

## Strong quality and performance of commercial Silicon solar cells

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**ABSTRACT:** our goal is to achieve low cost effective Czochralski (Cz) silicon crystalline materials and rapid process technologies that is favorable for industry. At high temperature phosphorus diffusion silicon solar cell, we found phosphorus precipitated in the form of dead layer due to over solubility limit, Due to this layer the recombination centers appear, as a result auger recombination increase. These recombination centers increase saturation current density as a result cell Voc and Jsc decrease due to high recombination rate. At low temperature p diffusion we found that about 80-90% P is active but at high temperature about 50-60% P is active. Emitters obtained by a single step thermal are in range of  $7-8 \times 10^{19} \text{ cm}^{-3}$  with sheet resistance  $\sim 60 \Omega/\square$  and junction depth  $0.71 \mu\text{m}$  and saturation current of emitter is  $130 \text{ fA/cm}^2$ . Our target in texturing optimization work have been met, that we decrease the amount of NaOH we used and IPA, give good wafers reflectivity about 11%. The phosphorus profiles were proceed experimentally, with only pre-deposition process by adding a drive-in after introducing thermal dry oxidation step after diffusion process for various diffusion temperature. The  $V_{oc}$  and  $J_{sc}$  values calculated by PC1D simulating program, using a Gaussian model with values of the emitter surface concentration  $N_s$  and sheet resistance for the corresponding values of depth junction.

**Keywords:** Industrial Silicon solar cell, PC1D simulating program, Phosphorus profiles, Silicon texturization.

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### I. INTRODUCTION

The phosphorus emitter is generally formed by a phosphoryl chloride ( $\text{POCl}_3$ ) diffusion in a conventional tube furnace. The resulting diffusion profiles shows a highly doped region near the surface, where it can appear some P precipitates, because the concentration can be over the solid solubility limit of phosphorus in silicon. This region is known as dead layer. These Phosphorous residue give inactive layer that produce centers of recombination, play important rule in efficiency electrical losses. They make increasing the emitter current density,  $J_{0e}$  and lowly lifetime of the emitter [1, 2]. In the emitter recombination we need to recognize the difference between the recombination in the bulk material, majority Auger recombination type, and the recombination happened in the emitter surface, that is characterized by  $J_{0e}$ , effected by the injection level and the impurity profile [3].

Silicon texturization of (100) oriented silicon substrate is an important step to reduce of optical losses of monocrystalline silicon solar cell. During texturization, pyramids are created on silicon surface either by chemical methods or by physical methods. Monocrystalline silicon wafers can be textured by etching along with faces of crystal planes which results in pyramids formation if the surface is appropriately aligned with respect to internal atom [4-6]

Czochralski (Cz) silicon solar cell materials Represent 40% in the world-wide solar cell production and are three times cheaper than Fz wafers, Cz silicon materials can be Treated at high temperatures and can yield high efficiencies well above 20% [7].

### II. EXPERIMENTAL WORK

For P diffusion p-type monocrystalline Cz-Silicon ( $\rho = 0.8 \Omega\text{-cm}$ ; thickness =  $150 \mu\text{m}$ ) with base doping  $N_{\text{base}} = 1.92 \times 10^{16} \text{ cm}^{-3}$  and size  $10 \text{ cm} \times 10 \text{ cm}$  has been taken for processing after chemical etching and cleaning. P pre-deposition is carried out at  $800-875^\circ\text{C}$  by using  $\text{POCl}_3$  as a source of phosphorus and nitrogen as a carrier gas in tube furnace see figure 1 under following conditions as shown in table 1. It is common to perform phosphorus diffusion in two-steps, pre-deposition and drive-in back. In this work we have introduced a step of wet oxidation between phosphorus pre-deposition and drive-in in order to remove the dead layer or area which is not electrically active, which originates during emitters formation.

Experiments consist of texturing monocrystalline silicon wafers with solutions containing sodium hydroxide and IPA in different quantities at a constant temperature of  $80^\circ\text{C}$  and a slight content of silicon dissolved. The NaOH concentration of etchant was diminished from  $34.6 \text{ g/l}$  to  $0.8 \text{ g/l}$  ( $3.4-0.5 \text{ wt} \%$ ) and IPA concentration starts at  $7.8 \text{ volume} \%$ . We measured the sheet resistance of the wafers using four-point probe technique, and the amount of electrically active phosphorus concentration also the inactive layer is calculated by using Tsai model for different diffusion temperatures. Phosphorus profile obtained using chemical etching with 4-point measurement until the sheet resistance shows that a total removal of the P emitter.

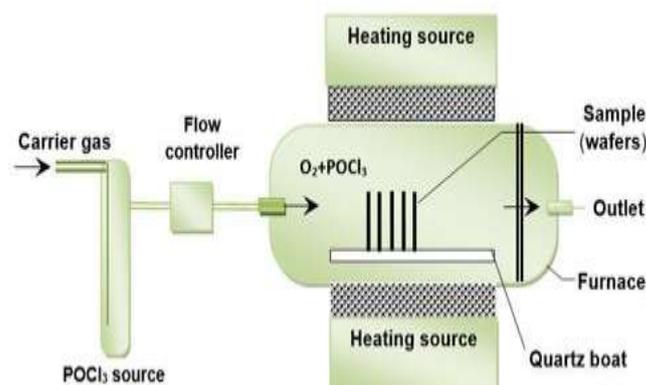


Figure 1 Flow sheet representation of phosphorus diffusion furnace

### III. RESULT AND DISCUSSION

Numerous phosphorus diffusion processes are carried out at various temperatures from 800 °C to 875 °C in order to get doping uniformity for different set of wafers. Usually wafers were loaded in the middle of the boat (carrier for wafers) to avoid the problem of inhomogeneous distribution. The proper position of the boat with wafers within the furnace is also important for maximum and uniform interaction of carrier gases with doping material. In our experiments, we had placed wafers at the last zone of furnace where carrier substrates were entering into the furnace, to seek that the flow is adequate to obtain uniform doping. There was one drawback in this process, wafers had a greater influence of flow on bottom. As a result, there was more doping at position 4 than position 2 in the wafer area. The sheet diagram for the proposed processes for the diffusion silicon solar cell showed in figure 2.

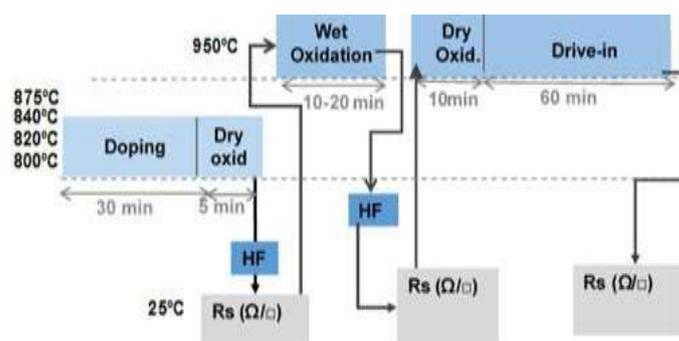


Figure 2

The main target of this work is decrease the industrial cost and give rapid process for silicon solar cell, as we see in the last three figure the Phosphorus emitter profiles after wet oxidation and drive in show decreasing in the surface concentration that give improvement in the cell life time due to decreasing surface recombination and P dead layer as we will see in PC1D data for IV characterization. Silicon texturization is very important step for improve the cell efficiency and performance. Figure 6 shows the relationship between the content of NaOH, the processing time and the quality of the resulted texturing as reflectivity values.

**NaOH amount. It is displayed the influence with the NaOH concentration employed in each dissolution.**

□ Solar Cell parameters calculated using PC1D program

The numerical simulation program PC1D is very used in silicon solar cells simulation; study the effect of process condition and modification on the cell parameters [9, 10]. Now we have to calculate our cell parameters according to the phosphorus diffusion profiles. The typical physics physical parameters that used as input for computer simulation program is two simulation data listed in Table 2. The I-V data for several surface concentration dopant that is observed listed in Table 3.

**Table 2 Simulation parameters input for PC1D**

No.	Base Resistivity $\Omega \cdot \text{cm}$	Carrier Life time $\tau$	Surface recombination velocity cm/sec
Simulation 1	1	200	100

Both  $V_{oc}$  and  $J_{sc}$  values result are increased at low diffusion temperature with introducing oxidation and drive in process with increasing the surface recombination and improve the life time.

**Table 3 I-V data for several dopant concentrations**

Diffusion Temperature ( $^{\circ}\text{C}$ )	Cell parameters Diffusion only	Cell parameters with drive in	Cell Parameters with drive in and thermal Ox.
820 $^{\circ}\text{C}$	$V_{oc}=0.613 \text{ V}$ $I_{sc}=35.5 \text{ mA/cm}^2$ Efficiency=16.1%	$V_{oc}=0.6581 \text{ V}$ $I_{sc}=36.89 \text{ mA/cm}^2$ Efficiency=19.3%	$V_{oc}=0.702 \text{ V}$ $I_{sc}=39.89 \text{ mA/cm}^2$ Efficiency=21.3%
840 $^{\circ}\text{C}$	$V_{oc}=0.600 \text{ V}$ $I_{sc}=34.2 \text{ mA/cm}^2$ Efficiency=15.5%	$V_{oc}=0.623 \text{ V}$ $I_{sc}=35.6 \text{ mA/cm}^2$ Efficiency=17.3%	$V_{oc}=0.692 \text{ V}$ $I_{sc}=38.6 \text{ mA/cm}^2$ Efficiency=20.3%
870 $^{\circ}\text{C}$	$V_{oc}=0.589 \text{ V}$ $I_{sc}=32.7 \text{ mA/cm}^2$ Efficiency=14.4%	$V_{oc}=0.609 \text{ V}$ $I_{sc}=33.8 \text{ mA/cm}^2$ Efficiency=15.9%	$V_{oc}=0.680 \text{ V}$ $I_{sc}=37.8 \text{ mA/cm}^2$ Efficiency=18.9%

As we see in the IV simulated data, When the emitter surface concentration  $N_s$  decreases from  $1 \times 10^{20}$  to  $7 \times 10^{19} \text{ cm}^{-3}$ , the cell efficiency increases from 14 to 19 % for 875 $^{\circ}\text{C}$  diffusion temperature that is indicate the surface recombination and thermal process play a strong rule to improve the cell efficiency.

#### IV. CONCLUSIONS

The targets set in improve the silicon solar cell performance and efficiency for industrial application with low cost and rapid process to get high efficiency. The silicon surface emitter have is play important rule to decrease the auger recombination. Silicon solar cell reflectance data show good improvement after texturization process with different NaOH content.

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