OCTOPUS

Frank Juergens, Director Sales & Marketing at INDEOtec SA, tells us more about the innovative top and bottom side deposition concept of the OCTOPUS system...

Motivation

High-efficiency solar cells of the heterojunction or IBC type, which are composed of bulk crystalline silicon and thin film layers, have the potential to gain a substantial share in the PV cell market in the future. Industry leaders like Panasonic currently hold the world-record in efficiency of 25.6% for the HIT cell type at R&D scale and 22.5% in mass production . Moreover, the cell manufacturing technology promises the costs will fall well below 0.30 USD/Wp. A study, which investigated the cost reduction roadmap for heterojunction cell types, predicts a level of 0.28 USD/Wp for SHJ, with a corresponding cell efficiency level of 24.9% .

Symmetrical cell architectures, such as the standard heterojunction (SHJ) cell type, have a simplified manufacturing procedure with less process steps in the state-of-the-art technology. One of the key, but critical processes is the deposition of a-Si:H layers on the top and the bottom side of the textured c-Si bulk material, which at first, passivates the Si surface and, secondly, creates the emitter by adding n- and p-type dopant layers. Nowadays, the common method of depositing a-Si:H films is PECVD in RF mode. The current industry knowledge base for depositing amorphous thin films by PECVD reactors is quite good, since the material was used, on a commercial scale, for PV thin-film cell devices in the past. In contradiction to this, the SHJ device requires the a-Si:H deposition on both sides of the bulk wafer, which sets a new challenge for the equipment suppliers, in terms of handling and costs. Also, the films are extremely thin (approx.10 nm) and hence the deposition time is very short, which means that special care has to be taken to ensure the correct plasma conditions immediately after ignition. A simple adaption of the state-of-the-art PECVD reactor technology from large substrate deposition to the new parameter set for HIT cells is therefore relatively risky.

In 2011 Indeotec SA assessed this new application for PECVD systems and started the development of a novel RF reactor type and the system as a whole, which was then introduced into the market under the name “OCTOPUS II”. Extensive research work has been allocated to the optimisation of the plasma conditions and a new reactor type (the Mirror Reactor), which allows the direct deposition of RF plasma to the top and the bottom side of a wafer, without needing to flip the wafer outside the system, and hence without the ubiquitous

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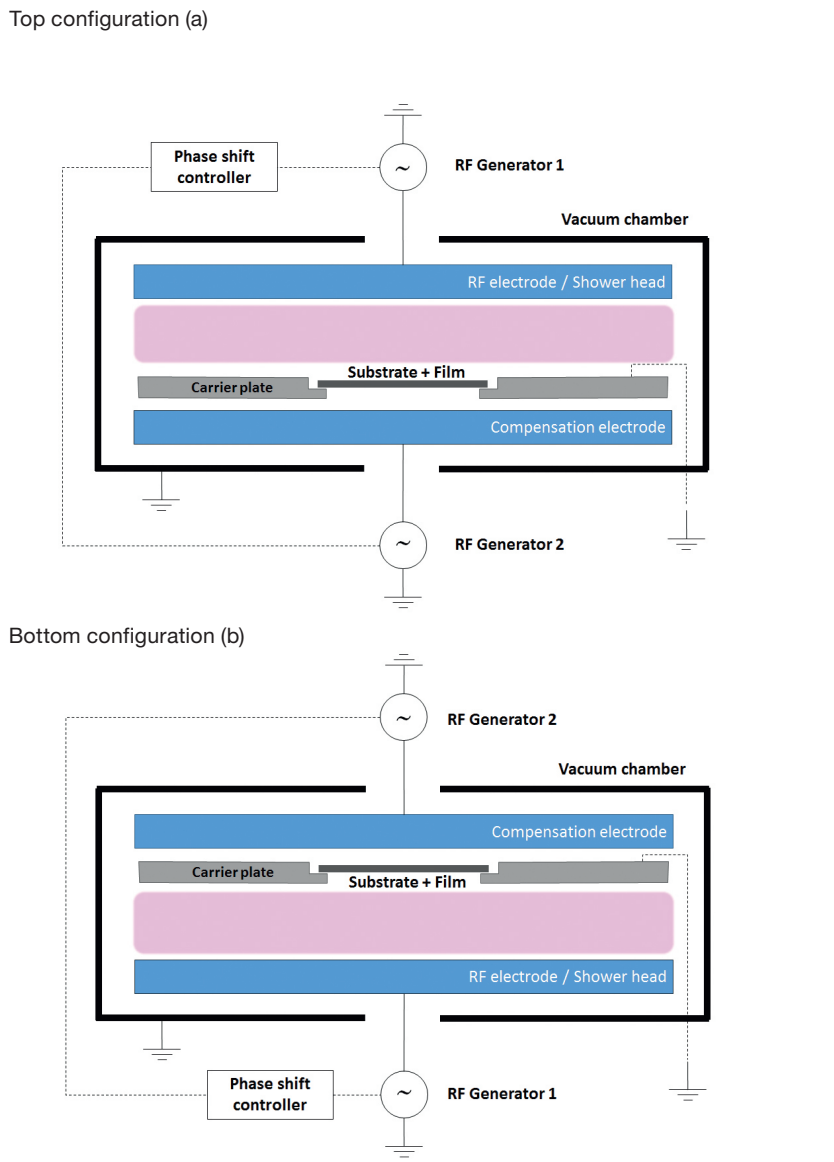

Figure 1: Schematic drawings of the PECVD Mirror reactors (a) in the top configuration (depositions from above the substrates), (b) in the bottom configuration (depositions from below the substrates). The substrates are hanging in a carrier plate with openings, and are accessible for depositions from both sides. Note that, in the bottom configuration, the wafer edges are covered by the carrier plate (at least on some parts) and that no deposition can be made on these covered locations.

break of the system vacuum. The proprietary concept was validated and tested successfully.

In the following some experimental data of the film uniformity, the minority carrier lifetime, which defines the passivation quality of a SHJ cell and complete SHJ cell data will be shown and the principles of the reactor function will be explained.

The Mirror Reactor concept

PECVD Mirror reactors allow for ultra-homogeneous depositions on both sides of a substrate without the need for flipping it and without any vacuum break. In a classical PECVD reactor, the substrates are simply lying on an electrically-grounded metallic carrier-plate. Deposition is therefore only possible on one side of the substrates. In order to deposit on the second side, typically the substrates have to be taken out of the vacuum process chamber and mechanically flipped. In the Mirror reactor, the substrates are hanging in a carrier-plate with openings ("bi-facial" carrier-plate), making depositions from both sides of the substrates possible. As shown in figure 1, two different reactor designs are required: one for depositions from above the substrates (called "top configuration"), and one for depositions from below the substrates (called "bottom" configuration).

The use of bi-facial carrier-plates induces additional challenges with regard to film uniformity. Indeed, the gap space below the substrate acts as an additional capacitor in the equivalent electrical circuit, which affects the global RF electrical field distribution and finally, leads to film inhomogeneity on the substrate. This reduction of the deposition rate in the center of the substrate compared to its edges results in considerable losses in performance and therefore is unacceptable for the production of high-performance SHJ solar cells.

The successful approach to overcome this problem is the use of a secondary RF electrode on the carrier-plate side. A properly adjusted RF power level fed to the secondary electrode can compensate the

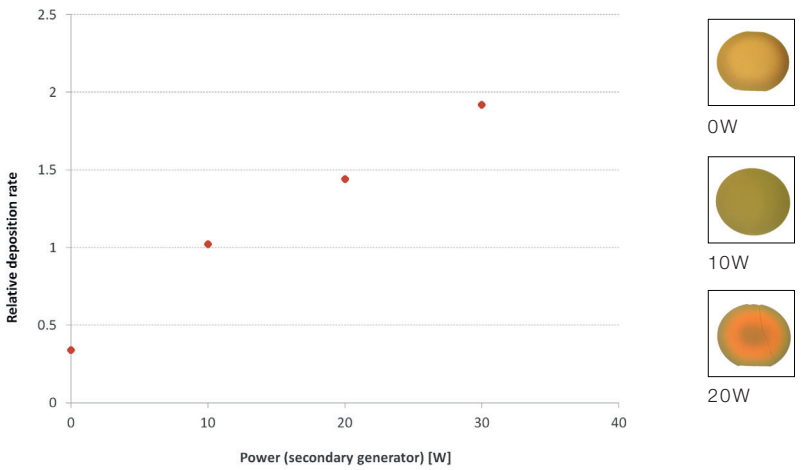

Figure 2: Effect of the power compensation on the deposition rate (thickness measured in the center of Ø10 cm round glass substrates). Images of some of the corresponding samples are shown on the right.

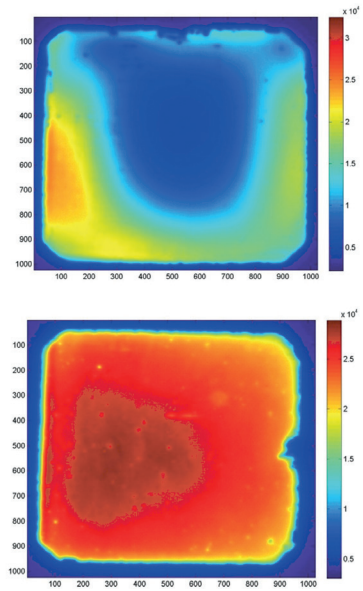

Figure 3: Photo-luminescence imaging of SHJ solar cell precursors produced in the Mirror reactor (a) without power compensation, (b) with proper power compensation.

Wafer deposition mode	Tau at 5E14 cm-3 [ms]	Tau at 5E15 cm-3 [ms]	Implied Voc [mV]
Mirror in/ip	6.8	3.5	744
Mirror in/ip	9.9	4.6	746

Table 1: Minority carrier lifetimes and and implied VOC for i-n/i-p passivation layers

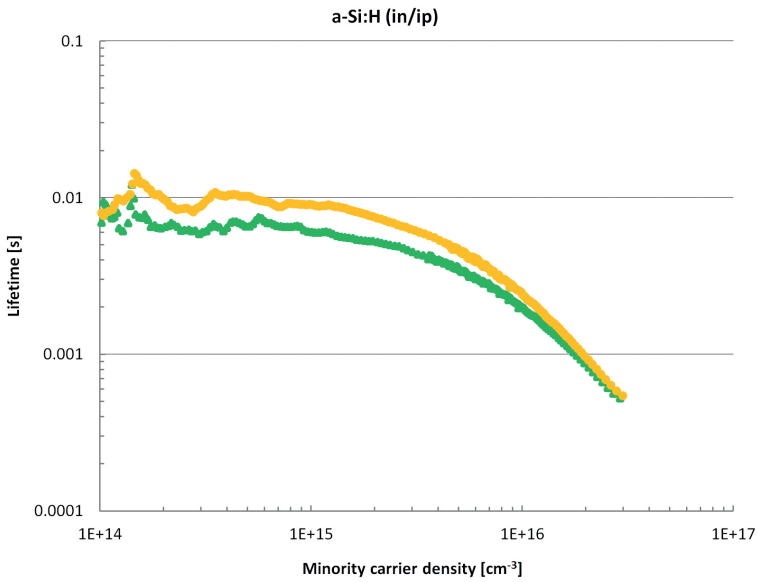

Figure 4: Plot of Minority carrier lifetime of SHJ solar cell precursors produced in the Mirror reactor

undesirable voltage drop in the gap space and hence, loss in local plasma power above the substrate. This compensation permits a film deposition as uniform as in the standard plate configuration, or even better. Layer thickness uniformity of less than 1 % has been obtained on the substrate surface due to this power compensation.

The proof-of-concept of the PECVD Mirror reactor has been successfully demonstrated. The results show that the deposition rate in the center of the substrate can be extremely finely controlled by the power applied to secondary electrode (see Fig. 2).

By applying the correct power compensation, very uniform and high-quality passivation on 6-inch CZ c-Si wafers were shown (Fig. 3b), whereas dramatically non-uniform results are obtained when there is no applied power (Fig. 3a). At first, this shows the absolute necessity of a proper solution to obtain uniform depositions when bi-facial carrier plates are used and secondly that the Mirror concept perfectly fulfils this need. Minority carrier lifetimes above 6 ms were obtained on solar cell precursors and SHJ solar cells with efficiencies up to 22%, were produced (full-area 6-inch cells, CZ c-Si). These results are on par with the ones obtained in the standard reactor using plain carrier-plates and with similar materials.

The minority carrier lifetime, which serves as a quality indicator for good surface passivation, has been validated in several test runs and consistently shows very high levels. The examples in table 1 and figure 4

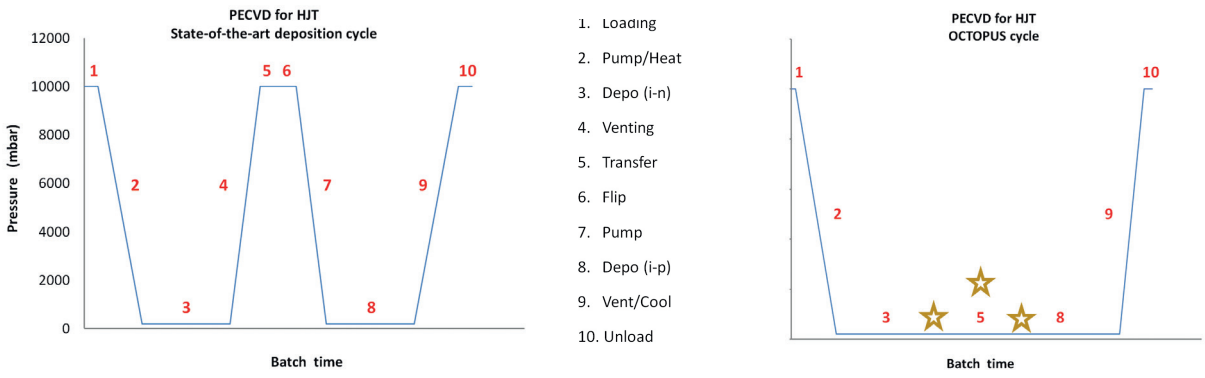

Figure 5: Comparison of deposition cycle in a state-of-the-art system vs. the OCTOPUS system. The stars represent handling steps, which do not exist in the OCTOPUS cycle.

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illustrate the passivation for a complete i-n/i-p layer device, which was manufactured in the mirror reactor.

Reactor design and impact to the Cost-of-Ownership structure

Various system configurations were evaluated and it was found that a cluster design is optimal for taking full advantage of the new mirror reactor concept and the specific deposition requirements of high-efficiency cells. The OCTOPUS II system for R&D and small scale production enables the processing of wafers by PECVD and PVD (TCO layers) , see image 1. Hence, all thin film depositions for SHJ can be done in the system without the need of flipping or vacuum breakage.

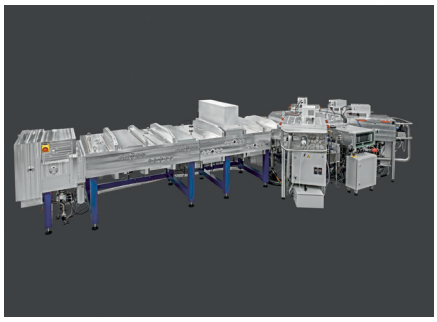

Image 1: OCTOPUS II system with 1 PVD module, 1 Load lock, 1 E-chuck, 3 PECVD modules

The OCTOPUS III system for SHJ mass production is fully optimised for the PECVD deposition process for high throughput. The system is equipped with 1 LL in, 1 LL out, 1 heating chamber and 6 (double stacked) PECVD reactor modules image 2

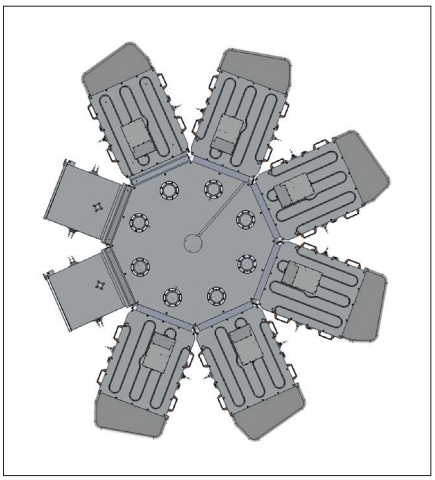

Image 2: Principle configuration of a high-throughput OCTOPUS system (heating module not shown)

In terms of system yield and cost savings the following design features have a strong positive impact:

System footprint: the cluster configuration saves significant footprint in relation to hybrid inline systems (up to 40% are possible). For example, an OCTOPUS III system of 80 MW throughput, fits within 48 sqm

Reduction of handling and system conditioning: In every given system the share of processing time should be as high as possible, which in the case of SHJ this is challenging, since this processing time is

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relatively short. With the Mirror reactor, the time for flipping and vacuum breakage is completely eliminated, see figure 5. All other wafer carrying plate transfer distances are short. Per any loading cycle up to 12 wafer carrying trays will be loaded. The shared application of pumping and heating (and also venting at the end of the cycle) additionally saves time. All these features result in a superior share of process time vs. handling time. The process time share per cycle will reach 75% and more, compared to 50% or less in state-of-the-art systems.

Although PECVD consumables do not exceed 6% of the entire SHJ cell line OPEX cost structure, the process system has to provide especially high yields and very low downtimes. The OCTOPUS design promises exceptional good levels of yield and uptime by the remarkable reduction of complex automated handling devices or by avoiding the excessive usage of moving parts.

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Principle process sequence in an OCTOPUS system

For a typical SHJ process comprising the deposition of a-Si:H i-n and i-p layers the sequences are shown in figure 6.

1 - Loading of wafer carriers in the load-lock. Pumping down to the system vacuum base level.

2 - Heating of the carrier plates up to 200°C.

3 - Consecutive transfer of the first set of plates into the process chambers.

4 - Deposition of i-n bottom layers (followed by quick cleaning after the chambers have been unloaded).

5 - Transfer to the subsequent top deposition chambers. Re-loading of the bottom deposition chambers.

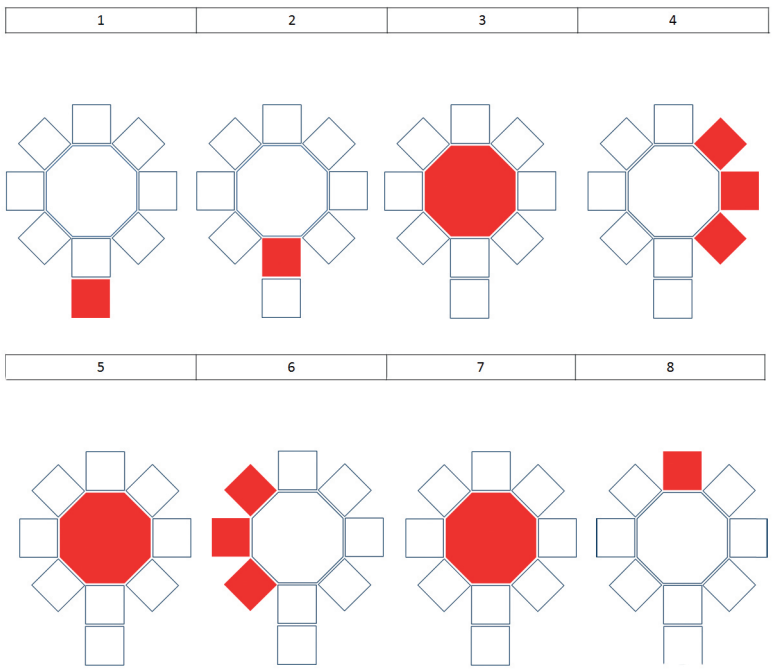
6 - Deposition of i-p top layers (followed by cleaning step).

7- Transfer to the Load-lock out. Transfer from bottom deposition chambers to top deposition chambers.

8 - Venting and unloading after all plates have been collected in the load-lock out

The cycle allows for overlapping of the process steps in a continuous way, which enhances even more the throughput. ■

Figure 6: principle process flow per system loading cycle



Summary

The innovative top and bottom side deposition concept of the OCTOPUS system provides a solution which fills a gap in the available spectrum of PECVD tools, dedicated to heterojunction cell processing. Passivation quality levels, throughput as well as the mirror reactor and the overall tool design concept are very promising and offer a viable solution to the industry for this key process in the heterojunction cell manufacturing value chain.

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[1] Panasonic Corporation, Eco Solutions Unit. www.panasonic.net

[2] Louwen A.; van Sark W.;Schropp R.,Faaij A.: A cost roadmap for silicon heterojunction solar cells. Solar Energy Materials & Solar Cells 147 (2016)