UPGRADE OF AN INDUSTRIAL Al-BSF SOLAR CELL LINE INTO PERC USING 3600 WAFERS/HOUR ALD Al_2O_3+SiN_X SOLUTION RAMP-UP

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ABSTRACT: In this paper, we present the results of the upgrade of a standard monocrystalline Aluminum Back Surface Field (Al-BSF) solar cell line to a passivated emitter and rear cell (PERC) solar cell line and ramp-up. Three additional process steps are added: spatial ALD Al_2O_3 using SoLayTec's InPassion ALD, rear side SiN_x capping layer deposited by a direct plasma system, using e.g. Tempress' SPECTRUM, and a laser to open the rear side dielectric layers, using a conventional laser system. The Al_2O_3 post-deposition anneal is integrated into the SiN_x capping layer deposition process. Besides a good PERC solar cell efficiency, also the wafer appearance of these solar cells is essential. The wafer appearance is a combination of scratches, marks and hazing. In this work, the wafer appearance is improved by optimization of the TMA consumption and the temperature of the integrated-Anneal SiN_x (iA-SiN_x) rear side capping recipe while maintaining the solar cell efficiency. Further adjustments are made in order to improve the throughput and reliability of the equipment. This results in a PERC process with a high solar cell efficiency, good wafer appearance and a throughput above 3600 wafers/hour.

Keywords: PERC, ALD, Al_2O_3, PECVD SiN_x, Manufacturing and Processing

1 INTRODUCTION

Within the last five years, the passivated emitter and rear cell (PERC) solar cell concept has been ramped-up in PV production by many manufacturers. Currently, the PERC solar cell concept has the largest market share of all advanced solar cell concepts of >20% of the total c-Si solar cell production, according to the ITRPV roadmap [1]. The upgrade to PERC leads to a solar cell efficiency increase of 0.5-0.8%$_{abs}$ and 0.6-1.0%$_{abs}$ with respect to the standard Al-BSF solar cell based on p-type multi-crystalline and p-type monocrystalline Si, respectively [2,3,4].

For an upgrade of the current Al-BSF solar cell line into PERC technology, the following three systems are added: spatial ALD Al_2O_3 using SoLayTec's InPassion ALD, rear side SiN_x capping layer deposited by a direct plasma system, using e.g. Tempress' SPECTRUM, and a laser to open the rear side dielectric layers, using a conventional laser system.

After ALD Al_2O_3 deposition, a post-deposition annealing step is required to activate the chemical and field-effect passivation. In addition, this annealing process drives out the gaseous H-species built in the ALD Al_2O_3 layer to prevent blistering of the ALD Al_2O_3 film, referred to as 'out-gassing' [5]. The annealing process is integrated into the rear side SiN_x capping process, which is only possible for direct plasma PECVD systems. This combined process is called integrated Anneal-SiN_x capping process (iA-SiN_x), as previously presented by Gay et al. [6]. Besides solar cell efficiency gain for PERC with respect to Al-BSF solar cells, also the wafer appearance is important to customers. The wafer appearance is judged by the customer and is a combination of scratches, marks and hazing. In this work, after achievement of the solar cell efficiency gain for PERC with respect to the Al-BSF solar cell as reference, the wafer appearance of the PERC solar cell is improved. Finally, ramp-up of the PERC solar cell line is started by increasing the wafer numbers and improving the reliability of the equipment of SoLayTec and Tempress.

2 EXPERIMENTAL SETUP

The process sequences for the standard Al-BSF and for the PERC solar cell manufacturing are described in Figure 1. It should be noted that the edge isolation and SiN_x anti reflection coating processes are identical for the Al-BSF and PERC process flows. The metallization and firing processes are optimized for Al-BSF and PERC solar cells, respectively.

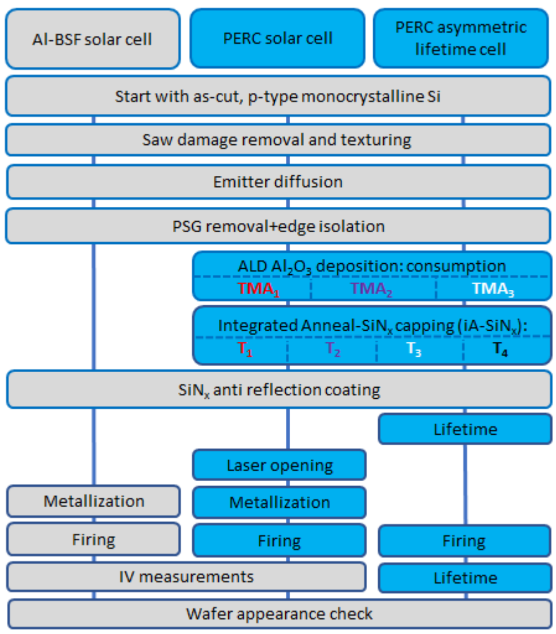

Figure 1: Process sequences for Al-BSF and PERC solar cells. For a faster investigation, asymmetric samples are used. These structures are equivalent to solar cells without laser and without metallization.

In this work the parameters TMA consumption and temperature of iA-SiN_x rear side capping process are both used to get a good wafer appearance while maintaining solar cell efficiency. In addition to the processing flow for complete Al-BSF solar cells and PERC solar cells, asymmetric lifetime cells are made. For these asymmetric lifetime samples different Trimethylaluminum (TMA) consumptions, which is precursor for the Al_2O_3 deposition, are tested as well as different temperatures of the iA-SiN_x rear side capping recipe. Three different settings of the TMA consumption are used: $TMA_1>TMA_2>TMA_3$. The temperature of the iA-SiN_x process is also varied and four different temperatures are tested with the following conditions: $T_1>T_2>T_3>T_4$. Successively, the process conditions for the asymmetric lifetime samples are tested on complete PERC solar cells.

3 RESULTS

In a first phase of the ramp-up, the PERC process is optimized. The focus is put more on the solar cell efficiency improvement. This results in a baseline process sequence with an ALD Al_2O_3 recipe corresponding to the TMA consumption TMA_1 and with an iA-SiN_x recipe using temperature T_1. The obtained solar cell IV-parameters are presented in Table I.

Table I: IV-parameters and appearance for the Al-BSF and PERC solar cells. TMA consumption TMA_1 and iA-SiN_x temperature T_1 are used.

	V_{oc} (mV)	J_{sc} (mA/cm²)	FF (%)	Efficiency (Eff.) (%)	Wafer appearance
Al-BSF	647±1	37.8±0.1	81.1±0.2	19.9±0.1	**Good**
PERC: **TMA_1** and **T_1**	660±1	39.0±0.1	80.2±0.1	20.7±0.1	**Poor**

The PERC solar cells obtained, show an efficiency gain of $0.8\%_{abs}$ with respect to Al-BSF solar cells. However, the employed process results in a poor solar cell appearance. In order to improve the solar cell appearance, first asymmetrical lifetime samples are used, see Figure 1 for the process flow. The implied V_{oc} of the samples is measured before and after firing and their appearance is checked in terms of scratches, marks and hazing. The obtained results are listed in Table II.

Table II: Implied V_{oc} results before and after firing and wafer appearance qualification for the investigated samples (**TMA_1>TMA_2>TMA_3** and **T_1>T_2>T_3>T_4**).

TMA consumption	iA-SiN_x temperature	Implied V_{oc} before firing (mV)	Implied V_{oc} after firing (mV)	Wafer appearance
TMA_1	**T_1**	667±1	681±2	**Poor**
TMA_1-repeat	**T_1-repeat**	670±2	684±2	**Poor**
TMA_1	**T_3**	666±2	681±2	**Poor**
TMA_1	**T_4**	666±2	681±2	**Poor**
TMA_2	**T_2**	668±4	680±4	**Poor**
TMA_2	**T_3**	668±3	680±3	**Good**
TMA_3	**T_3**	662±2	677±3	**Good**
TMA_3	**T_4**	662±4	682±2	**Good**

The results in Table II show that for good wafer appearance, it is essential to lower the TMA consumption as well as to lower the temperature of the iA-SiN_x capping process. For good passivation, before and after firing, it is essential to use the higher TMA consumptions, TMA_1 or TMA_2. Lowest TMA consumption, TMA_3, leads to lower passivation, even though good wafer appearance. Good passivation as well as a good wafer appearance is obtained for the combination of TMA consumption TMA_2 and iA-SiN_x temperature T_3. TMA consumption TMA_2 in combination with T_2 leads to a poor wafer appearance caused by the too high temperature of the iA-SiN_x capping process.
In order to confirm these results on solar cell level, a batch of solar cells is prepared. Again, the TMA consumption as well as the temperature of the iA-SiN_x capping process are varied. The results are presented in Table III.

Table III: IV-parameters and wafer appearance for PERC solar cells at different TMA consumptions and iA-SiN_x temperatures.

TMA	iA-SiN_x temperature	V_{oc} (mV)	J_{sc} (mA/cm²)	FF (%)	Eff. (%)	Wafer appea-rance
TMA_1	**T_1**	664±2	39.1±0.1	79.7±0.5	20.7±0.2	**Poor**
TMA_1-repeat	**T_1-repeat**	664±1	39.4±0.1	79.7±0.3	20.8±0.2	**Poor**
TMA_2	**T_2**	664±1	39.4±0.1	79.3±0.2	20.8±0.1	**Poor**
TMA_2	**T_3**	663±1	39.5±0.1	79.3±0.3	20.8±0.1	**Good**
TMA_3	**T_3**	660±2	39.1±0.1	79.8±0.4	20.5±0.1	**Good**
TMA_3	**T_4**	658±2	39.1±0.1	79.6±0.4	20.5±0.2	**Good**

The first two groups in Table III have the same conditions and show very similar IV-results. This shows the reproducibility of the results. For good wafer appearance it is essential to lower the TMA consumption as well as to lower the iA-SiN_x temperature, which is in agreement with the lifetime results. For good solar cell efficiency, it is essential to use TMA consumption TMA_1 or TMA_2. As in the case of the lifetime samples, the combination of the intermediate TMA consumption (TMA_2) with temperature T_3 of the iA-SiN_x deposition shows optimal results. For these settings, an efficiency on the same level as the reference process is achieved together with a good solar cell appearance. Note that TMA consumption TMA_2 combined with temperature T_2 of iA-SiN_x capping process has a good solar cell efficiency, but still leads to poor wafer appearance caused by the too high iA-SiN_x temperature T_2. Further reducing the TMA consumption to value TMA_3 results in a lower solar cell efficiency, despite the good wafer appearance. The lower solar cell efficiency for TMA consumption TMA_3 is mostly due to a reduced open circuit voltage caused by a reduced passivation quality. Hence, the lifetime sample results are confirmed on solar cell level. Settings of TMA consumption TMA_2 and iA-SiN_x temperature T_3 are found that deliver good solar cell efficiency as well as a good wafer appearance.

4 MACHINE PERFORMANCES

In a second phase of the ramp-up, the focus is casted on the improvement of the machine performances for the cluster SoLayTec's InPassion ALD and Tempress' SPECTRUM PECVD system. The throughput and rework rate of both systems are optimized.

4.1 InPassion ALD

Figure 2 shows the number of processed wafers during system ramp-up. Over a timespan of one month, the number of wafers processed per day was doubled from 30.000 up to 60.000. During the same time period, the InPassion ALD rework rate was reduced from 1.5% down to <0.25%. The main reasons for the reduced rework rate are standard adjustments and optimizations of the wafer scheduling. The breakage rate is not shown, because it is below 0.025% using the optimized so-called ‘DU2.0’ design of the InPassion ALD.

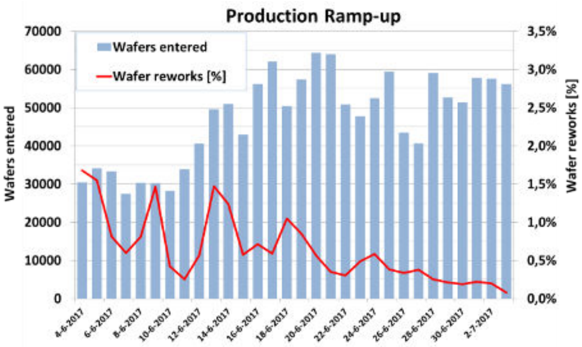

Figure 2: Production increase and rework rate reduction during the initial ramp-up.

4.2 SPECTRUM PECVD

In the process sequence used for the manufacturing of PERC solar cells, the rear side SiN_x capping layer is deposited prior to the front side SiN_x anti reflection coating. Prior to the rear side PECVD SiN_x deposition, the wafers are loaded automatically by a handling robot into a graphite boat with the front side of the solar cell in contact with the graphite plates. If the handling is not accurate, the front side surface of the wafers might be scratched during loading or unloading and the visual appearance of the final solar cells will suffer from that. Due to variations in the assembly of the graphite plates (referred to as ‘boat’), which can be a result of manufacturing tolerances, thermal expansion, wear during use and cleaning, scratching of at least part of the cells seemed inevitable. However, by making adjustments to the boat and the handling robot system, which is also part of the so-called ‘Tempress-Baumann scratch-free solution’, it is demonstrated that complete suppression of the rework rate can be reached. This can be seen in Figure 3.

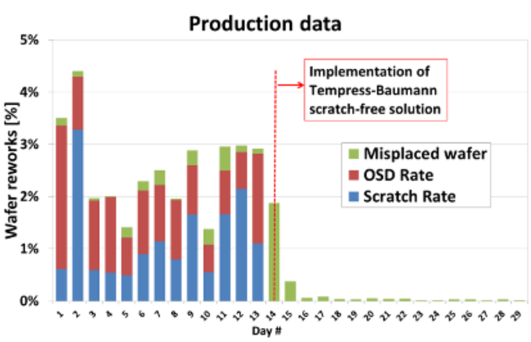

Figure 3: Evolution of misplaced wafer, OSD (Other Side Deposition) rate and scratch rate at handling of PECVD system of Tempress.

5 CONCLUSION

In this paper, we have shown the results of the successful upgrade of a standard Al-BSF monocrystalline solar cell line into a PERC solar cell line and its ramp-up. The addition of the InPassion ALD of SoLayTec, a direct PECVD system such as SPECTRUM PECVD of Tempress for rear side SiN_x capping and a laser tool allows for an efficiency gain of at least $0.8\%_{abs}$ absolute for PERC. The post-deposition anneal of the Al_2O_3 is integrated in the rear side SiN_x process. By tuning the TMA consumption of the ALD Al_2O_3 deposition recipe and the temperature of the iA-SiN_x, the appearance of the solar cells is improved while maintaining solar cell efficiency. Optimum is TMA consumption TMA_2 and iA-SiN_x temperature T_3. For the final ramp-up, the rework rate of the InPassion ALD is improved to <0.25%. In addition, for the SPECTRUM PECVD, the rework rate can be completely reduced by adjustments to the boat and the handling robot system, which is also part of the so-called ‘Tempress-Baumann scratch-free’ solution. This demonstrates the attractive potential of the cluster of InPassion ALD of SoLayTec for ALD Al_2O_3+SPECTRUM PECVD of Tempress for iA-SiN_x PECVD for PERC upgrades for >3600 wafers/hour.

6 REFERENCES

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