MULTIFUNCTIONAL PECVD LAYERS – COST ANALYSIS OF THE X-PERT APPROACH

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ABSTRACT: Multifunctional PECVD layers, which can be used as dopant source, surface passivation, anti-reflection coating, and isolation layer, can significantly simplify high-efficiency industrial solar cell production. A proof of concept for the production of Passivated Emitter and Rear Totally diffused (PERT) solar cells has recently been presented resulting in a peak efficiency of 18.3 %. In this work we want to enlighten the economical aspect of the extremely simple production of PERT cells, which will be called the X-PERT approach in the following. Based on detailed Cost of Ownership (COO) calculations, it will be shown that by the consequent use of the multifunctional PECVD layers it is possible to reduce the levelized costs of electricity (LCOE) by 0.6 €ct/kWh. A possibility to further improve the X-PERT approach to a bifacial solar cell will even further simplify the process and drastically reduce the LCOE by 1.0 €ct/kWh.
Keywords: Cost reduction, PECVD, Solar cell

1 INTRODUCTION

To adopt high-efficiency solar cell concepts in an industrial manufacturing environment, processes have to be kept simple, at low cost and efficient. Plasma-enhanced chemical vapor deposition (PECVD) can provide various functional thin films for crystalline silicon solar cell production such as anti-reflection coatings (ARC), surface passivation layers, masking, or dopant sources. The implementation of a single PECVD process, however, requires also additional equipment for loading and unloading the vacuum chamber resulting in much higher investment and maintenance costs. A combination of the different features mentioned above in one multifunctional dielectric layer system offers the use of this variety of PECVD applications while allowing a very simple solar cell manufacturing process. As already presented in [1] it is possible to produce such multifunctional PECVD layers allowing the application as dopant source, surface passivation, anti-reflection coating (ARC) and isolation against metal plating. In a first proof of concept a conversion efficiency of 18.3 % has been presented by use of a multifunctional ARC as phosphorous source and a multifunctional rear side reflection layer as boron dopant source for diffusion of a back surface field (BSF). The main problem for this first test was blistering in the ARC, which significantly reduced the short-circuit current. Additionally, the contact scheme was not fully optimized resulting in a loss in fill factor. Nevertheless, this first proof of concept has already shown the potential of the development of multifunctional PECVD layers for front and rear side. By overcoming the mentioned problems and further optimization of the cells conversion efficiencies exceeding 20 % can be expected by this approach.

However, in photovoltaics finally the achievable price per kWh is decisive for a new technology. We performed therefore COO and LCOE calculations for this new approach, which are presented in this work.

2 COST CALCULATIONS FOR THE X-PERT CELL

2.1 The X-PERT and the bifacial X-PERT approach

As already proven in [1] it is possible to produce Passivated Emitter and Rear Totally diffused (PERT) solar cells using multifunctional PECVD layers in a very simple process chain as it is depicted in Figure 1. This cell concept will be called X-PERT cell in the following. The process chain is especially attractive as it enables a division of the process chain in sequences with related technologies. This will say that all wet chemical processes can be combined at the beginning, the PECVD layers can be deposited in one vacuum step, only one high-temperature step is necessary for co-diffusion of phosphorous and boron, and directly after the diffusion the samples are ready for metallization (no prior wet chemical bath necessary). Because of the multifunctional PECVD layers it is possible to perform the diffusion in a cost-effective, open inline-furnace system. The phosphorous emitter is driven in relatively deep and the isolation properties of the coatings are increased to a very well level by oxidation during the high-temperature diffusion. Therefore, the approach is well suited to the combination with plated contacts.

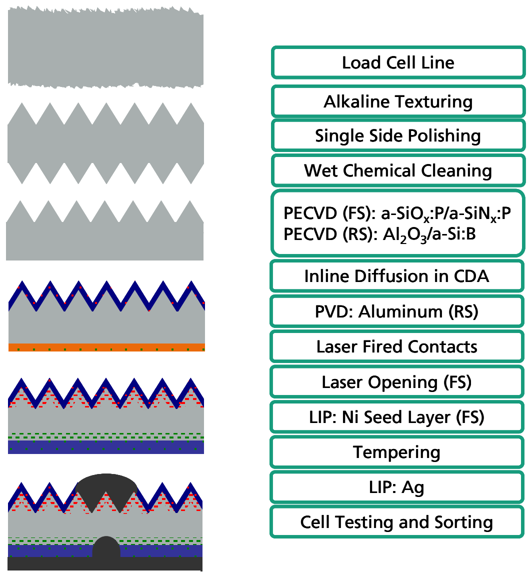

Figure 1: Process chain for the production of X-PERT solar cells.

Even though this process, whose feasibility has already been presented, seems quite efficient for industrial production we are aiming in our research group for an even simpler approach with a higher efficiency potential. This process is depicted in Figure 2. The idea is to advance the X-PERT cell to a bifacial X-PERT cell. Therefore, the single-side polishing becomes redundant and the metallization can be simplified as in principle the galvanic contacts can be grown simultaneously on the p- and the n-type surface of the solar cell. Certainly, more research work is necessary to achieve this structure. Especially the boron containing multifunctional layer has to be adapted that the a-Si:B oxidizes completely to assure a fully transparent layer on the boron side. Moreover, galvanic processes for the simultaneously growing of the contacts have to proof industrial feasibility. In this work we want to compare the costs for the X-PERT and the bifacial X-PERT to the well known standard technology using a $POCl_3$ diffusion for the phosphorous emitter and screen printed front and rear side contacts. The used standard process is given in Figure 3.

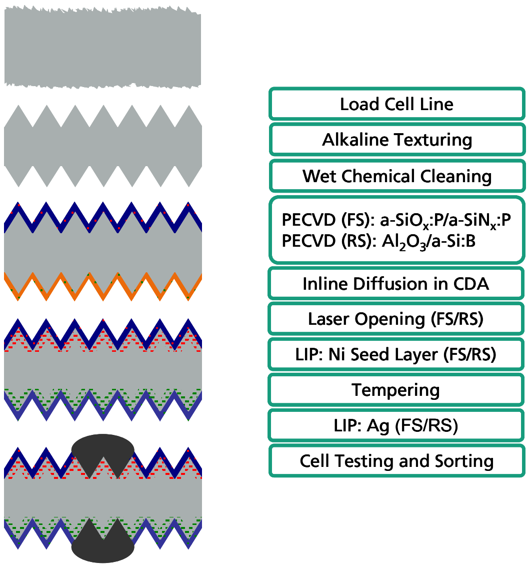

Figure 2: Process chain for the production of bifacial X-PERT solar cells.

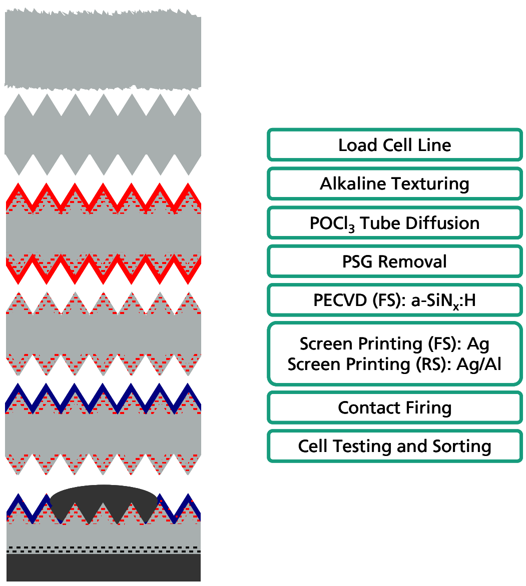

Figure 3: Process chain for the production of standard Al-BSF solar cells.

2.2 PECVD costs for the X-PERT solar cell

A decisive factor for calculating the costs of the X-PERT concept is the PECVD process for the multifunctional layers. These costs can only be estimated as no tool for such a four layer deposition including doped layers exists on the market so far. Our calculation therefore is based on an inline-PECVD tool, which is already available, using a linear microwave plasma excitation for the deposition of three layers [2]. Costs for equipment and spare parts have been scaled up for the assumed four layer PECVD tool. Moreover, the consumption of the different gases has been estimated for the multifunctional layers and the different scrubber system for filtering the phosphorous and boron containing gases has been considered. A quite critical part using poisonous doping gases is the maintenance work inside the plasma chamber. To not lose a lot of valuable process time we propose for our model an additional chamber around the plasma chamber in which the maintenance work has to be done using full inhalation protection. Of course, also a better gas security system is necessary using these gases. As there are many unknowns concerning the usage of the poisonous gases we estimated the costs for the extra facility invest quite conservatively. The proposed costs for the X-PERT PECVD system is plotted in comparison to the costs we calculate for the standard ARC silicon nitride deposition in Figure 4. The scale is given in percentage of the total costs of a standard silicon nitride ARC deposition. The PECVD costs per solar cell for the X-PERT approach results in this estimation to about 218 % of the standard PECVD costs.

Obviously, a strong increase of PECVD cost is present for the X-PERT approach. On the other hand, cost savings can be achieved due to the omission or change of standard process steps (PSG etch, diffusion, contact formation).

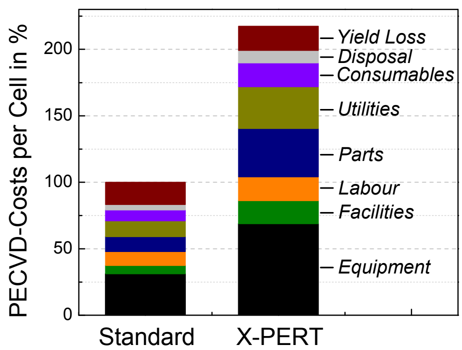

Figure 4: Comparison of the assumed costs for the four-layer PECVD system used for the X-PERT approach to the standard ARC silicon nitride deposition. The scale is given in percentage of the total costs of the standard deposition.

2.3 COO and LCOE comparison

Based on the demonstrated production process chains, we performed detailed cost of ownership (COO) calculations using a model presented at this conference [3]. The new X-PERT concept is calculated in the monofacial and in the bifacial approach for monocrystalline silicon. For the bifacial approach the use of p- and n-type material has been considered. The technology is compared to the well known standard Al-BSF solar cell like it is the standard in nearly all industrial production.

The presented technology comparison is based on a detailed bottom-up COO calculation of the solar cells' and modules' production process. For the model description and data base references see [3]. For the standard processes in the regarded process chains we use a data base to account for all arising costs including equipment, utilities and labor. Moreover, we have models to calculate the build-up costs for a corresponding 100 kWp flat roof top photovoltaic system and to simulate the energy which will be harvested [3]. It is therefore possible to calculate the achievable levelized costs of electricity (LCOE) in good accuracy for the standard Al-BSF process and for the X-PERT concept using the given cost approximation for the PECVD system.

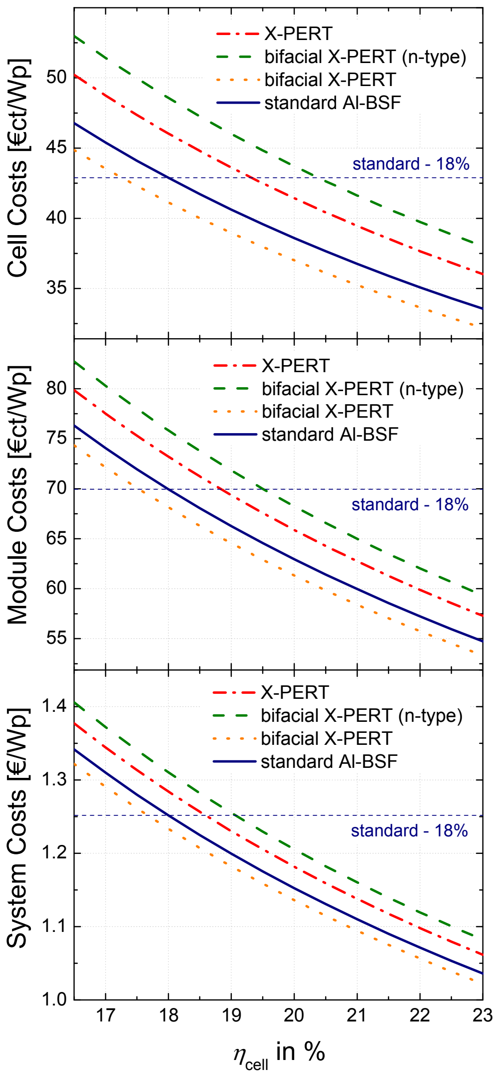

Figure 5: COO calculation from cell production to system costs for the different technologies.

In Figure 5 the costs per Wattpeak for cell production, corresponding module production and complete photovoltaic system installation is plotted for the four different technologies. The gap between the bifacial X-PERT p-type and n-type is only due to the different wafer price. As a reference cost level the standard process with an efficiency of 18 % is marked in the graphs. In comparison to the standard process the production costs for monofacial X-PERT cells and for the bifacial n-type X-PERT are higher whereas they are slightly less expensive for the bifacial p-type X-PERT. That means even with the same efficiency as a standard cell the bifacial p-type X-PERT concept could lead to a cost advantage. However, the efficiency potential for the both sides diffused and passivated solar cell is much higher.

Finally, the most decisive quantity for evaluating the potential of a new technology are the levelized costs of electricity (LCOE). We have calculated the LCOE for two systems: one in Freiburg, Germany and one in the sunnier region of Sevilla, Spain. By now, a possible difference in the performance ratio of the different cell concepts has been neglected. Especially for the bifacial concepts an improved power output due to collection of photons from the rear side is to expect.

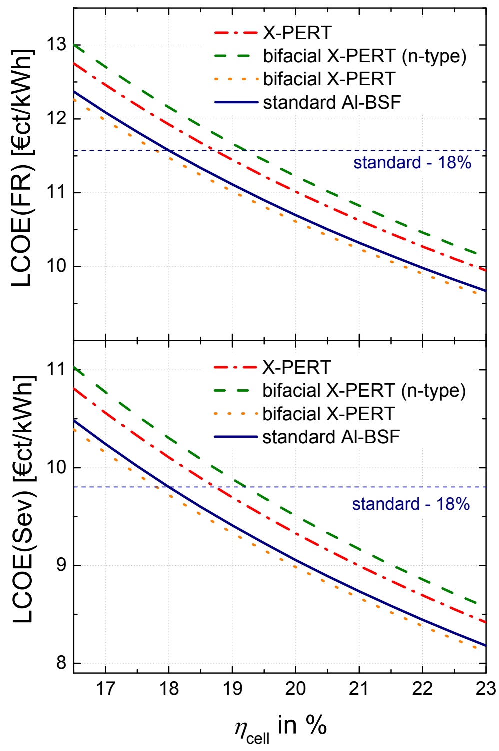

Figure 6: Levelized costs of electricity (LCOE) for a system in Freiburg, Germany and Sevilla, Spain for the different technologies.

From the presented cost comparison, we can easily see which minimal conversion efficiency is needed to save costs compared to the standard process. For the bifacial p-type X-PERT technology, as mentioned before, no efficiency improvement compared to the standard is needed, as even the costs per solar cell are smaller for this technology. For the monofacial X-PERT an efficiency of at least 18.7 % is necessary to achieve a gain compared to the standard process; for the bifacial n-type 19.2 % is necessary. If we estimate a conversion efficiency of 20 % for the p-type monofacial X-PERT approach, a cost advantage for a system in Freiburg, Germany of 0.6 €ct/kWh and for a system in Sevilla, Spain of 0.5 €ct/kWh can be expected. If we assume for the bifacial p-type cell as well 20 % a cost advantage of even 1.0 €ct/kWh for Freiburg, Germany and 0.8 €ct/kWh for Sevilla, Spain could be achieved. For the n-type bifacial X-PERT cell assuming 21 %, the results are a gain of 0.8 €ct/kWh for Freiburg, Germany and 0.7 €ct/kWh for Sevilla, Spain. A significant gain is therefore possible for all considered X-PERT approaches, even if a lot of additional advantages of the concept have not been accounted for so far. The bifaciality will further increase the power output and will additionally improve the power distribution over the day. The diffusion on both sides will decrease also the dependence of the base material resistivity and therefore lead to less distributed efficiency values. Moreover, the cell process is especially attractive for thin wafers, as a lot less wafer handling is needed and no screen printing processes are necessary. Finally, the use of plating metallization technique simplifies the introduction of copper instead of silver, which will lead to a further considerable cost advantage

3 SUMMARY

We have presented a possible production process for a bifacial totally diffused and passivated solar cell using multifunctional PECVD layers. Total costs of ownership (COO) and the levelized costs of electricity (LCOE) have been calculated for the former presented monofacial approach and the bifacial approach resulting in a considerable cost advantage compared to the common industrial standard. For the monofacial approach the LCOE could be expected to be lowered by 0.6 €ct/kWh, for the bifacial approach by 1.0 €ct/kWh (p-type) or 0.8 €ct/kWh (n-type).

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