modern high-performance technology

The cutting and sawing technologies employed in the production of solar wafers are being steadily improved and adapted to the requirements of the cell process. Meyer Burger systems enable customers to produce wafers with the perfect properties for modern high-performance technologies such as heterojunction and iPERC cells. For the surface processing and finishing of the wafers into cells, Meyer Burger is developing these important future-oriented technologies in order to achieve significant efficiency gains in cell production. In order for the new, ever more powerful high-performance cells to be able to unfold their full potential within the module, we are working on new processes for cell connection, lamination and testing of cells and modules.

Wafer process

Meyer Burger system solutions for perfect wafers: high angular accuracy, precise geometry and optimised surfaces ensure best possible material utilisation and maximum wafering yield. Our one-stop system solutions enable the production of suitable wafers with ideal specifications for every desired cell process – meeting the optimum specifications of the thinnest wafers for the production of high-performance cells.



MEYER BURGER GROUP

Cell process

Meyer Burger technology for high-performance cells: our solutions for the heterojunction and iPERC cell processes form the basis for cost reductions through higher cell efficiency. Integrated development throughout the solar value chain means that wafers can be optimally adapted for the cells and that both the module design and material, as well as the measurement technology, correspond to the requirements of the cells. Our system solutions ensure the perfect integration and harmonisation of all processes with the goal of cost reduction.

Module process

Optimised processes for low-cost module production: the new generations of highly efficient solar cells present particular challenges for the module process. In order to connect the thin, highly efficient cells, precise and gentle soft touch soldering technology is employed. Meyer Burger systems take the increased demands into account by using new cell-manufacturing technologies with new developments in automatic interconnection, soldering with multiple bus-bars, and lamination techniques, as well as newly developed test methods for highly efficient modules.

Process control

Monitoring and support of the entire production process: by integrating and combining all processes, machines, material flows and maintenance works into an overall software system, the complex photovoltaic production process becomes manageable. Meyer Burger FabEagle®$_{MES}$ functions as a control centre for all production requirements and generates benefits through higher-level functions that enable overview and control at every stage in the production process. The MES software enables weaknesses to be analysed. It is an effective tool for improving production in terms of efficiency and stability – for higher yield and lower costs in every production step from silicon to the solar module.

Worldwide service and process support

The Meyer Burger Group is represented in the key solar industry markets throughout the world. An international service network enables us to provide optimum support to our customers. Our process specialists and service engineers supply on-site support with process know-how, maintenance and repair services, spare parts and consumables, training and other services – directly, promptly and with the utmost dependability.

MEYER BURGER

Meyer Burger Technology AG
Headquarters
Schorenstraße 39
3645 Gwatt (Thun)
Switzerland

Phone
+41 (0)33 221 28-00

Fax
+41 (0)33 221 28-08

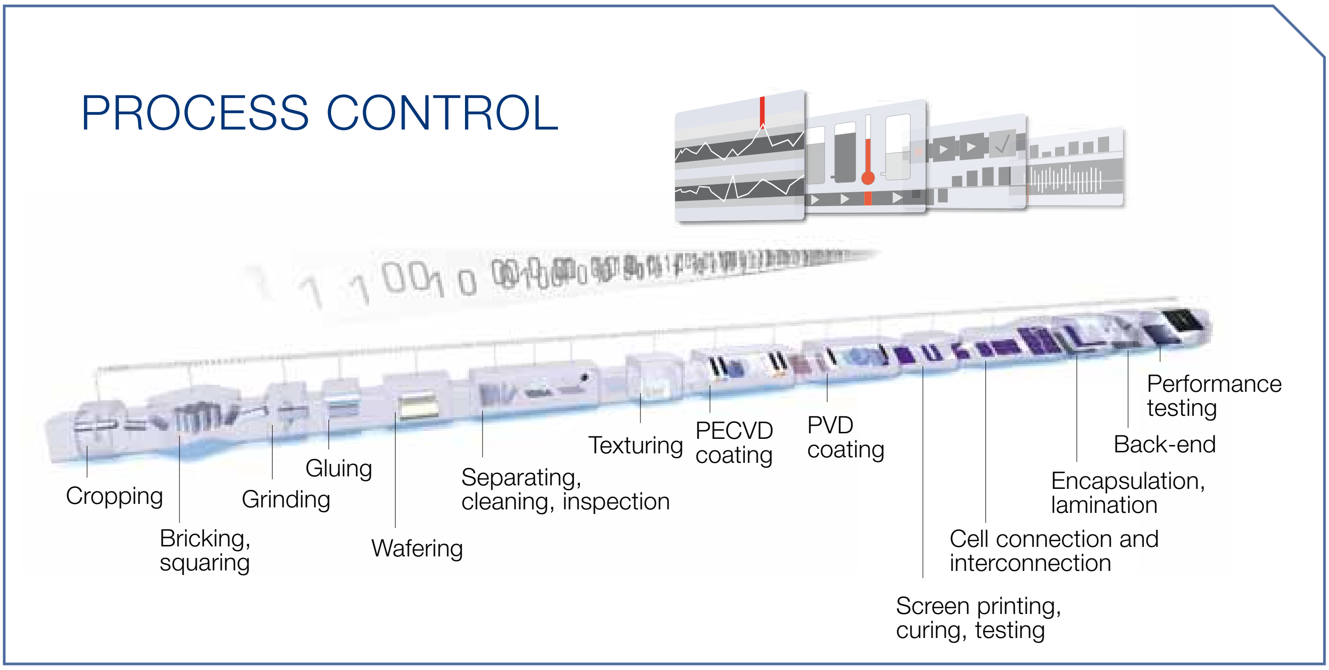
Email
mbtinfo@meyerburger.com

Web
www.meyerburger.com

Year founded
1999

Sales volume
1.315 billion CHF

Employees
2,500



Process control

AIS Automation Dresden GmbH

FabEagle® $_{MES}$ – We Manage Solar Manufacturing Lines

Optimise & control your entire PV manufacturing line with one automation solution

AIS AUTOMATION
SOFTWARE SYSTEMS

AIS Automation Dresden GmbH
Otto-Mohr-Straße 6
01237 Dresden
Germany

Phone
+49 (0)351 2166-0

Fax
+49 (0)351 2166-3000

Email
support@ais-automation.com

Web
www.ais-automation.com

Year founded
1990

Employees
152 (April 2012)

A member of Meyer Burger Group

AIS Automation is a global system integrator of innovative software solutions for factory automation and process control. Since 2011, AIS is a member of the Meyer Burger Group. Our FabEagle® $_{MES}$ functions as a control centre for all production requirements and generates benefits through higher-level functions that enable overview and control at every stage in the production process. The MES software allows weaknesses to be analysed. It is an effective tool for improving production in terms of efficiency and stability – for a higher yield and lower cost of ownership for every production step from silicon to the solar module.

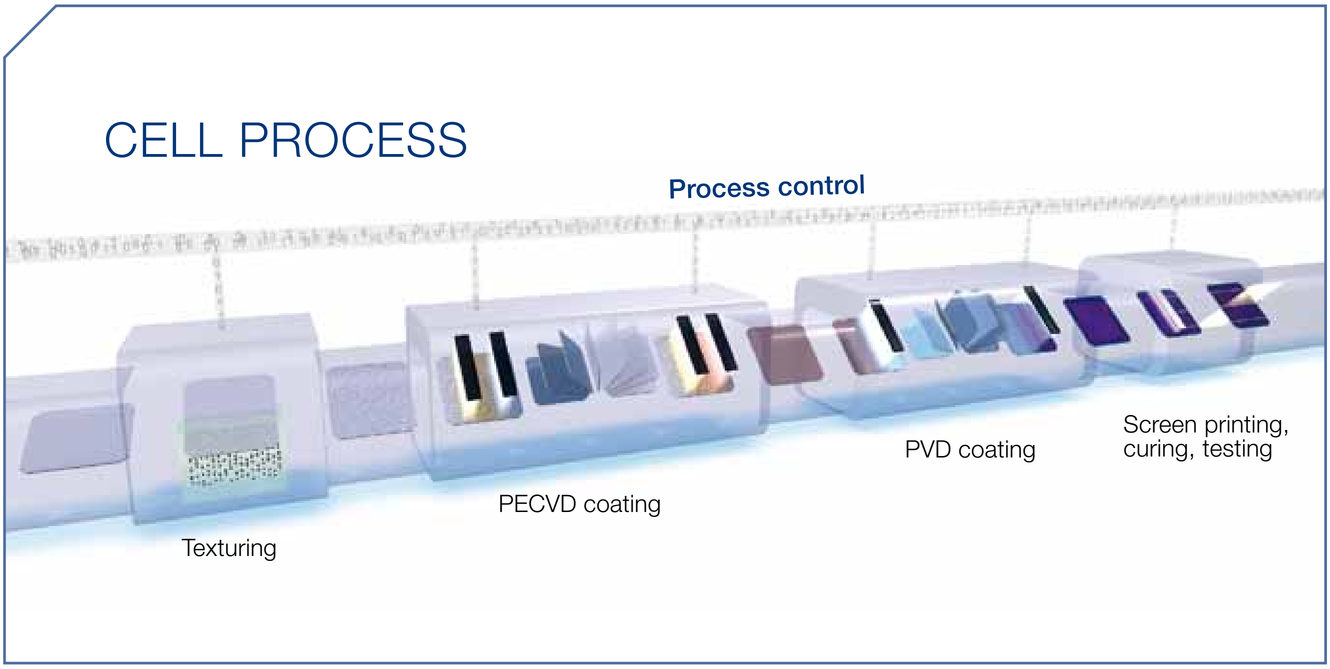
Integrated automation is key
Today's production environment is highly complex. Complex systems can only be managed if all the relevant elements are integrated and interact with one another, including processes, equipment, material flow and maintenance. Integration leads to networks. The FabEagle® functions as a control centre that manages process yield and guarantees on time delivery.

Supporting the entire PV manufacturing process
Advanced PV manufacturing lines are fully integrated, from crystal growing to the finishing of the PV module. The challenge for the automation system lies in the handling of different sizes and types of manufacturing materials, ranging from pure silicon to single PV wafers and finally complete PV modules.

Equipment integration
Equipment integration with FabEagle® $_{MES}$ provides process control capability and support for different process tools, load ports and carriers. Tool control functions include alarm handling, recipe management, material tracking and reporting. The equipment integration process is preconfigured to support standard interfaces like PV02, which enables easy integration.

Dispatching/Scheduling
Dispatching & short-term scheduling is important in optimising the movement of material and guaranteeing deliveries to customers. In order to balance out continuous variations in manufacturing parameters, such as unexpected equipment downtime, shortages of consumables or process yield, the dispatching system reschedules the manufacturing flow in real time.

Over 65 factories worldwide have placed their trust in AIS software solutions and use them to increase the transparency and efficiency of their production lines.



Cell process

Roth & Rau AG

Leading Coating Technologies for Higher Efficiency

Advanced cell technologies

A member of the Meyer Burger Group since 2011, Roth & Rau AG covers the specialist area of solar cells and offers all associated technologies and systems.

Roth & Rau's core area of expertise lies primarily in coating systems based on plasma and ion beam technology. The company's SiNA® and MAiA® plant series make it one of the global leaders in the production of antireflective coating systems for the solar industry. The MAiA plants make it possible to extend existing production lines and the passivation of the rear surface (iPERC) allows greater cell efficiency to be achieved.

PECVD and PVD coating plants for the manufacture of highly efficient solar cells using the innovative heterojunction technology (HJT) are also offered under the name HELiA. Roth & Rau is one of the very first companies to offer systems for the mass production of HJT cells, allowing its clients to produce highly efficient solar cells while lowering manufacturing costs.

Collaboration within the Meyer Burger Group means wafer and module production systems can be adapted to use heterojunction technology, resulting in finished solar modules also achieving highest rates of efficiency.

ROTH & RAU
CELL & COATING SYSTEMS

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

Phone
+ 49 (0)3723 671-234

Fax
+ 49 (0)3723 671-1000

Email
info@roth-rau.com

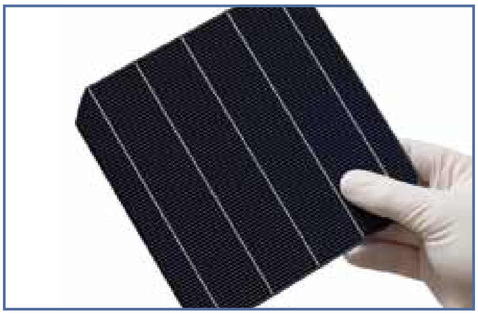
Web
www.roth-rau.com

Year founded
1990

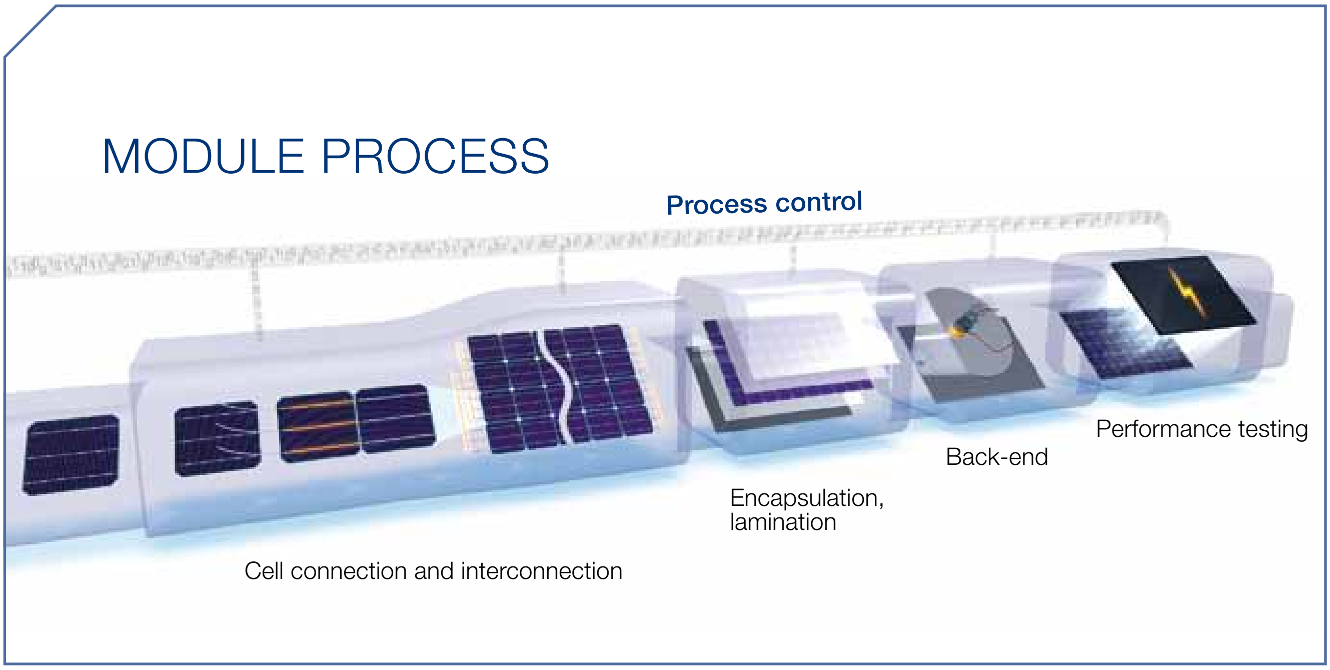
Employees
Approx. 1,100 (group)

A member of Meyer Burger Group

Transport carrier with heterojunction solar cells



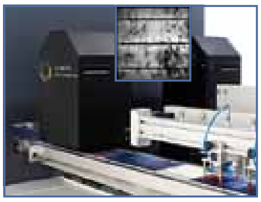
HJT-cell with five busbars



Processes and systems from the Meyer Burger Group – from cell to module

Somont — *Outstanding Worldwide Reputation for High Efficiency Cell and Matrix Connecting*

CERTUS ONE stringer



CERTUS TWO stringer with stringer-integrated electroluminescence testing unit

Competence in high-quality soldering and throughput for reliable stringing and matrix performance

Somont, a member of the Meyer Burger Technology Group, specialises in the development and production of systems for solar cell connecting. Being a member of the Meyer Burger Technology Group enables us to offer our customers synchronised solutions and systems within the entire module process – from cell and matrix connecting to laminating and performance testing. Optimised processes for high-quality module production at lowest total cost of ownership are guaranteed.

Somont, well-known in the industry for its high-quality automation systems, now offers an optional stringer-integrated electroluminescence (EL) testing unit, which is unique to the market.

Lay-up or box handling systems, fully automated matrix interconnection solutions and laboratory equipment are also part of Somont's product portfolio.

Key to our customers' success

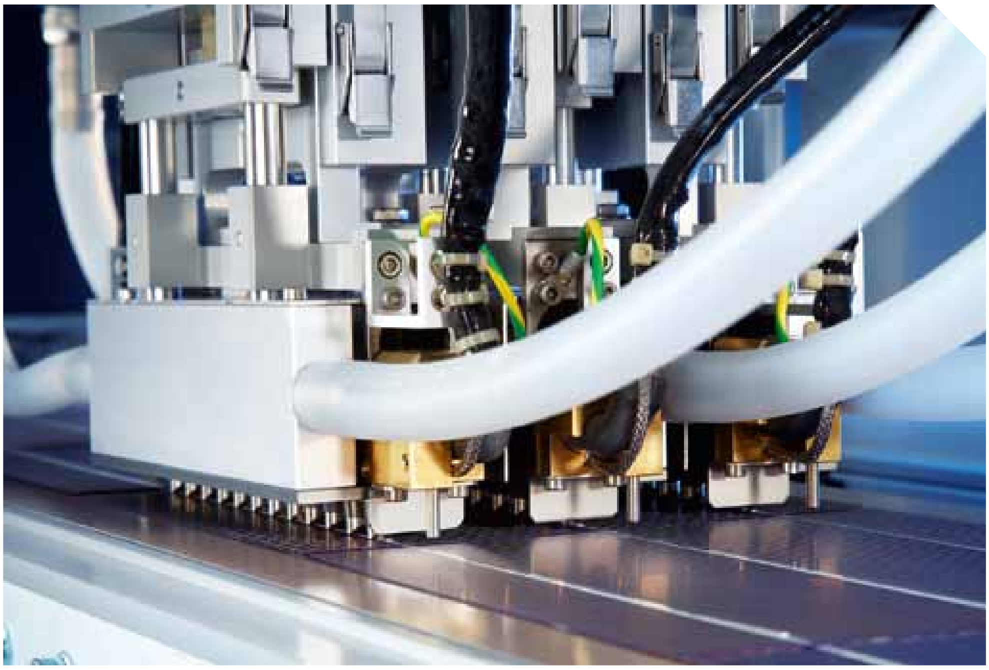
Cell connecting is Somont's core competency. The soldering technology for connecting the fragile solar cells as well as cell handling plays a crucial role in the manufacture of strings. Somont ensures high output and maximum quality throughout the entire production process. With its proven Soft Touch soldering process and its intelligent temperature management, even very thin solar cells can be handled and connected at top productivity rates.

In addition, the consistent reduction in process steps to minimise cell handling ensures high-quality soldering results with excellent peeling forces.

Designed for high-quality cell and matrix connecting solutions with an emphasis on continuous process improvement, Somont stringers enjoy an excellent global reputation in the solar industry. Expert advice, reliability, excellent customer service, top quality and the outstanding performance of Somont's products are the factors behind their customers' success.

Somont offers the right stringer, handling system and laboratory equipment for every requirement

- modular and flexible systems from 700 – 4,900 cells/hour
- high output at very low breakage rates and maximum stringer availability
- minimum cost of ownership
- easy and fast integration into existing module production lines or as key equipment in new lines



Soft Touch soldering process

Fully automated matrix interconnection

Box handling system

MEYER BURGER GROUP

- fast installation and ramp-up times
- on-site customer training and ramp-up assistance
- cost-, time- and space-saving laboratory devices for flexible material tests
- worldwide service network

Product portfolio

A critical factor in Somont's success has been its focus on quality and the continuous improvement of its systems. Together with 3S Modultec and PASAN SA, also members of the Meyer Burger Technology Group, fully integrated production systems can be offered to customers.

Somont offers:
- RAPID stringer (outstanding reputation for reliable cell connection)
- CERTUS stringer (cost-effective cell connection for high-class PV modules)
- CERTUS system (the perfect solution for cell and matrix connection)
- Lay-up and box handling systems (gentle and accurate handling)
- CONSOL and CONFORCE laboratory equipment (combined flexibility and efficiency)

The company also develops new innovative products and solutions that improve the cell connecting process and reduce its handling steps. All equipment is designed and manufactured in-house.

Stringer-integrated electroluminescence (EL) testing unit – the early detection of hidden cell defects leads to better module quality.

CONSOL soldering table – the cost-saving system for module, cell, ribbon and paste manufacturers, laboratories and institutes. The CONSOL soldering table is now available in a string or cell edition.

CONFORCE peel force tester – testing with standardised parameters leads to optimised verification of cell/ribbon connections.

Vision-upgrade with new Human Machine Interface (HMI) for existing customers – improved cell defects detection, intuitive operator guidance.

Outstanding service solutions make the difference

The main focus is to satisfy customers with maximum machine availability, high productivity and minimum cost of ownership. Somont's reliable and reproducible soldering processes and handling systems are enhanced by an excellent service package to support customers in every conceivable situation. Hotline support with competent service technicians, training, ramp-up assistance and efficient spare part management ensures high uptime for its customers worldwide.

SOMONT
CELL CONNECTING

SOMONT GmbH
Im Brunnenfeld 8
79224 Umkirch
Germany

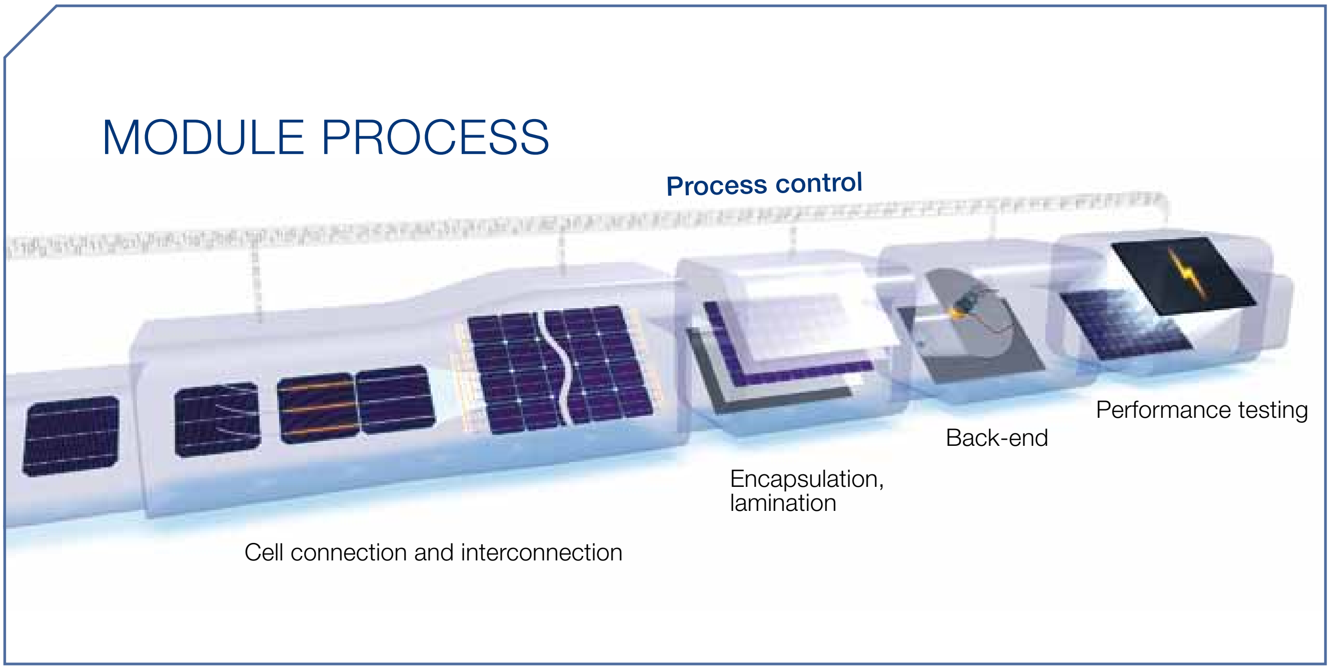
Phone
+49 (0)7665 9809-7000

Fax
+49 (0)7665 9809-7999

Email
info@somont.com

Web
www.somont.com

A member of Meyer Burger Group



Processes and systems from the Meyer Burger Group – from cell to module

3S Modultec and 3S Photovoltaics

Providing Your PV System and Process Solutions

System and process solutions at any stage of your development

3S Modultec and 3S Photovoltaics possess core expertise along the entire module technology value chain. Our research and development work has created state-of-the-art system and process solutions for our customers as well as for our in-house BIPV production line.
By using 3S Modultec solutions and services, customers around the globe are able to produce high-quality PV modules with lowest cost of ownership.

Productivity, uptime, yield
Processes and systems from 3S Modultec play a major role in increasing overall performance and profitability within the PV world. Based on our research & development and our experience in module production, we design our systems and processes to optimise material utilisation and to achieve both the lowest possible production costs and maximum availability.

Carrier glass preparation
3S Modultec's solutions offer a wide variety of materials and methods for preparing the front glass before it is married with the cells: laser marking for module identification, quality control in respect of surface and dimensions, cleaning, and handling of encapsulation materials all form the basis for a maximum line yield.

Cell connecting (from manual soldering to fully automated lines)
Tailored processes for cost-optimised module solutions: experience in module production enables 3S Modultec to find solutions for every challenge posed in established technologies. Our portfolio ranges from manual soldering to high-performance, fully automated lines. As a member of the Meyer Burger Group, we are involved in developing new generations of solar cells at a very early stage, meaning that challenges in the module process are solved in time to start new production lines without delay.

Encapsulation process determines the lifespan of solar modules
The quality of the lamination process determines the lifespan of solar modules. Over the years, the developers at 3S Modultec have perfected the company's encapsulation processes. They utilise our own patented heating device, which provides best-in-class temperature distribution, thereby achieving the shortest possible cycle times and minimum footprints per watt, and fulfilling the highest demands of the PV industry. Together with industrial partners we also work on new encapsulation methods and materials, such as silicon foils and liquid encapsulants. The new generations of highly efficient solar cells present particular challeng-

High-performance solar panels for efficient energy provision, Klein Matterhorn, Switzerland © *Schweizer Solarpreis 2010/Solar Agentur Schweiz*

es for the module process. 3S Modultec's systems take the growing demands into account by integrating new lamination techniques into the process.

Final assembly

Laminated modules are connected together through final assembly. Here, 3S Modultec offers the full range of devices and processes, from manual trimming, J-box mounting, tape and soap, and framing to fully automated assembly where even contacting and J-box mounting are carried out by robots.

Performance measurement

To ensure the quality and performance of the modules produced, the lines are equipped with the devices necessary to test all products, such as optical checks, EL testers and Hipot testers. The electrical characteristics of the modules are measured using a sun-simulator from Pasan, which is also a member of the Meyer Burger Group.

Process control (FabEagle®$_{MES}$)

Monitoring and supporting the entire production process: by integrating and combining all processes, machines, material flows and maintenance works in an overall software system, the complex photovoltaic production process becomes manageable. Meyer Burger FabEagle®$_{MES}$ serves as a control centre for all production requirements and generates benefits through higher-level functions that ensure overview and control at every stage in the production process. The MES software enables weaknesses to be analysed. It is an effective tool for achieving production improvements in terms of efficiency and stability – for higher yield and lower costs in every production step from silicon to the solar module.

Worldwide service and process support

3S Modultec, as a member of the Meyer Burger Group, is represented in the key solar industry markets throughout the world. An international service network enables us to provide optimum support to our customers. Our process specialists and service engineers supply on-site support with process know-how, maintenance and repair services, spare parts and consumables, training, production ramp-up, TÜV certification and other services – directly, promptly and with the utmost dependability.

3S MODULTEC
MODULE SOLUTIONS

3S Swiss Solar Systems AG
Schachenweg 24
3250 Lyss
Switzerland

Phone
+41 (0)32 391-1111

Fax
+41 (0)32 391-1112

Email
info@3-s.ch

Web
www.3-s.ch

Year founded
2001

Employees
170

A member of Meyer Burger Group

modustringer®simplex

Automatic ribbon preparation

Soldering head

MIKRON

Assembly Solutions for the Photovoltaic Industry

Premises in Berlin

Mikron Berlin GmbH
Landsberger Straße 252
12623 Berlin
Germany

Phone
+49 (0)30 98 3072 11

Fax
+49 (0)30 98 3072 20

Email
mab@mikron.com

Web
www.mikron.com

Year founded
1991

Employees
> 80

Our contribution to promoting green energy: Pull the strings!

Mikron Automation – The experts in assembly automation. Experience gained over 36 years in designing and manufacturing assembly and test solutions.
Integrated into the Automation Division of the Swiss Mikron Group, Mikron Berlin is the competence center for the photovoltaic industry, also providing customized systems to the market. Our customers benefit from the global platform and solutions expertise of a corporation operating worldwide.
In the field of silicon technology, Mikron has developed the modustringer®simplex, a high-performance stringer system with a new intelligent technical specification for the mass production of high-quality strings. High throughput, low breakage rates and perfectly soldered strings are just some of the benefits provided by this stringer system. A modular design which is easy to service reduces retooling and downtime to a minimum.

The modustringer®simplex can be integrated easily and flexibly into existing production lines or installed as a component of new module fabrication lines. The modustringer®simplex guarantees the highest possible rate of productivity while ensuring the careful handling of solar cells.

In addition, Mikron Automation offers layup systems with interconnection and string inspection functions.

The modu*layer is the perfect device to complement the modustringer®simplex. modu*layer systems can be easily integrated into mass production plants.

The advantage for our customers at this stage of the value-added chain is that they are provided with a comprehensive pool of expertise with everything available from one source.

Mikron's latest development is the modu*contec system for thin-film module production. It performs complete rear-side contacting of thin-film solar modules, including the contact interface for the junction box. modu*contec was developed with the modular structure and design of the modustringer® system in mind and is the first ever system to combine essential technologies with high processing speeds.

We utilize the experience gained over many years in designing and manufacturing assembly and test solutions to reduce costs and improve the efficiency of solar production facilities. We offer tailor-made automation systems from a single source, from consulting and system conception, design and manufacturing to full technical support. No matter where they are used across the globe, Mikron products are backed up by a professional customer support service.

Divided belt system

Process chamber RFS Fast Firing System

Edge contact stand-offs

Rehm Thermal Systems GmbH

Thermal Equipment for Metallization

Simply. More. Ideas.

Rehm Thermal Systems was founded in 1990 by Johannes Rehm and is a provider of reflow soldering systems and drying systems for the electronics industry, as well as a manufacturer of fast firing systems and solar dryers for the metallization of solar cells.

With Simply. More. Ideas. our goal is to become the technological leader in all areas of production and offer our customers sustainable and future-oriented products. This means we strive to be more innovative, more reliable and more efficient than our competitors and also offer our customers the best possible options in terms of cost-benefit ratio.
Long-standing partnerships with our customers, collaboration with renowned institutes and comprehensive expertise will ensure our continued success in the future. A large proportion of our products are manufactured in-house, meaning we can offer our customers the right solution to match their individual specifications.
To cover the increasing requirements of energy while reducing the consumption of fossil fuels, alternative sources of energy, for example solar energy, are increasingly gaining in importance. For the production of the required solar cells, Rehm offers firing and drying ovens to insert them into a metallization line.

Solar dryer

The RDS dryer for metallization lines dries pastes on silicon solar cells, which are applied by means of screen printing. The drying system comprises a combination of several infrared zones and one central convection zone. A VOC Thermal Oxidizer system is optionally available for purifying exhaust air.

RFS Fast Firing System

Rehm's new fast firing systems for typical mono- and polycrystalline solar cell manufacturing are distinguished by their outstanding quality and a modular design which allows for a variety of production line layouts.

- lowest possible breakage rates
- high throughput levels (up to 4,800 pcs. per hour with RFS-D 500)
- low maintenance costs
- highly efficient solar cells
- exact temperature profiling

solar awards WINNER 2011

RFS Fast Firing System

THERMAL SYSTEMS

Rehm Thermal Systems GmbH
89143 Blaubeuren
Leinenstraße 7
Germany

Phone
+49 (0)7344 9606-0

Fax
+49 (0)7344 9606-525

Email
info@rehm-group.com

Web
www.rehm-group.com

Year founded
1990

Employees
> 600 (group)

Tabber & stringer TS1200

Robotized cell handling

Infrared soldering system

MONDRAGON ASSEMBLY

With Us It Is Possible

Key equipment for module manufacturing

Vision system

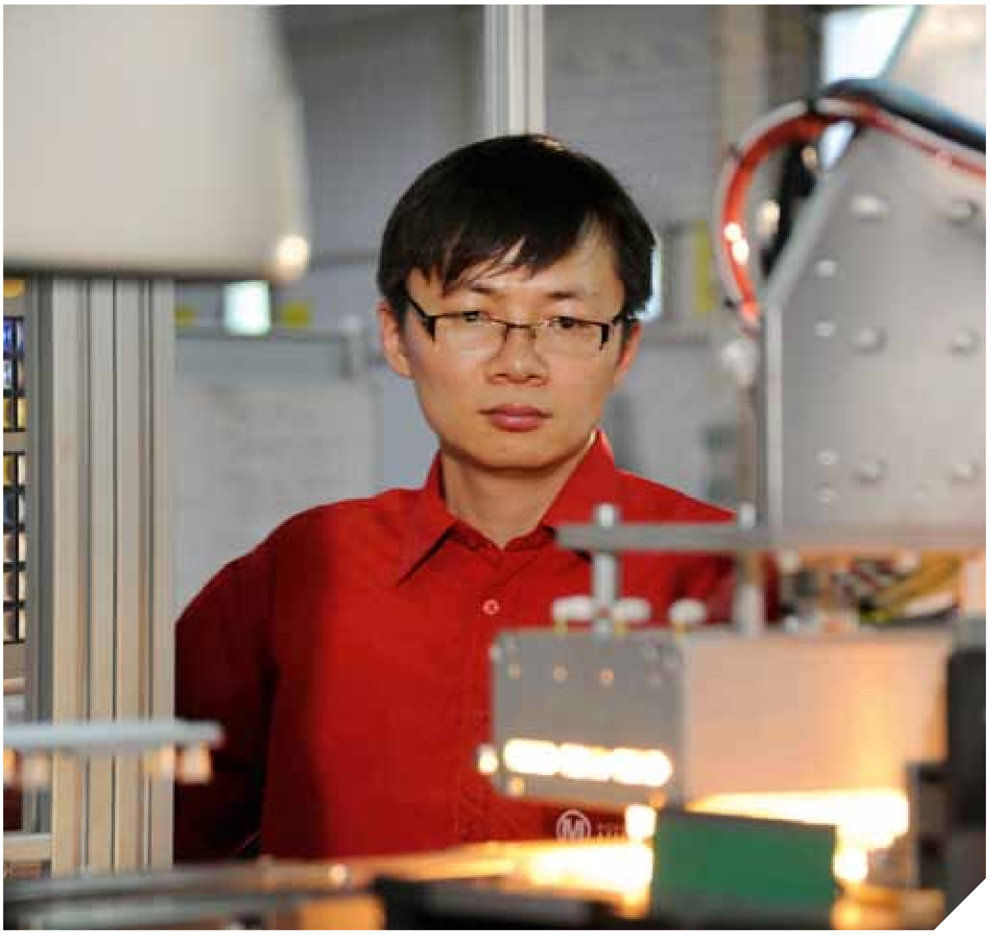
Mondragon Assembly is a part of the world´s largest cooperative group: the Mondragon Corporation. Starting in 1954 it is today a group of more than 255 companies and 90,000 employees that enjoys constant growth.

Mondragon Assembly is an established international group specialized in the development of integrated automation solutions. The parent company in Spain was founded in 1977 and was one of the pioneers in the use of high technology processes such as robotics, vision, dispensing, gluing, soldering and test machines. Today it is now an international group and has manufacturing plants in Spain, France, Germany and Mexico. In addition to this, the group has a strategic network of different subsidiaries and partners worldwide.

In 1999, using the experience gained over many years with state-of-the-art technologies, Mondragon started the development of high quality equipment for module manufacturing in the photovoltaic industry and the company has been successfully active in this sector for over a decade. With solutions for plant sizes from 10 MW to over 100 MW and for semi-automated and fully-automated turnkey lines alike, including the supply and development of all machinery, the company provides services ranging from module design to certification guarantees, raw material specification and process know-how training. Individual machines such as tabbers & stringers, bussing or interconnection systems, cell testers/sorters, slash testers, laminators and EL systems are supplied.

The focal point of the Mondragon Assembly product portfolio is standard solar PV modules, though we also specialize in more innovative solutions such as extra thin glass-glass modules for BIPV (building integrated) special high-tech modules with differently shaped strings or small special purpose modules with cut cells, for example.

Tabber & stringer TS 600 LT "Lite"



Maintenance service worldwide

Turnkey lines

Key equipment

Professional services that we provide:

- project design and assessment of the production plant and building
- layout and equipment for the module manufacturing plant, tailored to customer specifications
- machine installation and commissioning
- advice on raw materials
- training of personnel
- module certification
- preventive and periodic maintenance
- production start up and ramp up
- tele-diagnosis and online support
- design, manufacture, and installation of a wide range of systems and equipment for assembly process automation

Mondragon Assembly's experience

- over 35 years of experience
- more than 1,000 projects
- worldwide service – international presence

Technology and innovation

Mondragon Assembly applies its products and services to a large number of technologies and is a pioneer in the development of new ways to use automation.
Dedication to innovation, excellent management, and close relationships with our clients are the three values that have made Mondragon Assembly a reference point around the world.

MONDRAGON ASSEMBLY

Mondragon Assembly
Pol. Ind. Bainetxe, Pab. 5-A
20550 Aretxabaleta
Spain

Phone
+ 34 (0)943 71 20 80

Fax
+ 34 (0)943 71 22 10

Email
info@mondragon-assembly.com

Web
www.mondragon-assembly.com

Year founded
1977

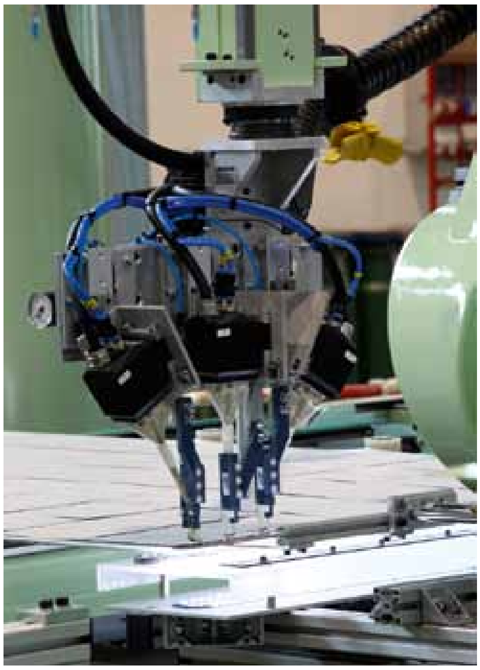
Employees
180

Our products

Mondragon Assembly's products are characterized by precision, proven reliability and a high level of productivity.

Courses and on-site training

Manufacture of photovoltaic modules: layup area



Robotic unit for string cross connection soldering on PV modules

REIS ROBOTICS

Fully automated framing station for PV modules

REIS ROBOTICS

REIS GmbH & Co. KG Maschinenfabrik
Walter-Reis-Straße 1
63785 Obernburg
Germany

Phone
+49 (0)6022 503-0

Fax
+49 (0)6022 503-110

Email
info@reisrobotics.de

Web
www.reisrobotics.de

Year founded
1957

Employees
1,300 (worldwide)

A leading partner for cost-optimized solar module production

Based on a large number of projects, REIS ROBOTICS has developed sophisticated standards for solar module production that are used worldwide by renowned production plants. Our customers' success is based on our high process know-how and the optimum price/performance ratio of our production systems.

The 130 systems installed to date by REIS ROBOTICS produce solar modules all over the world and generate more than 8 GW of additional, clean electric energy annually.

Single modular production cells and single items of equipment are provided by REIS ROBOTICS as well as complete production lines – from project planning to commissioning. Depending on the customer requirements, the options include manual, semi-automatic or fully automatic production systems for silicon, thin-film, and solar thermal module production. The solutions comprise all production steps from single items of equipment in single process stations to full integration and system optimization of all the production systems together – with cycle times of up to 17 seconds/module.
REIS ROBOTICS is an innovative, leading company in robot technology and system integration. The REIS ROBOTICS Group, which operates at international level, has its headquarters in Obernburg, Germany, and is a market leader in the production of automation systems for the photovoltaic industry. For more than two decades it has been one of the most important integrators for automation systems in all major industry sectors. Eight subsidiaries worldwide ensure consistently high integration results, an after sales service and reliable, fast customer service.

Our products and services:

- single-process stations for retrofitting and optimizing the performance of existing module production lines
- manual "low-automation" production line for module production
- single systems to complete production lines – manual to fully automated
- production systems for production of thin-film modules and solar thermal collectors
- handling systems and automation for ingot production
- test systems for quality assurance
- technology development and module certification
- system planning, material flow and 3D-simulation
- development of production methods
- after sales service and attendance on site
- MFR, host controllers

SCHMID headquarters in Freudenstadt, Germany

Polysilicon 11N grade produced using the SST monosilane method

Technology center at SCHMID Group headquarters in Freudenstadt, Germany

SCHMID Group | Gebr. SCHMID GmbH

Maximize your competitiveness – with SCHMID

SCHMID's way of thinking has been process and future oriented for almost 150 years. The company's tradition as a system supplier is already continuing in its fifth generation, with the focus on customer-oriented process solutions, economic concepts and the continuous development of new process technologies in its own research centers. SCHMID's solutions have been setting new benchmarks in technological innovations, high quality standards, creative new ideas and integrative process solutions, which customers all over the world profit from today.

As a globally active company the SCHMID Group has 2,500 employees worldwide in key markets in Europe, Asia and North America and is represented worldwide with a large number of service branches.

As one of the world's leading technology and equipment providers for the photovoltaic, printed circuit board and flat panel display industries, SCHMID sees itself as a pioneer in those markets. The production of solar cells is a sophisticated process which places high demands on the technology of the system. Through its technologies, SCHMID offers innovative solutions which fulfill these demands by 100%, covering the entire solar value chain from silicon to wafer, cell and module production with the highest percentage of in-house production within the industry.

SCHMID is one of the few companies in its sector to offer not only innovative single solutions, but also the planning, development and realization of turnkey systems with guaranteed performance parameters such as production capacity, yield and efficiency. As one of the leading manufacturers of integrative process solutions, SCHMID operates worldwide offering top-quality solutions for its customers' requirements.

Our partner Schmid Silicon Technology GmbH

Schmid Silicon Technology GmbH (SST) is a provider of the latest generation of high-end solar, electronic grade polysilicon (10N+) and monosilane gas (6N) production technology. SST invests in its own R&D projects and operates Schmid Polysilicon Production GmbH (SPP) in Saxony, Germany, designed to showcase its advanced monosilane technology. SST supplies single-equipment and turnkey solutions for polysilicon production, facilitating cost reductions of up to 40% compared to traditional production methods. SST and the SCHMID Group together provide state-of-the-art production technology covering the entire photovoltaic value chain.

SCHMID Group | Gebr. SCHMID GmbH
Robert-Bosch-Straße 32–36
72250 Freudenstadt
Germany

Phone
+49 (0)7441 538-0

Fax
+49 (0)7441 538-121

Email
info@schmid-group.com

Web
www.schmid-group.com

Year founded
1864

Sales volume
550 million euros
(Group 2011, not consolidated)

Employees
2,500 (December 2011, worldwide)

Group members
24 companies (2012)

Production facilities
9 facilities (2012)

Schmid Silicon Technology GmbH
Dr. Burkhard Wehefritz
Director | Sales Development Department
Robert-Bosch-Straße 32–36
72250 Freudenstadt, Germany

Phone
+49 (0)7441 538-673

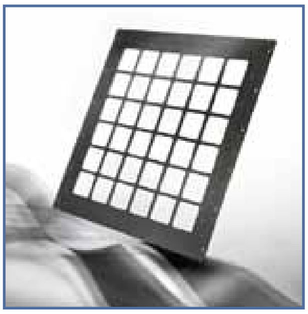
Email
Wehefritz.Bu@schmid-silicon.com

Schunk Group

Customized Solutions for High Temperature Applications

1

2



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Shaping the future together

Schunk Kohlenstofftechnik GmbH is part of the Schunk Group, a globally-active technology group. The group of companies offers a broad spectrum of products and services in the fields of carbon technology and ceramics, environmental simulation technology and climate technology, sintered metal technology and ultrasonic welding technology.

The company, founded in 1913, incorporates more than 60 operational companies with around 8,250 employees worldwide. The Schunk Group is represented in 27 countries, and in 2011 generated a consolidated turnover of approx. 957 million euros.

The Schunk Group is divided into the following technology branches:

- Schunk Materials
- Weiss Group
- Schunk Sinter Metals
- Schunk Sonosystems

Schunk is not only associated with high-quality materials and components, stable quality, safety and perfection with tradition; Schunk represents much more. The will to tackle problems differently and to strike new paths, as well as the passion for finding new solutions, are the driving forces. Our motto for the future is innovation.

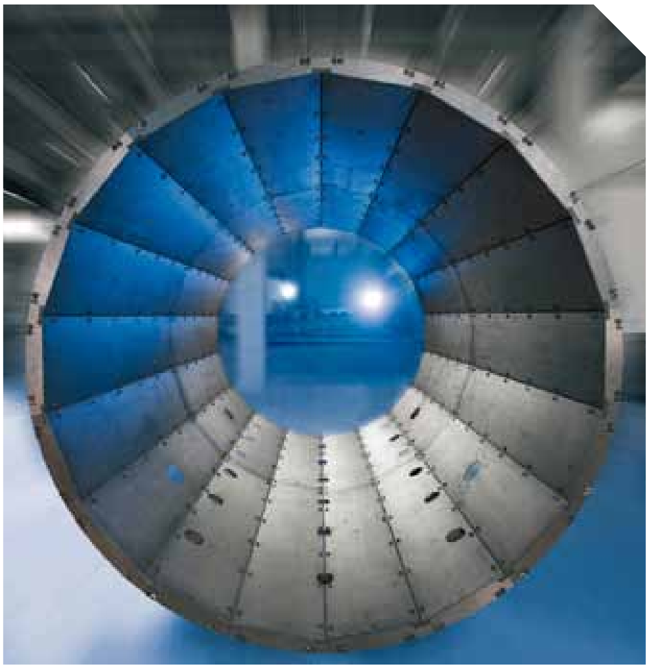
With regards to expertise and top quality, we always prove ourselves to be a reliable partner. In the future, we will show even more clearly how our extensive knowledge is used to turn our components into indispensable elements for countless efficient technologies, machines and devices.

Innovative technology for extreme temperatures

Schunk Kohlenstofftechnik GmbH specializes in the development of materials for the achievement of form, stability and resistance to extreme temperatures.

As an innovative provider of materials and products for the entire spectrum of modern crystal growing systems, Schunk supports its customers on their cost-intensive journey from raw materials to energy-supplying solar modules.
Our key areas of expertise include the manufacture, cleaning and coating of graphitized materials and carbon fiber reinforced carbon (C/C) for use at high temperatures.

Schunk heating and crucible systems made from graphite and C/C are used in current procedures for manufacturing silicon crystals. These systems are used to smelt and store raw material within the multi-stage processes for producing polycrystals and monocrystals.



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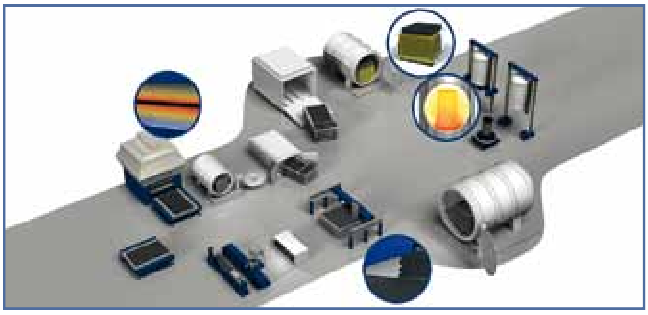


6

1 C/C crucible made by Schunk
2 Customized insulation made by Schunk
3 PECVD-C/C carrier made by Schunk

4 Customized C/C furnace inliner made by Schunk
5 Customized C/C furnace inliner made by Schunk
6 C/C production and refinement

Individual solutions for the highest temperatures and complex geometries

In addition to plate geometries, Schunk Kohlenstofftechnik GmbH also produces rotationally symmetric components.

Our C/C wound components are used primarily in the solar and semiconductor industries, where we are successfully positioned for high mechanical and the highest purity requirements.
After final dimension processing, our C/C wound components are subject to further finishing stages depending on their intended use.

Our strength lies in high-volume components with large surface areas. Targeted expertise and many years of experience make us one of the few providers worldwide with the ability to produce almost all components in maximum dimensions.

Our C/C manufacturing process is internationally renowned for customized materials with a very high level of stability and low density. In addition, we offer the utmost in process stability for every customer-specific requirement.

Our long-standing experience in the field of graphite and C/C refinement enables both the manufacture and targeted refinement of high-volume components. Using silicon carbide and pyrocarbon coating procedures, we are developing basic materials to be used in new areas of application.

Support from the first idea to manufacturing

We accompany our clients during the entire planning and development process. In this way, many application and client-specific problems can be solved in the early stages through the use of computer simulations. We offer support both in the design and dimensioning of components, and also in choosing the most economic form of production.

Schunk Group premises at Heuchelheim

schunk Group

Schunk Group
Rodheimer Strasse 59
35452 Heuchelheim
Germany

Phone
+49 (0)641 608-0

Fax
+49 (0)641 608-1223

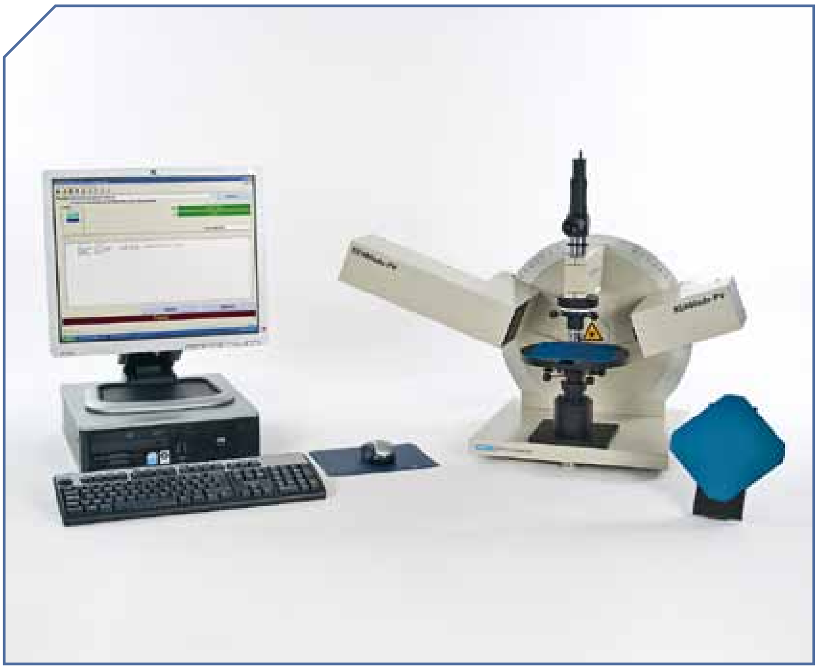
Email
infobox@schunk-group.com

Web
www.schunk-group.com

Year founded
1913

Sales volume
Approx. 957 million euros (2011)

Employees
Approx. 8,250



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3

SENTECH Instruments GmbH

Experts in Thin-Film Metrology

SENTECH Instruments GmbH
Schwarzschildstraße 2
12489 Berlin
Germany

Phone
+49 (0)30 63 92 55-20

Fax
+49 (0)30 63 92 55-22

Email
marketing@sentech.de

Web
www.sentech.de

Year founded
1990

Employees
55

Innovative measurement technology for the PV industry

SENTECH develops, manufactures and sells instruments and automated systems for the measurement of crystalline silicon and thin-film solar cells. The company is a market leader for tools which measure antireflective coatings on crystalline silicon solar cells and the haze of rough TCO films on large glass sheets. Customized solutions are offered for R&D and quality control of production processes. SENTECH offers solutions and services worldwide based on its extended distributor network.

Antireflective and passivating coatings

The laser ellipsometer SE 400adv PV and the spectroscopic ellipsometer SE 800 PV, specially developed for measurement on rough surfaces, are offered for the characterization of antireflective and passivating films on textured monocrystalline and multicrystalline silicon solar cells. Single films and multiple layer stacks can be analyzed. Customized solutions are available for offline and inline applications.

Thin-film solar cells

The horizontally or vertically configured, computer-controlled multiple sensor mapping platforms, SenSol H and SenSol V, are offered for offline measurements of film properties on large area glass sheets. The tools are used for R&D and quality control of production processes, especially the manufacture of thin-film silicon solar cells, and CIGS solar cells can also be monitored. Sensors are provided for the measurement of film thickness, reflection, transmission, haze, sheet resistance, crystallinity, band gap, I(V), and external quantum efficiency.

Inline measurement tools

Reflection and transmission measurements are suitable for the inline control of the thickness of single films and layer stacks during the manufacture of thin-film solar cells. SENTECH offers the FTPadv Inline which allows one controller to control up to seven sensor heads. Measurements can be made in the UV–VIS–NIR spectral range.

1 Ellipsometer for measurement on textured silicon solar cells
2 Sensor heads for reflection and transmission inline monitoring
3 Multiple sensor platform SenSol H for haze measurement on thin-film solar cells

Siemens Industry Sector

Plant-wide integrated solutions for the solar industry

Siemens' involvement in the solar industry reaches back to the 1950s – long before renewable energies conquered the market. The first notable achievement by Siemens was to produce ultra-pure monocrystalline silicon using zonal heating. That innovation was followed by the invention of the "Siemens reactor", a thermal decomposition furnace, which enables the production of polycrystalline silicon. Both technologies are still widely used today.

Today, Siemens provides products, systems and solutions for automation, infrastructure and IT in a wide range of applications. With this broad experience Siemens is the perfect partner for the major players in the solar industry. The portfolio for solar applications – for photovoltaics as well as for concentrated solar power – covers the entire value chain, from glass and silicon materials to module production and field installation. Whether our customers plan to enter new technology fields or expand their production in scale or scope, we provide plant-wide integrated solutions that integrate all automation, drive, instrumentation and energy distribution solutions. We accelerate time to market with virtual planning and commissioning. Services for the entire life-cycle of the plant ensure maximum plant availability and optimized operating costs. And for the field Siemens provides inverters, tracking control, wireless communication and other key automation components.

SIEMENS

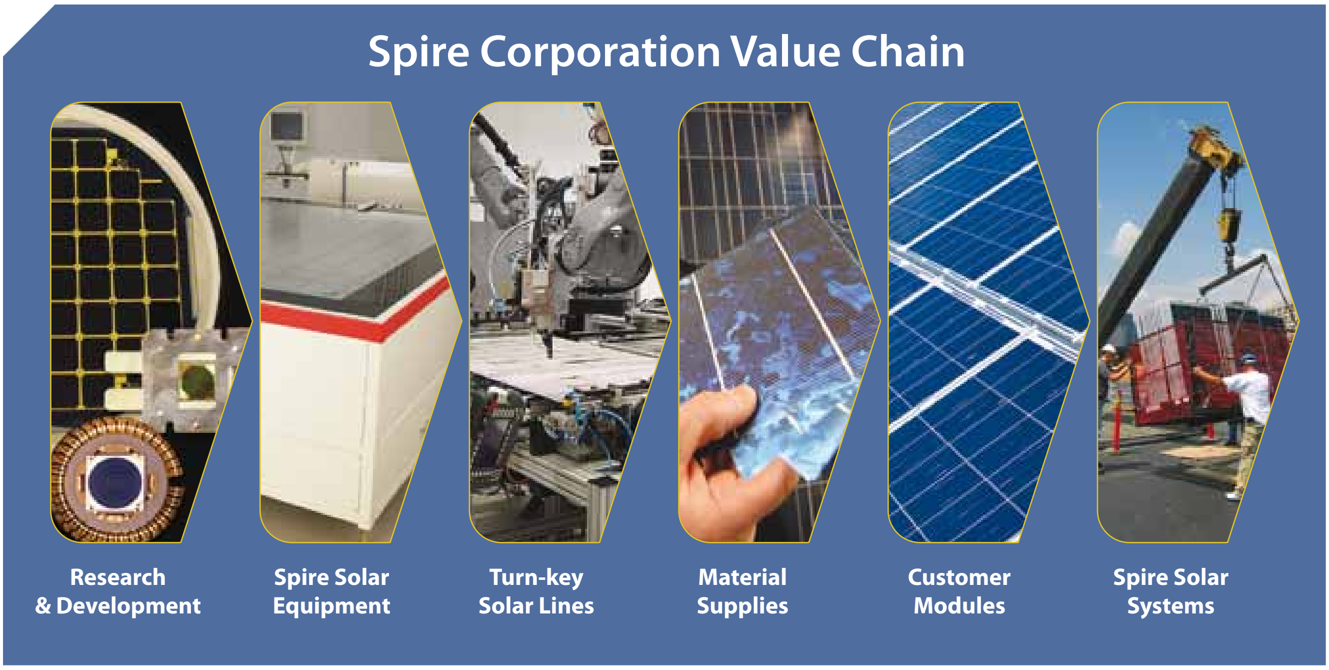
Siemens AG
Industry Sector
Industry Automation Division
VSS Glass & Solar
Siemensallee 84
76187 Karlsruhe
Germany

Phone
+49 (0)721 595-1552

Fax
+49 (0)721 595-4477

Email
solar.industry.automation@siemens.com

Web
www.siemens.com/solar-industry



Spire spans the PV value chain.

Spire Corporation

A Leading Global Solar Company

Spire Corporation
One Patriots Park
Bedford, MA 01730
USA

Phone
+1 781 275-6000

Fax
+1 781 275-7470

Email
pvsales@spirecorp.com

Web
www.spiresolar.com

Year founded
1969

Sales volume
61.1 million USD

Employees
> 160

Advancing solar technology through innovation

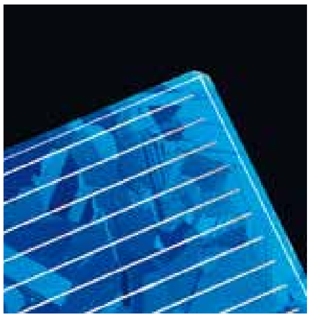
Spire Corporation is a Tier 1 global solar company providing turn-key solar factories, capital equipment, installed PV systems, and critical support services worldwide. With over 35 years of experience in the PV industry, Spire has developed the expertise and technical depth necessary to help make our customers successful. Embedded in our equipment and turn-key lines are the process recipes necessary to optimize cell and module manufacturing. Additionally, we provide world-class support services only possible from a company with Spire's extensive industry knowledge.

Spire's technologically advanced products provide customers with exceptional performance and the lowest total cost of ownership. Our turn-key cell and module lines permit new companies to enter the market and existing manufacturers to quickly and efficiently expand their capacity. Our flexible lines are available in a wide range of capacities, including a 20 MW/year module assembly line for new PV market entrants that provides over 30% reduction in normalized capital expenditures. The lines are offered in manual, semi-automated, and fully automated configurations, and are available for producing either silicon or thin-film modules.

Spire also offers a full range of module manufacturing equipment. Our Spi-Sun Simulators are considered the gold standard in the industry. They are being used by many UL and IEC module qualification and certification laboratories and have become a staple in production lines throughout the world. The most recent addition to Spire's Sun Simulator line, the Spi-Sun SimulatorTM 5600SLP, utilizes an innovative optical design that permits higher measurement accuracy and better control of measurement uncertainty. The system provides Class A+ spectral, spatial, and temporal performance in combination with excellent measurement repeatability. It also offers pulse widths exceeding 100 ms, which permits accurate power measurement of high efficiency silicon, thin-film, HIT, and multi-junction modules. The 5600SLP provides very high throughput rates and a low profile design that integrates easily into any production or test environment. The Spi-Sun Simulator 5600SLP is the core product in Spire's PV metrology line, which also includes electroluminescence testers, high potential isolation and ground continuity testers.

Spire Solar Systems provides module installation and integration services to commercial and federal markets. We provide a full spectrum of technology, service, and manufacturing partners as well as engineering, procurement, construction and maintenance services.

1



2

1 Border deletion on thin-film modules with the TruMicro 7050

2 Laser processing of crystalline solar cells

3 The TruMicro series 5000 is based on disk laser technology.

TRUMPF Business Field Laser Technology

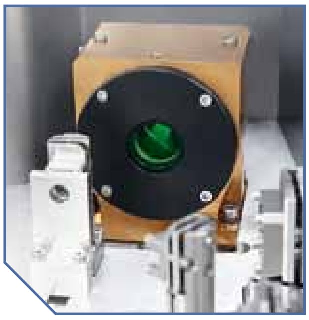
TruMicro Lasers – Getting More out of the Sun

Lasers for micro material processing

The TRUMPF Group is one of the world's leading companies in laser and production engineering. For micro processing solar cells, TRUMPF offers application-oriented lasers from the TruMicro series with an average performance of between 5 W and more than 750 W and with pulse durations from the pico to the nanosecond range. The short and ultra-short pulsed lasers enable micromachining with a perfect combination of quality, productivity and profitability. Whether for structuring, ablation, cutting or drilling, the laser has become indispensable in micro production technology. TRUMPF provides innovative solid-state lasers precisely tailored to these processing tasks. High quality and worldwide renowned customer care play a fundamental role for TRUMPF.

For edge deletion, TRUMPF offers a fiber-guided laser, the TruMicro 7050. The fiber homogenizes the laser power density on the workpiece, providing a large processing window. Furthermore, a narrow fiber diameter enables a larger working distance while the spot cross-section remains the same. The processing area is enlarged and contamination of the processing head is minimized. The TruMicro 7050 features a choice of square or round beam profiles. The series of square pulses enables a removal rate increase of over 50% in relation to the round fiber. The overlap can be reduced with process safety. With a laser power of over 750 W, the TruMicro 7050 achieves very high stripping rates, thereby enabling cycle times in production of less than 30 seconds for typical module sizes.

For structuring CI(G)S thin-film solar cells, TRUMPF offers the ultra-short pulsed lasers of the TruMicro series 5000. The innovative picosecond lasers produce no melt during material processing. For instance, they enable high-speed, crack-free removal of the molybdenum in CI(G)S modules. There is also high potential in "cold" processing the photoactive layer with ultra-short laser pulses. With P1 patterning, the laser can cut the track width by almost half in relation to nanosecond lasers; P2 and P3 patterning even reduce it by a factor of six. This surface gain leads directly to increased efficiency of the solar cell, thereby optimizing costs considerably. With quality and productivity benefits like these, the laser is leaving mechanical methods far behind.



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TRUMPF

TRUMPF Laser- und Systemtechnik GmbH
Johann-Maus-Straße 2
71254 Ditzingen
Germany

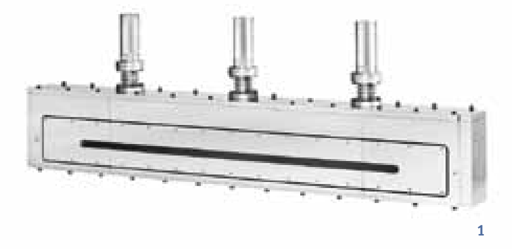
Phone
+49 (0)7156 303-30862

Fax
+49 (0)7156 303-930862

Email
info@trumpf-laser.com

Web
www.trumpf-laser.com

Employees
2,090



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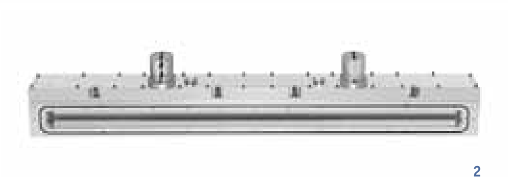
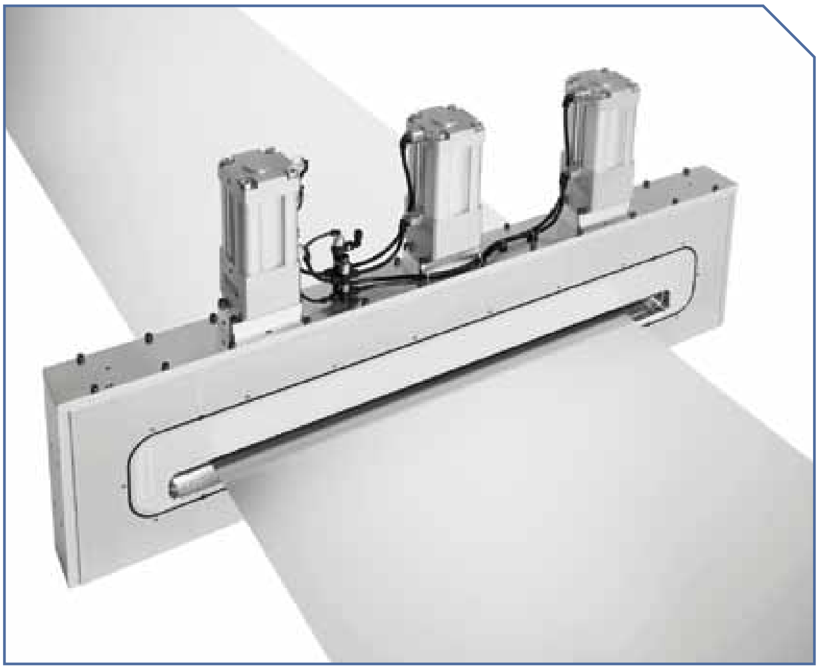


2

1 Transfer valve for PV production systems
2 Novel flapper valve for PV production systems
3 Roll coater transfer valve
4 VAT HQ at Haag, Switzerland



3

VAT

Leader in Vacuum Valves

4

VAT Deutschland GmbH
Am Hochacker 4
85630 Grasbrunn bei München
Germany

Phone
+49 (0)89 97897876-0

Fax
+49 (0)89 97897876-11

Email
de@vatvalve.com

Web
www.vatvalve.com

Year founded
1964

Sales volume
300 million USD

Employees
900

We do nothing but vacuum valves

Due to a wide range of products, highest quality standards, ongoing innovation and long-term service guarantees, VAT has become the world-wide leading manufacturer of vacuum valves.

More than ten subsidiaries ensure professional customer care all over the world. VAT vacuum valves are manufactured at the Swiss headquarters. Service and repairs can be carried out at our service centers or on site.

A variety of more than 1,000 standard valves can be ordered from our catalog. We not only supply standard valves, but also develop the vacuum systems of tomorrow in collaboration with our customers.

Specialized vacuum valves for solar panel manufacturing tools

VAT has made considerable investments in the development of a wide range of transfer valves tailored to the requirements of the most advanced solar panel manufacturing tools. One of the newest developments is the roll coater transfer valve. Due to the linear motion 3D sealing technology it is possible to clamp and seal the web (metal or plastic) without any damage.

Transfer valve SolVAT
- Small flange-to-flange dimension
- Closing mechanism designed for harsh process conditions
- Customer specified flanges
- Modular design enables easy upscaling.
- Tailored for PV and other production systems (such as architectural glass)

Transfer valve FlapVAT
- Closing mechanism designed for demanding process conditions
- Mechanically locked in closed position
- Compact design
- Available as valve, insert or door
- Modular design enables easy upscaling.

Roll-to-roll valve MONOVAT
- Proven three-dimensional MONOVAT sealing technology
- No damage to foil due to the mono-directional sealing movement
- Clamp piece captures O-ring in groove at high temperatures
- Best sealing performance by seals on bottom and top side of foil
- Highest safety by intermediate pumping between valve gate and body seals (only quad sealed version)

Associations

PV will change our world.

Together, we can make a difference.

SEMI PV Group

Stephan Raithel
Director, Photovoltaics Europe

SEMI PV Group
Helmholtzstraße 2–9
Haus D / 3. OG
10587 Berlin
Germany

Phone
+49 (0)30 303 080-770

Fax
+49 (0)30 818 788-79

Email
semiberlin@semi.org

Web
www.pvgroup.org

Year founded
1970

Employees
200

Advancing photovoltaic manufacturing and growing solar markets

SEMI is the global industry association serving the nano- and microelectronics manufacturing supply chains. The SEMI PV Group represents SEMI member companies involved in the solar energy supply chain. SEMI member companies are the engine of the future, enabling smarter, faster and more economical products that improve our lives. SEMI maintains offices in Beijing, Bangalore, Berlin, Brussels, Grenoble, Hsinchu, Moscow, San Jose, Seoul, Shanghai, Singapore, Tokyo, and Washington D.C. For more information, please visit www.semi.org and www.pvgroup.org.

Connect to growing solar markets

SEMI PV Events is the only global event series focused on serving the PV manufacturing supply chain. We connect you to the world's leading solar manufacturing companies and markets at our events and bring together customers and suppliers. From feedstock and materials, cells and modules to system integration and utility-scale project management, SEMI PV Events are your gateway to expanding your solar business. Find detailed information on www.pvgroup.org/Events.

SEMI international standards

Over 4,000 volunteers, 23 global technical committees, and more than 200 task forces have worked tirelessly to create the library of over 800 SEMI standards and safety guidelines.

The industry supports the standards development process because it provides a forum for free exchange of technical expertise and is protected by anti-trust regulations. Companies that participate actively in standards work have a head start on their competitors in adapting to market demands and new technologies. In addition, a recent study has shown that research risks and development costs are reduced for companies contributing to the standardization process.

SEMI is the recognized leader in manufacturing standards – standards created by the industry, for the industry, to make PV a reality throughout the world.

International Technology Roadmap for PV (ITRPV)

Leading crystalline silicon (c-Si) solar manufacturers are working on an international technology roadmap for c-Si photovoltaics (PV). The aim of this roadmap is to inform suppliers and customers and set a basis to intensify the dialog about required improvements and standards. Initial results were published by cell manufacturers in September 2009 and a first roadmap document in March 2010 at the PV Fab Managers Forum in Berlin. Since then yearly updates have been published. All publications are availble on www.itrpv.net.


Annual meeting 2012

View of a cell tester and sorter

Innovation in production

VDMA Photovoltaic Equipment

Your platform for photovoltaic equipment in Germany

The German Engineering Federation (VDMA) represents more than 3,000 companies in the engineering industry and more than 40 sector-specific associations, making it the largest industry association in Europe. 450 employees and 22,000 honorary appointments help the predominantly medium-sized enterprises to remain competitive worldwide with VDMA's network, industry services and advocacy. International support is provided by the VDMA offices in Brussels, Tokyo, Beijing, Shanghai, Kolkata, Delhi, Bangalore, and Moscow.

VDMA Photovoltaic Equipment started in 2007 as a co-operation between the following VDMA divisions: Productronics, Glass Technology, Robotics and Automation Energy, Laser and Photonics, Surface Treatment, Vacuum Technology, Organic Electronics, and Displays. In 2010, VDMA Photovoltaic Equipment became a separate association platform within VDMA. At the same time, activities for members were extended and the visibility of the industry was increased.

The membership base of VDMA Photovoltaic Equipment represents the entire process chain of PV production from polysilicon production and ingot growing through wafer sawing, texturing, anti-reflective coating, metallization, tabbing and stringing, soldering and lamination to automation, handling, optical inspection, and software. For this reason we have established a broad selection of services dealing especially with photovoltaic production and ways to keep our members competitive.

Our annual general assembly serves as an effective information and networking platform. We perform a unique book-to-bill statistics program. Business climate surveys allow us to reliably track the mood in our industry sector. We organize workshops on technology roadmapping, total cost of ownership, supporting innovations and cost-competitiveness. Moreover, we increase the visibility of our members through a multitude of public relations activities. Join us to gain a lead in the European photovoltaic supplier industry! *www.vdma.org/pv*

Blue Competence – VDMA's new sustainability initiative. Sustainability – one single word combining fundamental expectations, demands and hopes when new energy concepts, resources, and environmental technologies are discussed. Sustainability is rarely mentioned in the same breath as mechanical and plant engineering. Clearly the message is not yet sufficiently widespread that only innovative technologies can ensure renewable, environmentally-friendly, energy- and resource-efficient solutions for a better quality of life. This needs to change urgently! Which is exactly where Blue Competence comes in. *www.bluecompetence.net*

Photovoltaic Equipment

VDMA – Verband deutscher Maschinen- und Anlagenbau
Lyoner Straße 18
60528 Frankfurt am Main
Germany

Phone
+49 (0)69 6603-1592

Fax
+49 (0)69 6603-2592

Email
sabine.egerer@vdma.org

Web
www.vdma.org/pv

Year founded
1892

Employees
450 (worldwide)

BLUECOMPETENCE
Engineering a better world

Publishers

1

2

3

Solarpraxis AG – *Engineering, Conferences & Practical Expertise for Renewable Energies*

Solarpraxis AG is one of the leading knowledge service providers in the renewable energy sector

SOLARPRAXIS
engineering | conferences | publishing

Solarpraxis AG
Zinnowitzer Straße 1
10115 Berlin
Germany

Phone
+49 (0)30 726296-300

Fax
+49 (0)30 726296-309

Email
info@solarpraxis.de

Web
www.solarpraxis.de

Year founded
1998

Sales volume
6.9 million euros

Employees
70

Since 1998 the Berlin-based company has been providing clients with expertise and professional services in the fields of engineering, conference organization and publishing.

Engineering
The engineering division at Solarpraxis AG generates up-to-date knowledge, which is then prepared for and presented to manufacturers, wholesalers, planners and trade professionals in a targeted, project-specific manner. Whether in the area of photovoltaics, solar thermal technology, heat pumps or pellets, clients receive expert and reliable support for reporting, large-scale solar projects, technical documentation, training, expert hotlines and customer service.

Conferences
The conference division focuses on organizing high-quality industry events for decision makers both in Germany and abroad. These events are substantiated, relevant to the market and customer-oriented. Using specialist lectures and topical panel discussions, the division provides practical knowledge on market performance, finance and politics. The "Forum Solarpraxis", which celebrated its tenth anniversary in 2009, is well known beyond Germany's borders and is Solarpraxis AG's oldest and most renowned event.

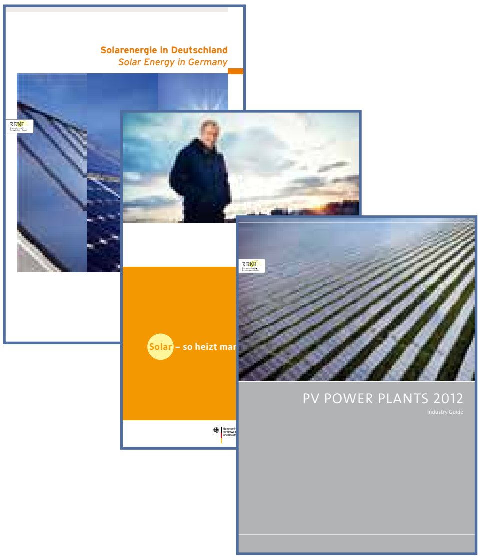
Publishing
With its monthly and quarterly trade magazines "photovoltaik", "pv magazine" and "pv magazine Chinese edition", as well as the accompanying websites, Solarpraxis AG provides a comprehensive and topical overview of the PV industry.

Solarpraxis AG uses multilingual industry reports, published under the umbrella brand RENI | Renewables Insight, to respond to the demand for high-quality industry and technology guides dealing with renewable energies. In collaboration with various professional associations, information on technology and markets is provided and companies are given an opportunity to communicate expert knowledge about their products and services.

1 Solarpraxis communicates expertise and practical knowledge to professionals.

2 The engineering department generates up-to-the-minute knowledge.

3 Solarpraxis' conferences are valued industry platforms.



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Sunbeam GmbH

Communications for the Renewable Energy Market

Sunbeam offers technically oriented communication services perfectly tailored to the dynamic environment of the European renewable energy market.

Since 1998, Sunbeam has been providing in-depth market knowledge and excellent contacts with industry associations and the media. We offer our expertise in the following areas:

Communications

With over ten years of experience in renewable energy, Sunbeam has acquired expertise in all relevant technologies as well as an extensive media network in the field. The company has successfully conducted a variety of campaigns for governmental departments and offers a wide spectrum of services to corporate clients, ranging from PR concepts and consultancy to the complete management of all press contacts.

New media

Sunbeam is one of the leading German agencies for information-oriented, accessible websites. The agency has won a prestigious BIENE award and ranks top in relevant listings for the content management system TYPO3. Two team members are also the authors of renowned specialist books on the design and implementation of web presentations.

Design

Sunbeam values visual communications as a key success factor in the renewable energy market, and thus offers comprehensive expertise in presenting complex matters to technically oriented target groups. In our work for companies, associations and governmental departments we specialize in editorial design for periodical magazines, high quality brochures and extensive industry guides.

Added value

Sunbeam operates through all media channels connected to public relations, new media and design. Clients benefit from our experience both in the management of individual formats and the creation of integrated marketing solutions. Examples of this cross-media approach include our widely distributed press reports on solar, wind and bioenergy ("PresseTrend") and various services for print to web and/or social media publishing.

1 Design and production of prime print products

2 We combine high-quality communications with expertise in technologies and markets in the field of renewable energy.

3 Partner for your cross-media solutions

sunbeam
communications | new media | design

Sunbeam GmbH
Zinnowitzer Straße 1
10115 Berlin
Germany

Phone
+49 (0)30 726296-300

Fax
+49 (0)30 726296-309

Email
info@sunbeam-communications.com

Web
www.sunbeam-communications.com

Year founded
1998

Sales volume
1.4 million euros

Employees
19

3

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Imprint

Publisher

Solarpraxis AG
Zinnowitzer Straße 1
10115 Berlin
Germany

PHONE
+49 (0)30 726296-300

FAX
+49 (0)30 726296-309

EMAIL
info@solarpraxis.de

WEB
www.solarpraxis.de

RESPONSIBLE UNDER THE GERMAN PRESS ACT
Karl-Heinz Remmers

CONCEPT, IDEA, TEXT EDITOR
Solarpraxis AG

PROJECT MANAGEMENT / EDITOR "THE INDUSTRY"
Solarpraxis AG / Dr. Roland Ernst

EDITOR "COMPANIES"
Solarpraxis AG / Ute Bartels with
Lena Kuhn and Sandra Steinmetz

LAYOUT & COMPOSITION
Sunbeam GmbH / derMarkstein.de

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Solarpraxis AG / Tom Baerwald

CHARTS
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"THE INDUSTRY" AUTHORS
Dr. Detlef Koenemann (The Market, The Technology, Manufacturing)
Jürgen Arp, Daniel Pohl (Quality Assurance)
Heiko Schwarzburger (Ecology)

"THE INDUSTRY" EXPERT ADVICE
Dr. Harald Binder

"THE INDUSTRY" TRANSLATION
Peschel Communications

PRINTING
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BOOKLET WEBSITE
www.suppliers-pv.com

ORDERING
Solarpraxis AG
Fax: +49 (0)30 726296-309
Email: info@solarpraxis.de

In 2011, 29.7 GW of PV systems were connected to the grid wordwide, up from 16.8 GW in 2010. PV has continued its triumphant success story – despite the financial and economic crisis and massive consolidations in the industry.

The photovoltaics industry's growth is not only thanks to the manufacturers of solar cells and modules. Plant and machinery manufacturers also have a share in solar technology's unprecedented success story.

"engineering the solar age" provides information about key applications, technologies and, most importantly, the key players in the fields of machine engineering, automation, factory design, and raw and process materials.

www.suppliers-pv.com

SOLARPRAXIS
engineering | conferences | publishing

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