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LOW COST SELECTIVE EMITTER FOR MULTICRYSTALLINE SOLAR CELLS WITH 0.4% POINT EFFICIENCY GAIN.

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ABSTRACT: We demonstrate use of a patterned semi-permeable diffusion barrier for the fabrication of a selective emitter for multicrystalline solar cells. In combination with an inline diffused emitter the efficiency increased by 0.4% point, using one high-temperature process step. In combination with $POCl_3$ tube furnace emitter, the efficiency benefit of the selective emitter is 0.1% point.

1 INTRODUCTION

To reduce costs of PV we aim for higher efficiencies by introducing cost efficient process steps in existing or new production lines
One approach is to use a selective emitter. In this concept, two doping levels are used: a highly doped region beneath the front contacts to optimize contact resistance, and a lightly doped active region between the contacts to reduce recombination [1]. The selective emitter approach is utilized for record efficiency solar cells, which typically employ screen print or laser ablation steps in order to align contacts to the highly doped regions of the cells [2]. Some concepts use the principle to etch back the emitter using a selective mask [3]. This mask should be removed completely afterwards to prevent the risk of contamination of the emitter side, which can be a problem when this stripping process is implemented in industrial solar lines. Other methods use a double diffusion to create a highly and lowly doped emitter area [4]. This makes the solar production line significantly longer and is therefore less cost efficient.

In this paper we show an alternative process flow which is compatible with today's mc-Si cell manufacturing lines. The advantages of the process are that no new high temperature step is introduced and that the process works without steps such as photolithography and laser ablation. The process consists of the formation of a patterned semi-permeable diffusion barrier (figure 1). The phosphor drive-in is limited for the areas which are covered by the barrier. As a result, a selective emitter can be formed.

This new process was tested on p–type mc-Si wafers with (1) in-line emitter formation and (2) $POCl_3$ tube furnace emitter formation, and compared with the ECN baseline process.

2 APPROACH

The consecutive steps towards our selective emitter cell concept are:

1) First step: development and optimizing the fabrication of the semi-permeable diffusion barrier in combination with inline diffusion. This is done by:
   - Testing the influence of barrier thicknesses on emitter sheet resistance.
   - Optimizing the size of the open area. The size is influenced by the screen, the paste and adjusting the delay- and/or etch time between printing and rinsing.
   - Adjusting the diffusion setting to obtain a highly doped contacting region below the metal electrodes, with an emitter sheet resistance of 40 to 50 Ohm/sq.
2) The second step consists of adjusting the process for $POCl_3$ tube furnace diffusion and tests both combinations on cell level in our baseline process see figure 1.

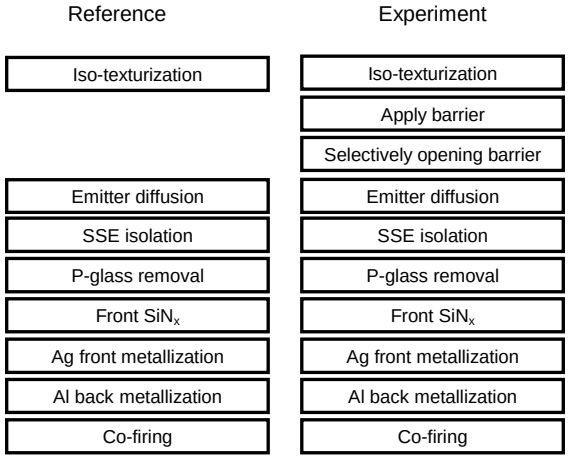

Figure 1: Flow chart of processing reference and experimental groups in our baseline process.

3 EXPERIMENTS, RESULTS AND DISCUSSIONS

3.1 Formation of a uniform semi-permeable barrier layer.

We apply a uniform semi-permeable barrier layer by spinning a liquid precursor with the active compound. The curing occurs at room temperature. The barrier layer is patterned by screen printing in such a way that the open area of the barrier layer resembles the contact format. Single step diffusion then results in a highly doped area where the electrodes will be printed and a lowly doped emitter between the contacts. The barrier layer also decreases the amount of interstitious phosphor in the emitter [5].
The barrier layer is removed during the PSG removal without leaving visible traces. Different mixtures were tested on wafers to determine influence of mixture composition on phosphor diffusion (figure 2). When the barrier thickness is increased, emitter uniformity, under identical processing conditions, is decreased. The increase in Rsheet results in a relatively higher standard

deviation of the emitter resistance, but this is also affected by the lower P concentration itself.

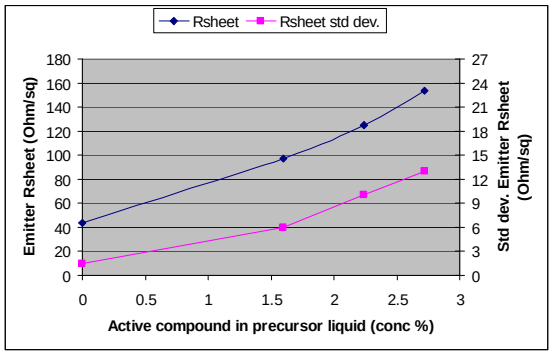

Figure 2: The sheet resistance of a uniform emitter after diffusion through barriers with various thicknesses (as determined by the active compound concentration).

3.2 Opening of the barrier layer.

After deposition of the barrier layer, it is selectively opened. Removing the layer using a screen printed etching paste will not damage the surface and the layer is ready for further processing without additional cleaning steps. After diffusion, the selective emitter area is clearly visible. The highly doped region, where the barrier is opened, shows a much thicker and darker PSG layer, than the unopened area between the fingers, see figure 3.

Figure 3: A wafer with an H-pattern selective emitter after diffusion, before PSG removal.

The selective emitter is not visible by eye after PSG removal and PECVD. This complicates the alignment of the front side contacts. One method is to use laser markings for aligning the wafers during the different processing steps. Another option is to use dummy wafers in order to align the screen printer. We prepared dummy wafers with full area PSG, and opened up those selectively together in the same run as the experimental wafers with the barrier. Those wafers are used for visual alignment of the front side printer.

3.3 Testing the selective emitter at cell level with in-line diffusion or $POCl_3$ diffusion.

P-type mc-Si neighboring wafers (200 µm thick, 156x156 mm^2) were processed using the sequences shown in figure 1. Reference groups are processed according to our ECN baseline process. For the experimental groups a semi-permeable barrier layer is deposited after wet-chemical iso-texturization. Two barrier liquid concentrations were tested; 1.6% (A) and 2.1% (B). The barrier is selectively opened with screen printing a barrier etching paste. After a reaction time of 10 seconds, wafers are rinsed with water to remove the paste. Standard in-line diffusion is performed with settings to obtain a sheet resistance under the contacts lower than 50 Ohm/sq in order to decrease the contact resistance. Between the contacts we aim for 100 to 120 Ohm/sq emitter sheet resistance. From this point the experimental groups followed the same processing sequence as the reference group: a single-side etch isolation step, PSG removal in 9% HF (RT), and passivating SiN_x ARC layer. An H-pattern Ag metallization was used for front side contacting and a full area Al metallization for back side contacting. The front side Ag metallization is aligned, with the help of the dummies, to the format of the selective emitter. Co-firing is carried out in a firing furnace.

To analyze the effect of the semi-permeable barrier layer which results in highly and lowly doped phosphorus areas, high resolution sheet resistance mapping using a Sheresscan is carried out. As shown in figure 2, the use of a 1.6% solution results in an emitter sheet resistance of approximately 100 Ohm/sq on the area below the barrier, and about 45 Ohm/sq where the barrier has been opened (see figure 4).

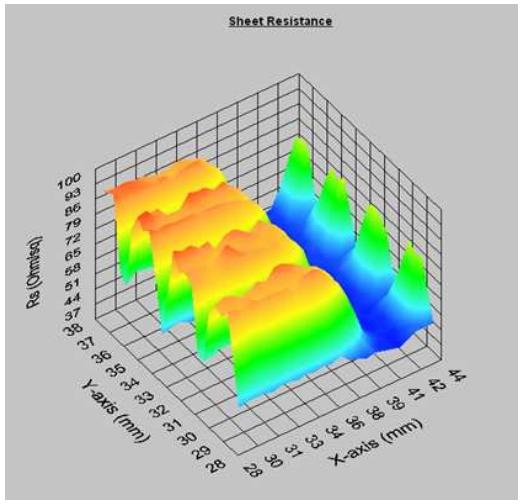

Figure 4: Sheresscan of a selective emitter after inline diffusion, made with a 1.6% barrier solution.

Two comparison experiments have been performed; the first compares a uniform in-line emitter with the in-line selective emitter. The second compares a uniform $POCl_3$ tube furnace emitter with two different tube furnace selective emitters. The IV characteristics of the complete solar cells were measured using a Class AAA solar simulator according to the IEC 60904-9 norm. In table 1 and figure 5 the IV results of all groups are shown. Group 1 is the inline diffusion reference, group 2 is the semi-permeable barrier (1.6% barrier conc.) + inline diffusion. Group 3 is the tube furnace reference. Groups

4 and 5 are with a semi-permeable barrier with respectively 1.6% (group 4) and 2.1% (group 5) barrier concentration + tube furnace diffusion.
The material used for groups 1 and 2 (i.e., in-line emitter formation) is not related to the material used for groups 3 – 5 (i.e., tube furnace emitter formation) and therefore it is not possible to compare the two diffusion methods directly. Each group consisted of 9 cells.

Table 1: IV results of the 5 different emitter groups.

Group	Jsc (mA/cm2)	Voc (V)	FF	eta (%)	max eta (%)	Voc * Jsc
1	34.06	0.610	0.753	15.64	16.10	20.78
2	34.39	0.614	0.761	16.09	16.36	21.13
3	34.82	0.613	0.767	16.37	16.72	21.34
4	34.85	0.610	0.776	16.49	16.73	21.25
5	34.93	0.612	0.752	16.08	16.52	21.37

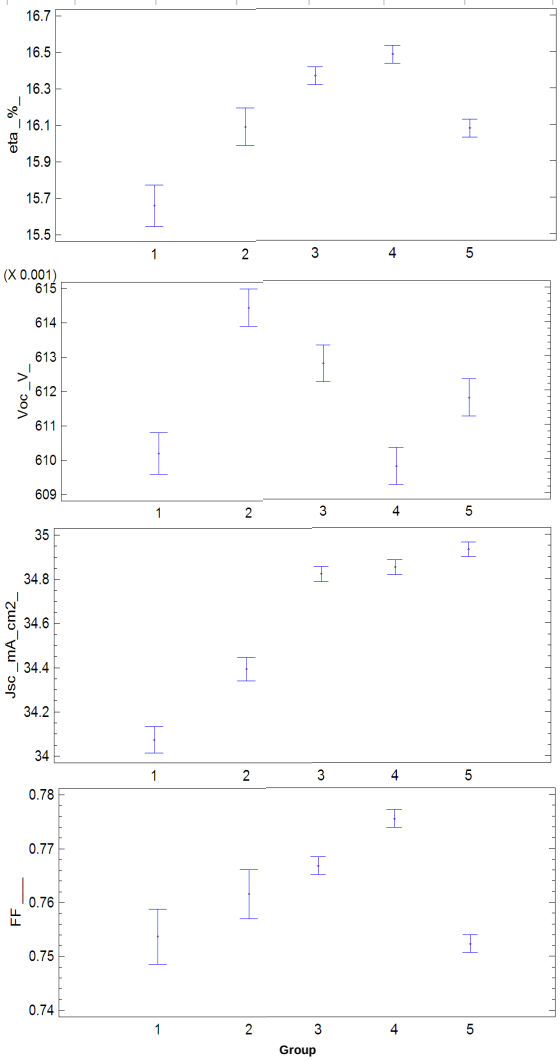

Figure 5: Means and 95.0% Tukey HSD Intervals of efficiency, voltage, current density, and fill factor of the five different groups. Group 1: Inline Reference, Group 2: Inline + Selective emitter A, Group 3: $POCl_3$ Reference, Group 4: $POCl_3$ + Selective emitter A and Group 5: $POCl_3$ + Selective emitter B.

4 DISCUSSION

The use of a semi-permeable patterned barrier in combination with in-line diffusion (group 2) results in a selective emitter with a significant increase in Voc (+ 4 mV) and Jsc (+ 0.3 mA/cm^2) as compared to the uniform emitter. This resulted in an increase in cell efficiency of 0.4% point. The increase in Voc and Jsc are both caused by an improved blue response due to a lower phosphor doping between the silver fingers, see figure 6.

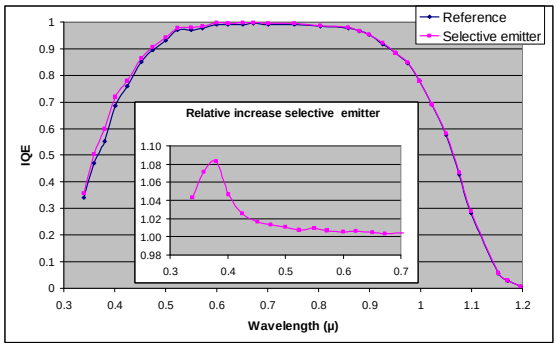

Figure 6: IQE of Group 1: Inline diffusion Reference compared with group 2: Inline diffusion + Selective emitter. The insert shows the relative increase of the selective emitter.

For tube furnace diffusion, (groups 3-5) the Voc is significantly lower and the Jsc is comparable to the reference. For group 4, the FF is significantly higher and the resulting increase in cell efficiency is 0.1% point. The effect of the increase in voltage, seen in the inline diffusion comparison, is possibly compensated by the loss in voltage due to the higher doping in the areas surrounding the silver contacts.

The barrier used in group 5 resulted in a thicker semi-permeable layer. In the IV characteristics the FF was significant lower but the Voc significantly higher than in group 4. This indicates that the highly doped area below the fingers became too small, resulting in a higher contact resistance and less reduction in Voc due to the highly doped area. This group can possibly be improved by using a wider highly doped band below the silver finger to avoid shunting.

5 CONCLUSIONS

The use of industrially applicable semi-permeable patterned diffusion barriers for in-line selective emitter formation resulted in an increase in the cell efficiency of at least 0.4% point as compared to a uniform emitter. The extra process steps: applying the barrier, and selective opening of this barrier can easily be introduced in an existing manufacturing line, using commercially available equipment. The benefits of this method of selective emitter fabrication are that no extra high-temperature step is needed and that no residues of e.g. etch resist remain on the surface after emitter formation.

6 REFERENCES

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