RTP Furnace에서 공정과정이 태양전지에 미치는 영향

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InfluenceoftheOptimizedProcessinRapidThermalProcessingonSolarCells

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Abstract

The effect of the process parameters on the stable lifetime in rapid thermal firing (RTF) was investigated in order to optimize the process for the Cz-silicon. The process temperature was varied between 700 ℃ and 950 ℃ while the process time was chosen 1 s and 10 s. At below 850 ℃ the stable lifetime for 10 s is higher than that for 1 s and increases with increasing by the process temperature. However, at over 850 ℃ the improved stable lifetime is not dependent on the process time and temperature. On the other hand, two high temperature processes in solar cell fabrics are combined with the optimized process and the non-optimized process. The last process determines the stable lifetime. Also, the degraded stable lifetime could be increased by processing in optimized process. The decreased lifetime can increase using the optimized oxidation process, which is a final process in solar cells. Finally, the optimized and non-optimized processes are applied solar cells.

Key Words : Czochraski, light induced degradation, RTP

1. INTRODUCTION

The minority carrier lifetime degradation is activated due to illumination or application of a forward bias and is deactivated by an anneal step at 200 ℃ in boron-doped Czochralski-grown silicon (Cz-Si), which is used widely for the fabrication of electric devices and solar cells. This degradation by the light-induced metastable defect is definitely correlated with boron and interstitial oxygen [1]. Recent studies have shown that concentration of the metastable defect can be reduced using an optimized process by conventional tube furnace [2] and by a fast annealing process in a rapid thermal processing [3].

In this work, rapid thermal firing (RTF) is used. The firing of screen printed contacts is necessary in order to obtain the desired electrical contact properties and drying of the paste after screen printing (SP) [4]. The firing of contacts by rapid thermal processing (RTP)is more attractive for use in production than firing in conveyor belt furnaces since RTP can lead not only to lower processing times and thermal budgets but also every process step of RTP can be regulated easily of thermal cycle and gas atmosphere. In the present optimization study, the two key parameters such as process temperature and time have been varied. Also, there is two high temperature processes in solar cell produce, namely, diffusion and oxidation. Each optimal process and non-optimal process is varied subsequently and compared with the stable lifetime. The effect of the optimal process on the solar cells has been investigated.

2. EXPERIMENT

In this work, Cz boron doped silicon materials of 0.9 Ωcm resistivity with 350 μm thickness and an oxygen concentration [O_i] of 7.6~8.0 x 10^{17} cm^{-3} were used. After RCA-cleaning the wafers were passivated with 60 nm SiN_x and were treated in different RTF-processes. The SiN_x layer was removed with plasma etching and then all wafers were passivated again with 60 nm of SiN_x. The stable lifetime was measured using MW-PCD [5] before and after degradation.

In order to investigate the influence of optimized and non-optimized process on the solar cell results two different materials were chosen for solar cells: P-type FZ-Si with a resistivity of 1.25 Ω cm and 1 Ω cm Cz-Si corresponding to Baysix.

Fig. 1 shows the solar cell process steps for the experiments. After damage etch of 20 μm on each side, a 2 μm thick aluminum layer was evaporated on the rear side. A commercially available phosphorus dopant spin-on source was deposited on the front side and the samples were processed for the simultaneous formation of emitter and BSF in the first high-temperature step. After removing the P-glass, two different processes were chosen and carried out as rapid thermal oxidation (RTO) used for emitter passivation which is the second and last high-temperature step in the RTP solar cells process; 900 ℃ (an optimized process) and 1050 ℃ (a non-optimized process). The front and rear contacts were realized using metal evaporation. All cells were covered by TiO_2/MgF. Finally, edge isolation has been carried out using a Nd:YAG laser.

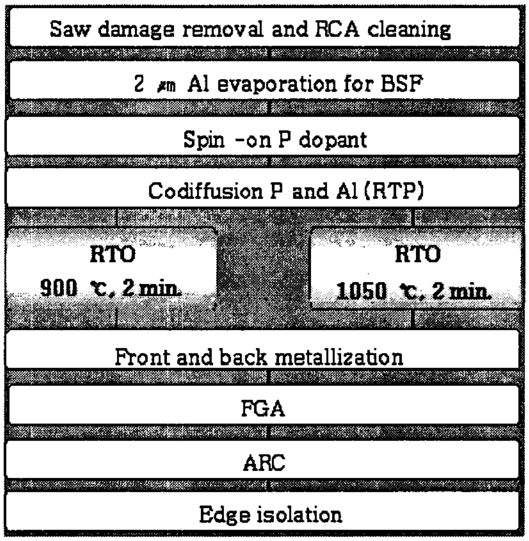

Fig. 1 . Crocessing sequence for the RTP silicon solar cells.

3. RESULTS AND DISCUSSION

3.1 Optimization of rapid thermal firing (RTF) for screen printed contacts

The important two parameters in contact firing, i. e. plateau temperature ($T_{plateau}$) and plateau time ($t_{plateau}$) are varied. $T_{plateau}$ was varied between 700 and 950 ℃. $t_{plateau}$ was chosen to be 1 s and 10 s.

Fig. 2 shows the stable lifetime as a function of plateau temperature for 1 s and 10 s. For 1 s the stable lifetime is enhanced drastically up to more than 40 % at temperatures in the range of 850°C-950 ℃ while no increase is observed below 820 ℃. All Cz materials treated by the RTF-process for 10 s show an increased stable lifetime. The largest increase in the stable time is reached at 850 ℃. The improvement of the stable time is decreased slightly with an increase to higher plateau temperatures. These results support the previous observations that the plateau temperature has the most important influence on the stable lifetime.

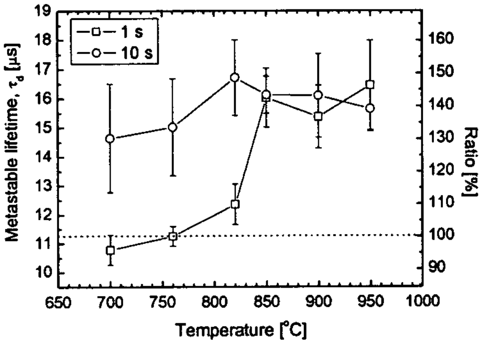

Fig. 2. The metastable lifetime as a function of plateau temperature for 1 s and 10 s RTF time (R_{up} = 90 °C/s and R_{down} = 30 °C/s).

3.2 Influence of two subsequent high-temperature steps

In solar cell fabrication there is two high-temperature steps one for emitter diffusion and the other for oxidation. we choose two subsequent high-temperature steps on the stable lifetime combining an optimized (good) and a non-optimized (bad) process. Fig. 3 shows the stable lifetime after the two subsequent processes. The dotted line represents the non-RTP-treated reference wafer.

The stable lifetime is reduced from 14 μs to 9 μs after one bad RTP-process whereas the stable lifetime increases from 14 μs to 22 μs after one good RTP-process. For the process sequence with two non-optimized (bad-bad) RTP steps the stable lifetime is reduced by 36 % from 14 μs in the reference wafer to 9 μs after the first non-optimized (bad) step. No further reduction is observed after the second non-optimized (bad) step. Replacing the second step by an optimized (good) process we observe an increase of stable lifetime up to 19.5 μs (after a single optimized process the stable lifetime is increased of from 14 μs to 22μs). From this experiment it is clear that the last high-temperature step determines the stable lifetime and that the lifetime reduction due to a first non-optimized step can be reversed by an optimized last step.

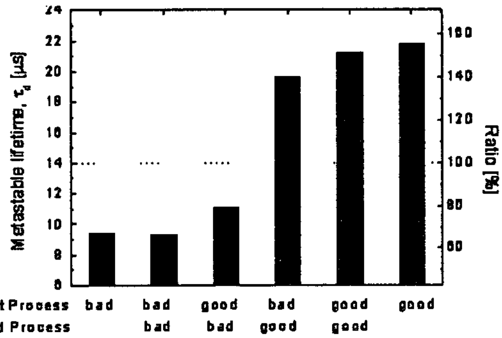

Fig. 3. Impact of two subsequent processes on the stable lifetime.

3.3 Effect of improving processes on the RTP solar cells

The effect of each thermal process on the cell performance before and after degradation is shown Table 1. As expected V_{oc} and J_{sc} measured before light-induced degradation are higher than measured after degradation. Cells processed at 900 ℃ have a better J_{sc} than those processed at 1050 ℃. But, it is quite difficult to conclude only from the short circuit current measurement if this small improvement is caused by the better lifetime due to the optimal process. The internal quantum efficiency (IQE) measurements in Fig. 4 show that all cells processed at 900 ℃ have a better performance especially in the long-wavelength range. In the short-wavelength range the quantum efficiency of cells processed at 900 ℃ is slightly higher than the one of cells processed at 1050 ℃since the sheet resistance at 900 ℃ (112 Ω/Sq.) is lower than the one at 1050 ℃ (82 Ω/Sq.).

Table 1. Comparison of solar cells after two different processes in Cz- and FZ-Si before degradation and after degradation with a 1-sun for 30 h.

Type	Deg.	Temp. [℃]	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
Cz	before	900	620.1	35.58	78.1	17.2
		1050	620.8	34.91	79.9	17.3
	after	900	613.9	34.76	78.8	16.8
		1050	612.9	34.22	80.0	16.8
FZ		900	628	35.74	79.3	17.8
		1050	632	35.56	80.6	18.1

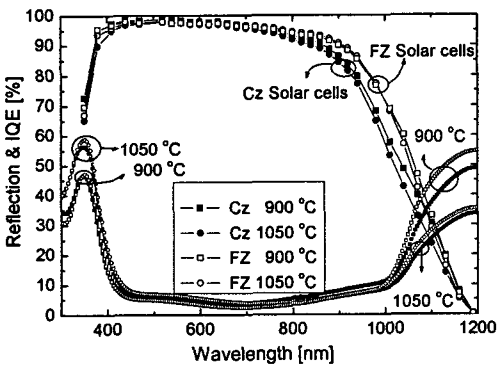

Fig. 4. The effect of two different processes on the reflection and internal quantum efficiency of Cz and FZ solar cells.

Also, in Cz cells the IQE for wavelengths above 800 nm is better for cells processed at 900 ℃ than for cells processed at 1050 ℃. It is certain that the lifetime of the cell at 900 ℃ is better than that of the cell at 1050 ℃ since the long wave IQE response is attributed to bulk diffusion length.

Resulting of calculation of effective diffusion length, L_{eff} from the measured IQE, the cells processed at 900 ℃ have a L_{bulk} around 240 μm which corresponds to a $_{bulk}$ around 21-22 μs. The cells processed at 1050 ℃ show a L_{bulk} ($_{bulk}$) around 205 μm (15-16 μs).

4. CONCLUSION

In this work, we have investigated the improvement of the sable lifetime by rapid thermal processing (RTP). In contact firing even though the plateau time is very short only 1 s and 10 s, the stable lifetime is improved by about 40 % above temperatures of 800 ℃,

In the two subsequent processes, the stable lifetime is mainly influenced by the last high-temperature process. For example, the lifetime reduction from 14 μs to 9 μs after the non optimized process in the first step can be increased up to 20 μs due to the last optimized process.

Finally, an optimized (900 ℃) and a non-optimized (1050 ℃) RTO process, being the last high-temperature step in RTP-solar cell process, were performed in order to investigate their influence on solar cells.

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