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High Industrial Silicon Solar Cell Efficiency and Performance

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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 x10^{19} cm^{-3} with sheet resistance ˜ 60 Ω/□ and junction depth0.71 µm and saturation current of emitter is 130 fA/cm^2.Our target in texturing optimization work have been met, that we decrease the mount 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.*

I. INTRODUCTION

The phosphorus emitter is generally formed by a phosphoryl chloride (POCl3) 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 J0e, 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 (ρ = 0.8 Ω·cm; thickness= 150µm) with base doping N_base = 1.92E16 cm^-3 and size 10 cm × 10 cm has been taken for processing after chemical etching and cleaning. P pre-deposition is carried out at 800-875^{0}C by using $POCl_3$ 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 80ºC and a slight

content of silicon dissolved. The NaOH concentration of etchant was diminished from 34.6g/l to 0.8g/l (3.4-0.5wt %) and IPA concentration starts at 7.8 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 [8] 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.

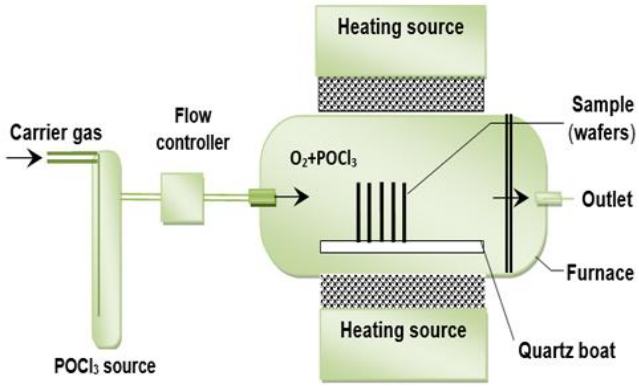

Figure 1 Flow sheet representation of phosphorus diffusion furnace

Table 1. Show the Process Steps and the flows of gases

Steps	Time in minutes (T in ^oC)	Gases flow
wafers loading	5 minutes at (750^0C)	N_2 6 l/min + O_2 0.1 l/min
Stabilization	5-15 ($800\text{-}875^0C$)	N_2 6l/min + O_2 0.1 l/min
Bubbler temperature and flow rate. $20\ ^0C$		240 cc/min $N_2/POCl_3$
Doping	30 ($800\text{-}875^0C$)	N_2 6 l/min + O_2 0.1 l/min +
Oxidation	5 ($800\text{-}875^0C$)	O_2 2 l/min
Exit (wafers unloading)	5 (750^0C)	N_2 2 l/min

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.

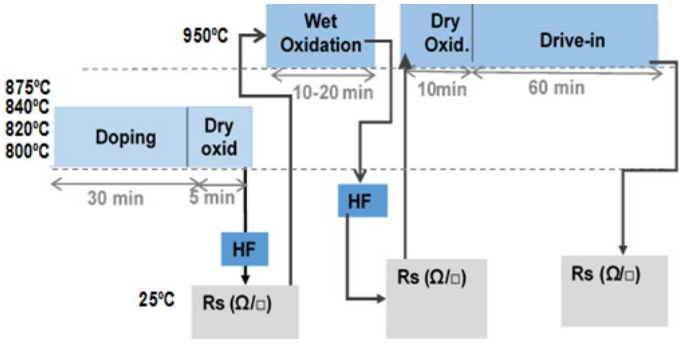

Figure 2 Flow sheet diagram for the proposed processes, a sequence of all the steps used in P pre-deposition with drive-in to corresponding temperature with time description.

Using PC1D program, the doping concentration for various diffusion profiles of phosphorus emitters at 3 different diffusion temperatures under different oxidation and drive-in conditions are simulated. The Emitters which are obtained through phosphorus diffusion with wet oxidation and drive-in are deeper than the emitters obtained normal phosphorus diffusion as showed in the next 3 figures 3, 4 and 5 for low diffusion temperature at 820 ^{0}c, 840 ^{0}c and 870 ^{0}c.

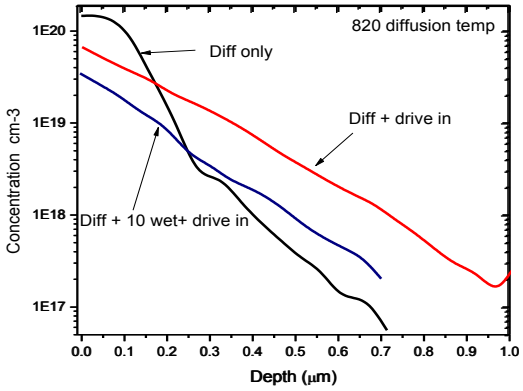

Figure 3 phosphorus diffusion at 820 ^{0}c with different process.

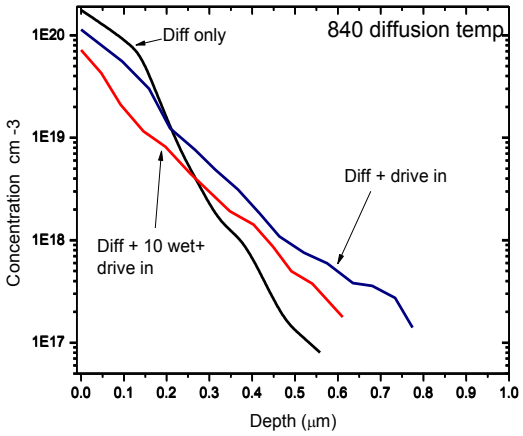

Figure 4 phosphorus diffusion at 840 ^{0}c with different process.

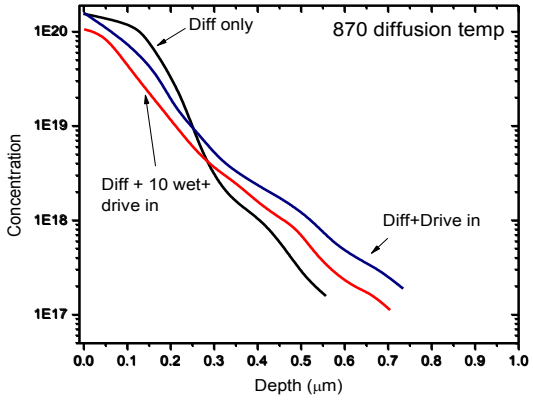

Figure 5 phosphorus diffusion at 870 ^{0}c with different process.

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.

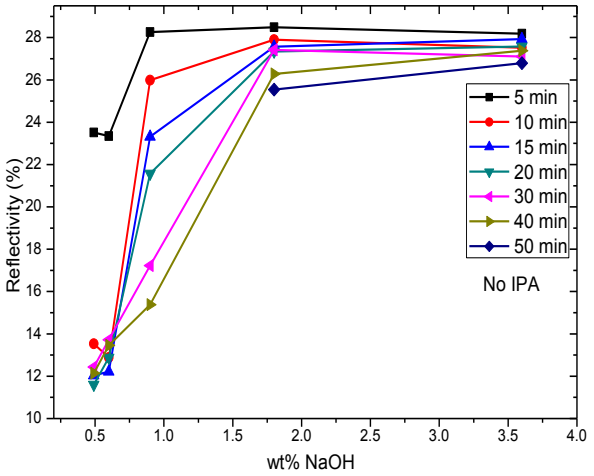

Figure 6 Reflectance values (%) at a wavelength of 725 nm, for the different samples, each one at determined time and different NaOH amount. It is displayed the influence with the NaOH concentration employed in each dissolution.

- 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 accourding 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 Ω·cm	Carrier Life time τ	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 (^{0}C)	Cell parameters Diffusion only	Cell parameters with drive in	Cell Parameters with drive in and thermal Ox.
820 ^{0}C	V_{oc}=0.613 V I_{sc}=35.5mA/cm^2 Efficiency=16.1%	V_{oc}=0.6581V I_{sc}=36.89mA/cm^2 Efficiency=19.3%	V_{oc}=0.702V I_{sc}=39.89mA/cm^2 Efficiency=21.3%
840 ^{0}C	V_{oc}=0.600 V I_{sc}=34.2 mA/cm^2 Efficiency=15.5%	V_{oc}=0.623 V I_{sc}=35.6 mA/cm^2 Efficiency=17.3%	V_{oc}=0.692 V I_{sc}=38.6 mA/cm^2 Efficiency=20.3%
870 ^{0}C	V_{oc}=0.589 V I_{sc}=32.7 mA/cm^2 Efficiency=14.4%	V_{oc}=0.609 V I_{sc}=33.8mA/cm^2 Efficiency=15.9%	V_{oc}=0.680 V I_{sc}=37.8mA/cm^2 Efficiency=18.9%

As we see in the IV simulated data, When the emitter surface concentration Ns decreases from $1x10^{20}$ to $7x10^{19}$ cm^{-3}, the cell efficiency increases from 14 to 19 % for 875ºC 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 git 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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