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PV-TEC – Research factory for solar cells

22. November 2007

The current photovoltaic boom makes for a good environment for companies in this country. The rate of growth is enormous and global competition and cost pressure are ever increasing. As in other high-tech fields, what is important is improving the production, the quality and the efficiency of solar cells through technological innovations, while simultaneously reducing units costs. With production plants working at full capacity, the photovoltaic industry has only limited opportunities for testing new technologies and concepts. This is where the Photovoltaic Technology Evaluation Centre (PV-TEC for short) comes into its own. Since the beginning of 2006, solar cell, wafer and module manufacturers as well as system manufacturers can analyse and develop innovative processes, materials and systems in an ultra-modern production line for crystalline silicon solar cells, without having to interrupt operation on their own production lines.

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In PV-TEC every single product goes through a complete, mainly automated monitoring system – from the wafer to the finished solar cells. Photo: Fraunhofer ISE

In November 2007 Solarserver.com in cooperation with BINE Informationsdienst presents the PV-TEC research factory as "the solar energy system of the month" and highlight crucial aspects of research and development.



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The system technology has been conceived and designed so that for every production stage individual parameters can be varied and innovative technological alternatives can be tested. PV-TEC is a large laboratory in the Fraunhofer Institute for Solar Energy Systems; it is located in Freiburg in the Solar Info Center building, close to the main building. The construction of the Centre was mainly financed out of the research budget of the German Federal Ministry for the Environment (BMU); funds were also provided by the Fraunhofer-Gesellschaft. The purpose of the Centre is to secure and strengthen the competitiveness of the German PV industry and develop solar technologies in the immediate future. Already in the first year of operation many well-known solar cell manufacturers and production suppliers have completed projects at PV-TEC. Now, the facility is to be financed by industrial projects, supplemented by a share of essential research projects from the public energy research sector.

Why a test and evaluation centre?

Solar power generation will continue to be dominated by crystalline Record-breaking tempo silicon solar cells. Solar cells on the market today are still comparatively thick ($240\ \mu\text{m} = 0.24\ \text{mm}$) and the efficiency levels of 14-16% still offer potential for optimisation: The feasibility of $99\ \mu\text{m}$ thin polycrystalline silicon cells with an efficiency level of over 20% has already been shown in laboratory scale and small-scale production. These successes have been achieved with solar cell concepts and industry-comparable production stages, which are now being tested in PV-TEC. This should accelerate the introduction of new solar cell designs and innovative production technologies into industrial solar cell manufacture. The optimisation of solar cells is based on individual parameters, details and processing stages. It is therefore necessary to quantify the advances in comparison to cells from reference processes or reference materials. In the PV-TEC test and evaluation centre separate process stages or the design of individual cells or an assembly of cells can be varied without the production line having to be completely reorganised.

Equipment and opportunities of the test factory

The PV-TEC has surface area of 1,200 m². The systems and machinery for energy and utilities supply are accommodated on 800 m² in neighbouring premises: Pure air, cold, vacuum, various gases, distilled water, purification processes etc. ensure smooth operation of the production systems.



Picture: Fraunhofer ISE

The facility offers a flexible test, experimental and evaluation line under productioncomparable conditions. The experiments can be evaluated systematically and on a broad statistical basis. This is because every single product goes through a complete, mainly automated monitoring system – from the wafer to the finished solar cells. And up to 200 specimens can be processed per hour.

Layout of the process line

The production line consists of individual automated process islands, each of which has high-level flexibility, can handle a throughput of 200 to 1,000 silicon wafers per hour and can process different wafer sizes up to a format of $210 \times 210\ \text{mm}^2$, as well as very thin wafers. The wafers are transported from one process to the next in special magazines (fig. 2). There are two variants for wet and dry processes, accommodating 100 wafers in each case, as well as integrated cassettes for thermal processes (diffusion + oxidation)

Automation concept

The wafer cassettes can be automatically loaded and unloaded at the process stations. Every wafer has a laser-marked code (fig. 2), and each magazine has an individual identification code and a communication system linked to the process stations. Thus selected wafers can be withdrawn at a specified process station (fig. 3) so that fully automated special experiments and comparative processes can be carried out.



Fig.. 2: Wafer with laser coding. Fig.. 3: Automatic wafer handling at PV-TEC. Pictures: BINE Informationsdienst

Elementary process stations

The production line includes various classical stations, which are loaded individually or in batches. In wet chemistry, for example, this applies for diffusion, thermal oxidation and screen printing.

Innovative process stations

Innovative production stages are also tested, alternatively or in addition, usually with installations where the cells can also be processed inline. There are different high temperature systems and one system for wet chemical processing, e.g. for the texturing of polycrystalline silicon wafers (Fig. 4). In addition, innovative coating systems are used and tested, for example:

a) The PECVD system (Plasma Enhanced Chemical Vapour Deposition) for coating solar cells with silicon nitride, silicon oxide or amorphous silicon (inline). The coat deposition from a silane / ammonia plasma is carried out as a continual process. The process is also suitable for rear passivation and the deposition of gradients or multilayer coatings.

b) The PVD system (Physical Vapour Deposition or "sputtering", fig. 5) for the application of silicon nitride, silicon oxide and aluminium coats (inline). Here the coat deposition is not carried out on the basis of silane gas, rather with silicon substrate and cathode sputtering. The process is also suitable for surface passivation, transparent electric-conducting coating, rear side reflection, etc. Another processing system with diverse application possibilities is the laser station with different beam control options. The laser can mark the of solar cells, structure surfaces, doping profiles or contacts, drill contact vias etc.



Fig.. 4: In-line installation for wet etching of silicon wafers. Fig. 5: Processing alternative: PVD-Coating. Pictures: Fraunhofer ISE

Analysis and characterisation stations – inline and in the laboratory

The test centre offers innovative, rapid and high-resolution inline characterisation processes and measurement technology for determining material and cell parameters. In a final stage, an industrial solar cell tester and sorter records the electrical parameters of the experimental solar cells.

Exemplary innovations

In PV-TEC various subjects are worked on, all of which have one aim: producing cost-effective solar cells with high efficiency, long-term stability and uniform quality.

Characterisation process:

- Non-contact sheet resistance measurement:** The “Sheet Resistance Imaging” method (SRI) is used to measure the electrical resistance of the emitter layer, which is vital for solar cell efficiency. This purely optical process enables non-contact measurement of topographies of the emitter doping in seconds – an important instrument for the optimisation of diffusion processes.
- Photoconductivity measurement:** With the “Quasi Steady State PhotoConductance” method (QSSPC), the effective life time of free charge carriers in solar cell materials can be determined by the non-contact measurement of photoconductivity. This rapid, widely used measuring method is being further developed so that data can now be collected with higher spatial resolution.

Coating method

- Cathode sputtering with rotating target:** The coating quality, service life and operating costs of the PVD coating system will be optimised in PV-TEC in cooperation with the manufacturer Applied Materials. In the process two rotating, cylindrical silicon targets are now tested as a substrate (fig. 6). With the previous planar targets only around 20% of the silicon substrate could be used, due to the irregular material removal. Utilisation increases up to 80% with the new method.

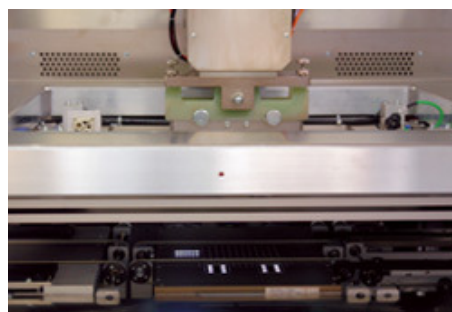
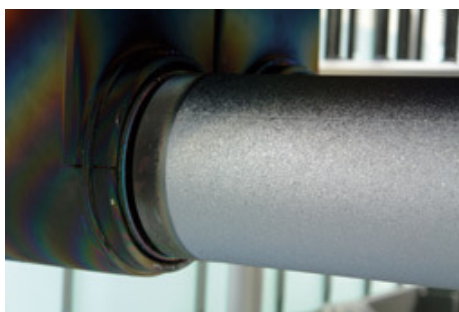


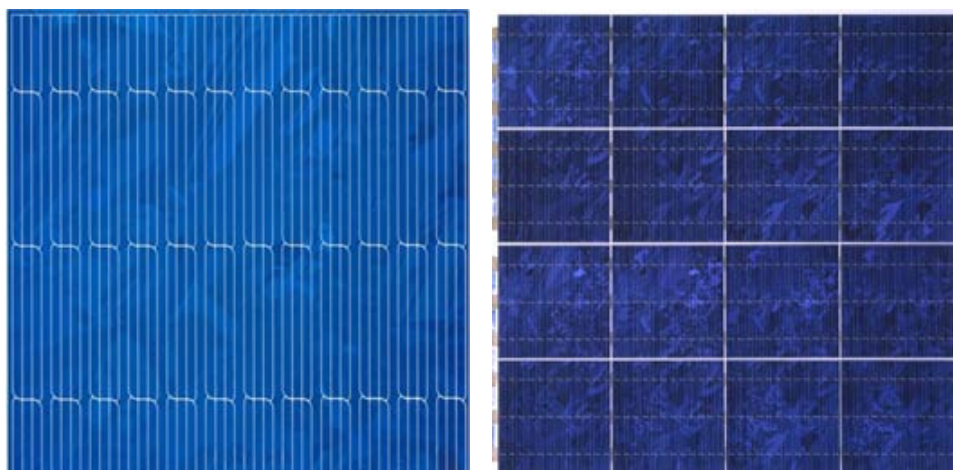
Fig. 6: Cylinder targets for PVD system. Fig.. 7: Screen printing station makes contacts. Pictures: BINE Informationsdienst

Contacting methods

- **Hot-melt screen printing:** Special hot-melt pastes are deposited on the solar cells using screen printing and electrically heated at the same time (fig. 7). This eliminates high temperature drying processes and the equipment, time and energy requirements this involves. Moreover, shading by the frontal contact grid is reduced by a narrow contact finger contour, without impairing the electrical conductivity.
- **Light-induced electroplating:** Extremely filigree and low-shade contact grids are achieved with this combined process. In a two-stage process the frontal contact fingers are initially prepared with lineal contacts applied as seed layers. This can be done with the screen printing method or with new non-contact methods which are still being tested at laboratory scale. Examples of this are "Metal Aerosol Printing" or laser melting of metal powder. The seed layers provide a very good contact to the silicon. In order to improve the lateral electrical conductivity of the contacts, silver is applied in an electroplating process in the second stage. The illuminated solar cell provides the required voltage.

Processing of new cell concepts

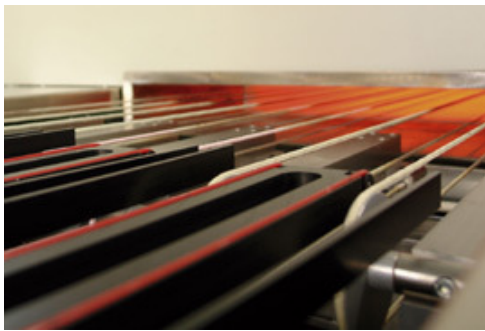
- **MWT (Metal Wrap Through)** Here only the contact finger is situated on the front of the solar cells (fig. 8). These conducting paths are routed at certain points from the front to the rear through laser-induced perforations (approx 50 per cell). The current collecting bus bars are situated at the rear of the solar cell, so that the serial connection of the solar cells takes place entirely at the rear. The relocation of the cell connectors to the rear also contributes to the reduction of shading.



Left: New front contact solar cell (MWT). Right: Panel prototype consisting of 16 MWT solar cells. Pictures: Fraunhofer ISE

- **EWT (Emitter-Wrap-Through):** In contrast to the MWT cell, here even the contact finger at the front is dispensed with. This is achieved in that the highly conductive semiconductor layer on the front is routed through a large number of perforations (over 20,000 per cell) to the rear. The connection of several solar cells again takes place completely on the rear side.
- **Rear contact cell:** A particularly elegant variant of a very efficient solar cell for highpurity silicon material is the rear contact solar cell, where both the negative and positive contact are located at the rear. These cells are characterised by a homogeneous appearance, high efficiency and simple module connection. However, the separation of p and n diffused areas is considerably more complex than with standard solar cells. The development of the related laser structuring technology will be transferred to industrial production.
- **Inline-diffusion:** Inline diffusion: The emitter layer, which is vital for solar power production, is applied at temperatures of approx. 900 °C in the diffusion furnace. Up to now this process has involved batches of 200 to 400 wafers at a time, which are inserted into a tubular diffusion furnace in a

quartz cassette. The inline diffusion process has various advantages; but due to process problems it is only used in isolated cases. A production-scale diffusion furnace is currently being developed and tested in PV-TEC in collaboration with Centrotherm Photovoltaics AG.



The most exciting feature of the four lane system is the contamination-free throughput system with ceramic walking string system (Fig. 9). The method is also suitable for various oxidation processes, for contact burn and for simple drying processes.

Innovative inline diffusion furnace.
Photo: BINE Informationsdienst

Utilisation possibilities

PV-TEC is a facility that provides opportunities for photovoltaic manufactures and production suppliers. Different utilisation models are possible, ranging from small service jobs, i.e. carrying out standard processes, up to intensive research cooperations for the development and testing of innovative concepts, processes and systems. The centre offers training opportunities for manufacturing and plant engineering companies, who want their employees trained in classical and innovative production technologies.

References

Solar cell manufacturers and production suppliers are showing great interest in the new test and evaluation centre. The following companies are already collaborating with PV-TEC: Applied Materials, Centrotherm Photovoltaics, Conergy, Ersol Solar Energy, Schmid, Manz Automation, Q-Cells, Roth & Rau, Schott, Solarfabrik, Solar World, Solland Solar, Sunways, Trumpf, and many more.

Conclusion

Germany, together with Japan, is the global leader in the manufacture of solar cells and has great expertise and potential in research and technological development. However, the competition – particularly in Asia – is growing. And the costs of photovoltaic systems have to be significantly reduced, to make solar power more cost-effective. The opportunities to achieve the set goal of grid parity in the next 5-10 years are good – however, this is only possible if certain fundamental technological innovations in solar cell design and in series production technology can be successfully implemented.

The cost reduction potential of the new thin-film solar cells appears to be very good. However, wafer-based silicon solar cells have still great potential and are in a higher league in terms of efficiency. Thus also in the long-term, they will play an important role in all applications with limited surface areas or high costs proportional to area. Competence centres such as the PV-TEC test and evaluation centre should help create and intensify an innovative environment. PV-TEC also contributes to giving smaller companies a practical platform for practical testing of technological innovations. This enables research results and the innovations that evolve from them to be incorporated more quickly in production. And ultimately, centres of this type can sustainably strengthen the German and European research and technology landscape.



With 60 employees, over 20 current development projects and an annual R+D budget of approx. 4 million euros, PV-TEC is on course to supporting itself in the future, mainly from industrial projects. One reason for this success is that undergoing an extensive testing process at PV-TEC can be counted as confirmation of the practical feasibility of a technological innovation.

Photo: Fraunhofer ISE

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