RIE- textured Silicon Solar Cells with Screen printed Metallization

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1. Introduction

Screen printing is the commonly used method for metallization of solar cells in industrial fabrication. Thus the introduction of any new technological step depends on its compatibility to the screen printing process. The emitter diffusion by Rapid Thermal (RT) processing and the surface structuring performed with Reactive Ion Etching (RIE) technology have already been investigated at the Chemnitz University of Technology [1, 2]. The current work presents an additional investigation of the compatibility of these both technologies to screen printing.

2. Optimization of RIE, RT processing and screen printing techniques

Former investigations [1] have shown, that an excellent decrease of the surface reflection can be achieved by means of RIE texturing based on non-toxic SF_6/ O_2 gas. For texturing an Alcatel GIR220 reactor have been used. In order to obtain a homogeneous texturing of the wafer surface, different process parameters (pressure, gas flow, etc...) were optimized. As known [3], RIE causes damages on the surface itself, and beneath. Therefore the process time was limited to a necessary degree. It was found, that in conjunction to the remaining process parameters a process time of 4 minutes produces a surface with markedly reduced reflection. Therefore, all the wafers selected for texturing and cell manufacturing were etched for this time.

RT-diffusion was performed by means of an AG Associates Heatpulse 610 furnace. Just before the diffusion phosphorus dopant was deposited by spin-on. Since an emitter deepness of more than 300 nm is essential for the application of screen printing technology, a temperature profile with plateau- times of 120 s have been applied for the diffusion. The diffusion temperature was varied in order to form an emitter with the optimal sheet resistance value (40-45 Ω/□). All the RIE- textured surfaces diffused in this work presented larger sheet resistances than planar surfaces.

Three silver based pastes of 2 manufactures have been applied for the front side metallization. For the initial investigation of paste properties a test screen (figure 1) was developed and manufactured. Due to the reactor geometry the wafer diameter was fixed to 4 inch. The screen contains a number of apertures with different widths and orientations. It enables the detection of the minimal aperture width necessary for the formation of uninterrupted fingers on the wafer surface. Additionally it allows to check the dependency of the finger quality on the apertures orientation in respect to the screens wire orientation.

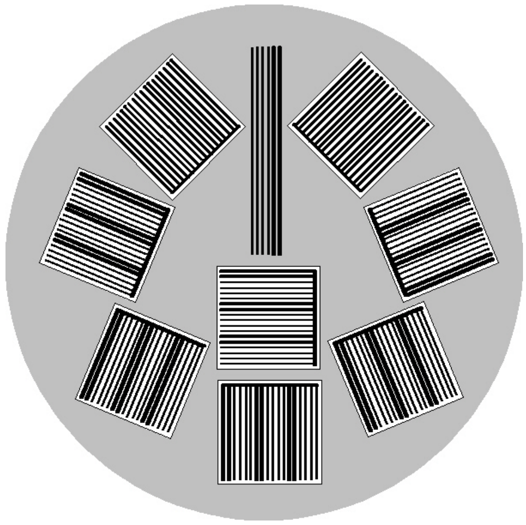

Figure 1: Test screen

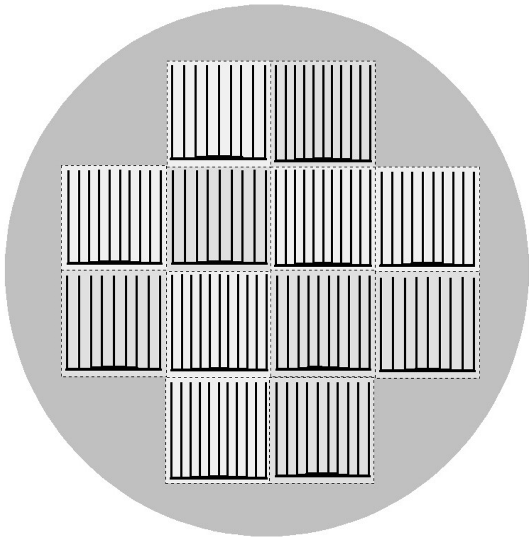

Figure 2: Screen for printing of solar cells

Several single-crystalline silicon (sc- Si) and edge-defined film-fed grown silicon (EFG- Si) wafers (planar or RIE- textured, respectively) were printed with a Quad 100MV screen printer. The accomplished tests allowed the following conclusions:

- the quality of the printed fingers only slightly depends on the type of the paste
- for the different pastes the optimal screen printing parameters for a formation of narrow fingers are the same
- it is possible to print fingers down to a width of 85 µm
- no remarkable difference of finger quality for differently oriented fingers has been recognized
- fingers printed on RIE- textured surfaces, presented the same widths like the ones printed on planar surfaces.

Considering these results a screen suitable for simultaneous printing of 12 (2x2) cm^2 cells was developed (figure 2). Both screens were manufactured with 325 mesh stainless steel wire. In order to warrant a continuous printing quality of the fingers of every cell, their width was set to 120 µm. With respect to the difference between values of sheet resistance of planar and RIE- textured wafers cells with different number of fingers were included to the screen pattern.

3. Preparation of solar cells

For the solar cell fabrication sc Czochralski silicon wafers with a bulk resistivity of about 1 Ωcm and EFG- wafers were applied. A number of small (2x2) cm^2 cells were produced by the following process sequence:

- Wafer cleaning
- RIE texturing (only for the selected wafers)
- RT- diffusion
- Rear side aluminium coating
- Front side PECVD SiN_x coating
- Screen printing of silver pastes
- Separation of cells by a dicing saw
- Firing through the SiN_x- layer.

After RT- diffusion the phosphosilicate glass was removed by wet-chemical etching in HF solution. The coating of the back side with 1 µm aluminum layer was accomplished by sputtering. For the passivation and antireflection coating 80 nm SiN_x (measured on the planar wafer) were deposited at the front side by means of PECVD (Plasma Enhanced Chemical Vapor Deposition). The same deposition parameters were applied for planar and RIE textured surfaces. After screen printing and cell separation, the cells were fired through at maximal temperatures of (760...820) °C with firing times of about one minute in the hot zone (over 600°C) and total process times of about 5 minutes. Two thermal profiles of contact firing are shown in figure 3. After firing all fingers showed a stable width of about 120 µm (figure 4). As expected, the edge of the metallized layer contains a large amount of glass frit. A cross view of a finger (see figure 5) shows, that the texturization obviously remains conserved after firing. Therefore firing with realized firing profiles doesn't promote a formation of short circuits by direct contacts between metallization and low- doped emitter regions.

4. Results and discussion

The results show the applicability of the described process technology for solar cell manufacturing in a laboratory scale. The cell parameters listed in table 1 present the picked out best values .

Table 1: Best parameters of manufactured cells

wafer material	surface	j_{sc}, mA/cm^2	U_{oc}, mV	FF, %	η, %
sc	planar	**32,6**	**605,3**	**78,4**	**14,7**
sc	RIE	**33,4**	**594,7**	**72,3**	**13,8**
EFG	planar	**27,8**	**559,2**	**76,5**	**11,6**
EFG	RIE	**29,8**	**545,2**	**74,7**	**10,8**

Although the maximal values of short-circuit current density (j_{sc}) were measured at RIE- cells, the maximal values for open-circuit voltage (U_{oc}), fill factor (FF) and efficiency (η) were obtained with planar cells. The losses of U_{oc} at RIE cells are probably the direct consequence of plasma damaging. Therefore it seems to be advisable to add a defect removal etch (DRE) after the RIE- step. The DRE imbedded into the process sequence would allow to make a better estimation of the effectiveness with respect to a combination of RIE, RT processing and screen printing technologies. The optimization of firing profiles for several Ag- pastes has shown, that different pastes need to be fired with different maximal temperatures to get the best efficiency. On the other hand, the cells fired with the optimal conditions, present about the same efficiency level independently on the kind of paste.

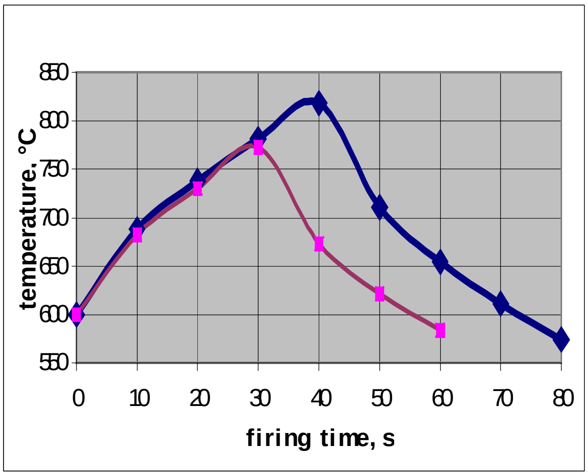

Figure 3: Typical firing profiles

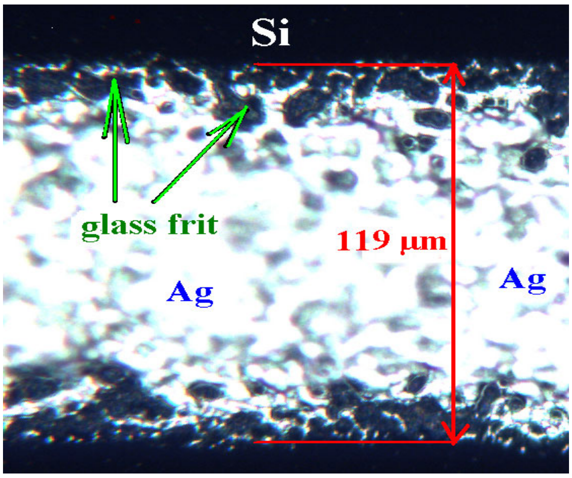

Figure 4: Top view of a fired finger

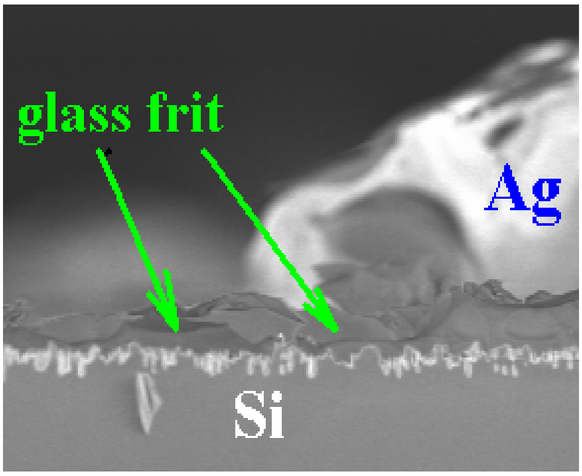

Figure 5: Cross view of a fired finger on the RIE-textured surface

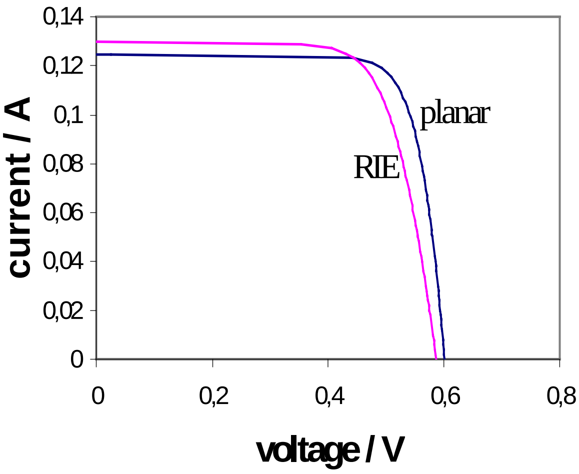

Figure 6: I/U characteristics of cells with best efficiency

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