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HIGH THROUGHPUT IN-LINE DIFFUSION: EMITTER AND CELL RESULTS

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ABSTRACT: We present new in-line diffusion equipment, consisting of a spray system in connection with an IR lamp heated conveyor furnace, which is used on laboratory and industrial scale to apply emitters to solar cells. The spray system deposits on two sides a uniform layer of phosphorous dopant that is diffused into the silicon wafer in the IR lamp heated conveyor furnace. Uniform emitters are produced of nominal 62 and 82 Ω/sq. Sheet resistance mapping is done using the Sherescan on a larger number of wafers for the different groups. Uniform emitters are obtained with standard deviation of maximum 2.2 Ω/sq. Cells are processed using the ECN in-line 16% process with the new in-line equipment, and compared with cells produced with reference laboratory spin-on applied dopant. Results show about 0.5% increase in V_{oc} and about 1% increase in I_{sc} for the laboratory scale and equal results for the industrial equipment.
Keywords: Diffusion, Doping, Manufacturing and Processing

1 INTRODUCTION

In-line phosphorous diffusion is getting increased attention from the PV-industry [1]. The application of thin and large wafers in cell production lines does make $POCl_3$ tube-diffusion less attractive because of batch type handling, automation, and yield issues. Also the emitter quality, with focus on uniformity can be an issue, especially in case of high ohmic emitters. On research level several papers have addressed various aspects of in-line diffusion, such as the application of the phosphorous dopant material and the actual diffusion in an IR lamp heated conveyor furnace [2, 3, 4].

The ECN cell process always has used an in-line diffusion furnace. However, deposition of dopant material was done by the batch type dipping and spin-on process. Application of double sided diffusion allows for enhanced gettering, especially for lower quality material [5], and turns out being effective for impurity gettering, and in that way for negating any effect of the metal belt. With the 17% cell efficiencies that are achieved over the last years [6, 7], the ECN process has shown to effectively deal with diffusion in a conveyor type metal belt furnace. However, to obtain a fully in-line ECN process it was necessary to implement an in-line dopant coating process. Based on our experience with various phosphorous deposition methods, such as spray coating, a two sided multi-lane dopant coating and diffusion process and associated equipment was developed together with Despatch Industries and installed in our laboratory.

Very first results using this dopant coater, and our to that date standard in-line diffusion furnace cell were presented in Dresden [8]. These first results showed an 0,6% increase in I_{sc} and a 0,3% increase in V_{oc} for the spray-on system compared to the spin-on.

We report in this paper results of the testing of the full in-line diffusion equipment in our laboratory, with a state of the art IR diffusion furnace. As a reference, cells are also processed using spin-on dopant diffusion, which has been the basis of our industrial 16% process scheme. Further, results on wafers and cells coated with dopant material and diffused in the industrial sized Despatch DCF-3630 In-Line Diffusion System are given. The throughput of this 5 lane industrial in-line diffusion equipment is 1450 wafers/hour. For obtaining low resistance metal contacts on higher ohmic emitters, the uniformity of the emitter plays a dominant role, since the operating window for the electrical contact formation by firing gets smaller. So, we also demonstrate the processing of high ohmic emitter cells using the new in-line spray system and IR lamp heated conveyor furnace.

2 EXPERIMENTS

In-line diffusion using spray coating was performed at ECN in the one-lane laboratory equipment and at Despatch in the in-line diffusion system using 5 lanes. In our testing we used 156 mm x 156 mm multi-crystalline silicon wafers of 200 µm thickness. Spray characteristics have been optimized in flow rate of carrier gas, pressure and concentration of dopant material in order to obtain uniform and reproducible deposited layers while minimizing spray consumption. Glass formation and diffusion of dopant material was done in the IR lamp heated conveyor furnace. Four groups were prepared from wafers taken from one ingot column, and selected such to obtain neighbours.

At ECN a 62 Ohm/sq sprayed emitter was made (62C, group 2), and as a reference to our 16% ECN process [10], also a group with emitters of nominal 62 Ω/sq were processed using spin-on phosphorous deposition and same furnace settings (62S, group 1). At Despatch two groups were prepared with nominal 62 (62D, group 3) and 82 Ω/sq (82D, group 4) using different furnace settings. On a selection of wafers (not used for cell processing), the sheet resistivity of the emitter was mapped using the 4-point probe Sherescan instrument [9].

From the diffused wafers cells were made at ECN using the ECN in-line 16% cell process [10]. The process as given in Table I was followed for processing cells and performing characterization.

Table I: Process sequence and details

Acidic texturing
In-line coating and diffusion
Emitter characterisation using Sherescan
Glass removal and ECN Clean
PECVD SiN
Screen print and dry contacts
Co-firing
Isolation
IV & additional characterization

A limited firing optimization was done to assess the settings of the firing furnace. Additional characterization included the Suns-Voc fill factor, Corescan and IQE.

3 RESULTS AND DISCUSSION

3.1 Emitter diffusion

During coating and diffusion in the laboratory and 5-lane in-line diffusion furnace, wafers are extracted at regular intervals for sheet resistance scans using the Sherescan. The average sheet resistance data, prior to glass removal and over the indicated number of cells is given in Table II.

Table II: Average sheet resisivity values for laboratory diffusion using spin-on, and spray coating and industrial in-line diffusion and spray coating

Group	Type	Average (Ω/sq)	St. Dev. (Ω/sq)	No. wafers
1 (62S)	Lab spin-on	60.4	1.9	9
2 (62C)	Lab spray	61.6	2.2	9
3 (62D)	Ind. Spray	63.3	1.9	20
4 (82D)	Ind. Spray	81.4	2.1	21

Two representative examples of Sherescan results of the spray-on emitter are given in figures 1 and 2.

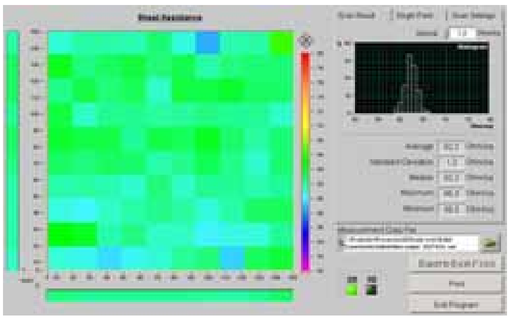

Figure 1: Sheet resistance of sprayed emitter of 62 Ω/sq

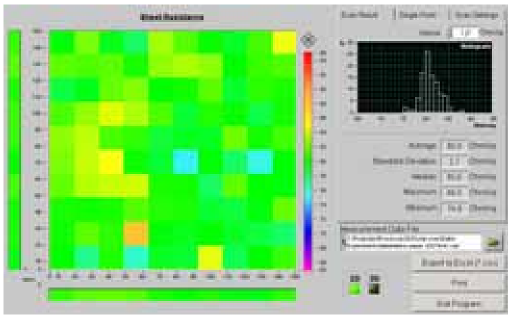

Figure 2: Sheet resistance of sprayed emitter 82 Ω/sq

3.2 Cell processing

From the 4 groups cells were made using two sets of firing parameters, for the nominal 62 groups and 82 Ω/sq groups. For the groups the best IV results are given in Table III, and median results in Table IV.

Table III: Best cell results for the groups

Group	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)	$J_{sc}\cdot V_{oc}$ (mW/cm^2)	η (%)	FF SunsVoc (%)
1	33.7	605	76.0	20.4	15.5	79.9
2	33.8	608	74.8	20.6	15.4	79.6
3	33.7	605	75.6	20.4	15.4	79.8
4	34.7	605	74.7	21.0	15.7	79.4

Table IV: Median cell results for the groups

Group	No. cells	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)	$J_{sc}\cdot V_{oc}$ (mW/cm^2)	η (%)	R_{series} (mΩ)
1	20	33.7	604	75.5	20.4	15.4	6.8
2	20	34.0	608	74.3	20.7	15.2	7.3
3	20	33.7	605	74.3	20.4	15.1	7.2
4	45	34.2	602	73.5	20.6	15.1	7.0

On the best cells of the groups additional characterization is performed. Suns-Voc fill factor is measured for the best cells and added in table III. The relative low Suns-Voc FF for all the groups indicates here rather inhomogeneous material quality, since the IV results show no significant shunt problems.

The used 16% cell process sequence is optimized for 62 Ω/sq spin-on diffusion. Corescan mapping does reveal that the spray coated cells show a non-optimal contact resistance. This is also confirmed by the slightly higher average series resistance for these groups as compared to the reference spin-on group, as shown in Table IV. Process optimization will yield higher FF for other groups and higher V_{oc} for the high ohmic emitter cells.

In figure 3 the V_{oc} is plotted against J_{sc} for all cells per group.

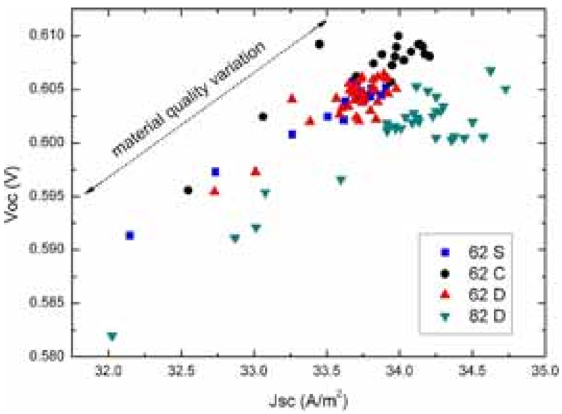

Figure 3: $V_{oc}(J_{sc})$ graph for all data and groups. The line drawn is a guide to the eye to indicate the influence of the material quality.

Just as observed in the Dresden paper [8], in this experiment also improved V_{oc} and J_{sc} are observed for the spray coated cells. The use of the industrial spray-on system shows similar V_{oc} and J_{sc} as the spin-on system, while the laboratory spray-on system clearly shows increases in both V_{oc} and J_{sc}. The cells produced with high ohmic emitter present large increases in J_{sc}, but a slight decrease in V_{oc}, which should increase as the process is more optimized.

The IQE is determined for neighboring cells from each group and is shown in figure 4.

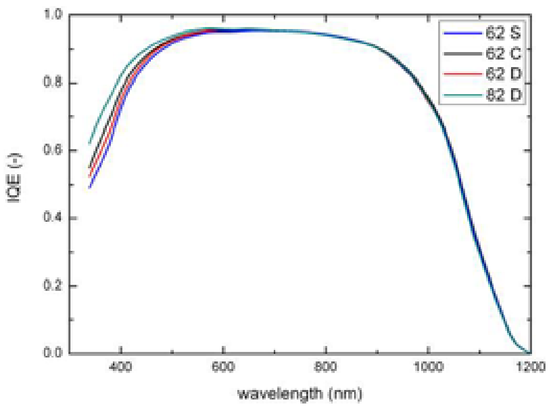

Figure 4: IQE graphs from neighboring cells from the four different groups.

The IQE ratio relative to the spin-on reference is shown in figure 5.

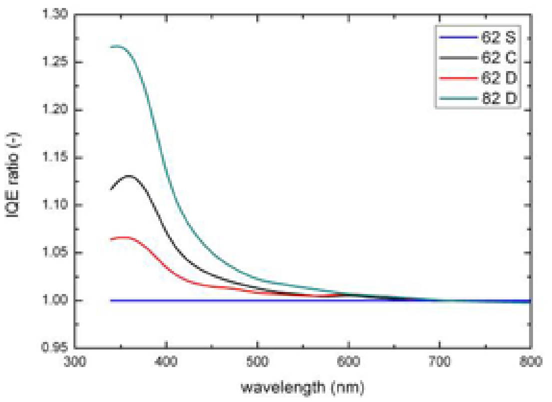

Figure 5: The IQE ratio relative to the spin-on reference for neighboring cells from each group.

In both figure 4 and 5 it can clearly be seen that the IQE at short wavelengths is significantly higher for the laboratory spray coater than for the spin-on system, with an increase of almost 15% relative at 360 nm. The industrial spray coater shows an increase up to 7% relative. The differences between the industrial spray-on system and the laboratory spray-on system can be related to differences in the diffusion furnace and its settings (peak zone settings and belt speed). The use of the high ohmic sheet resistance further increases the IQE at 360 nm to more than 25% relative.

4 CONCLUSIONS

This paper describes successful testing and results of in-line dopant coating and diffusion on laboratory scale and using industrial in-line equipment. Also cell results of wafers coated and diffused in the in-line equipment are reported.

In summary the conclusions are:

1. Highly uniform emitters are obtained in both laboratory and industrial in-line spray-coater diffusion systems.
2. Cell results of the in-line system demonstrate to be at least as good as the spin-on batch process.
3. Very promising results are acquired on high ohmic emitters.
4. Through further optimization of the processing for these emitters improved cell results can be obtained.
5. In-line spray-on and diffusion is viable for industrial application.

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