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Low temperature diffusion and its impact on hydrogenation

Lihui Song [a,*], Alison Wenham [b], Stuart Wenham [b]

[a] College of Materials & Environmental Engineering, Hangzhou DianZi University, Hangzhou, China
[b] School of Photovoltaic and Renewable Energy Engineering, UNSW, Sydney, NSW 2033, Australia

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ABSTRACT

The impact of a low temperature diffusion (LTD) step at about 650 °C after emitter diffusion on the performance of silicon solar cells is investigated. Neighbouring wafers from a silicon ingot with and without LTD were chosen to make the cells using screen printed techniques. The efficiency was measured and detailed photoluminescence images were performed for the cells with and without LTD. It is found that LTD can significantly increase the efficiency of the cells about 2% by a gettering effect. The post-firing hydrogen passivation was then applied to the screen printed cells made with and without LTD. The efficiency and photoluminescence image before and after post-firing hydrogen passivation were measured to examine the impact of hydrogenation on the cells made with and without LTD. It is found that cells with LTD can respond better to hydrogenation.

1. Introduction

Cast mono-crystalline silicon solar cells are rich in crystallographic defects, which extend across the silicon bulk and junction [1–5]. These crystallographic defects are detrimental to the efficiency of silicon solar cells, by significantly degrading the short circuit current, opening the circuit voltage and fill factor of silicon solar cells [6–8]. Passivation of these crystallographic defects is significant, as it can reduce the junction recombination and thus increase the fill factor, open circuit voltage and efficiency of the silicon solar cells.

It is known that phosphorus diffusion can passivate the crystallographic defects to some extent [9]. This paper investigates the impact of LTD subsequent to phosphorus diffusion on passivation of crystallographic defects, and therefore on the performance of silicon solar cells. Krain et al. [10] reported a reduction of the interstitial iron concentration in multi-crystalline silicon (mc-silicon) wafers after a low temperature anneal at temperatures from 300 to 500 °C for about 0.5 h performed after phosphorus diffusion. Pickett and Buoriassisi [11] found that a similar anneal can significantly improve the efficiency of solar cells made of string ribbon wafers. Several papers [9,12,13] also reported that low temperature anneal was good for impurity gettering.

LTD is known to enhance impurity gettering, and is hence able to improve the minority carrier lifetime of the silicon wafers. In this paper, we will further investigate the passivation of crystallographic defects by LTD. During LTD, the phosphorus atom can diffuse into the grain of silicon wafer, and thus passivate the dangling bonds at the grain boundaries. It is also expected that metal impurities can be gettered into the silicon grain along with the phosphorus atoms diffusing into the silicon grain.

Post-firing hydrogenation is also applied to the silicon solar cells made with and without LTD. The impact of LTD on the effect of post-firing hydrogenation is investigated and it is found that LTD increases the effect of hydrogen passivation on the silicon solar cells. After LTD, numerous phosphorus atoms can occupy the silicon grain and therefore block hydrogen diffusing away through silicon grains. In this case, hydrogen can easily passivate the dislocations and grain boundaries that exit between grains.

It is also reported that dopant atoms can block hydrogen diffusion. For instance, in p type material, hydrogen exists in the charge state of H^+ [14], while the ionised boron atoms are in the negative charge state. Therefore boron atoms can attract positively charged hydrogen atoms in place due to colombic attraction force and hence the ionised p type dopant atoms can retard the diffusion of hydrogen in silicon. Similarly, the phosphorus atoms can block negatively charged hydrogen atoms diffusing away through the silicon grain. Therefore it is believed that LTD can enhance the effect of hydrogen passivation on silicon solar cells.

2. Experimental method

The silicon substrates used in the experiment were four 156 × 156 mm 1 Ω cm random pyramid textured cast-mono crystalline silicon wafers. The samples were selected from adjacent

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[*] Corresponding author.
E-mail address: songchengwan@sina.com (L. Song).

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locations from the ingot to ensure that crystal defects were closely matched. After RCA cleaning the sample surfaces were doped in a tube furnace using a $POCl_3$ process (795 °C and 25 min for pre-deposition step, 885 °C and 30 min for drive-in step) to achieve a phosphorous emitter with a final sheet resistance of 55 Ω/□. Four wafers went through a low temperature diffusion process at 650 °C for 12 h. The control wafers did not undergo the low temperature diffusion process. Subsequent to diffusion, the front sides of the wafers were deposited with a SiN_x:H layer of thickness 75 nm and refractive index 2.08 via PECVD. The wafers were then cleaved into 40×40 mm^2 tokens with the location and orientation of each carefully matched to allow comparison between sets of tokens. After cleaving, the samples were screen-printed with an aluminium full area back contact and a silver front H-bar contact grid and then fired in a belt furnace with a peak temperature of 800 °C. Edge isolation was achieved by laser cutting and cleaving the samples from the rear, resulting in a final cell area of 8.55 cm^2. The samples were then characterized using 1-Sun light IV, dark IV, spectral response and photoluminescence (PL) imaging. The IV tests were performed on a custom built IV tester, for spectral response the EQE was measured using a spectral response system and the reflection with a Perkin Elmer, PL images were obtained using a BT imaging tool.

After the final cell processing and characterisation, the samples received an additional hydrogen passivation treatment. This treatment involved heating on a hotplate for 4 min with the samples removed after each minute, quenched by placing on a damp cloth and then characterized. Some of the samples were illuminated during the hotplate treatment using a 938 nm laser with a spot size that entirely covered the sample. The laser illumination resulted in an increase of the substrate temperature that was accounted for by lowering the hotplate set point such that the final cell temperature was 543 K in all cases. Three different laser intensities were used with the intensity measured using a calibrated photodiode. A summary of the processing conditions applied to each sample is shown in Table 1.

3. Results and discussion

The performance of the silicon solar cells made with and without LTD is shown in Fig. 1.

Table 1
Processing parameters for post-firing hydrogen passivation anneal.

Group without low temperature diffusion	Group with low temperature diffusion	Number of cells	Laser intensity (Photons/cm^2/s)	Hotplate set point (K)	Target cell temperature (K)
1	1(2)	1	0	623	543
2	2(2)	1	6.943×10^{18}	594	543
3	3(2)	1	1.113×10^{19}	580	543
4	4(2)	1	1.513×10^{19}	568	543

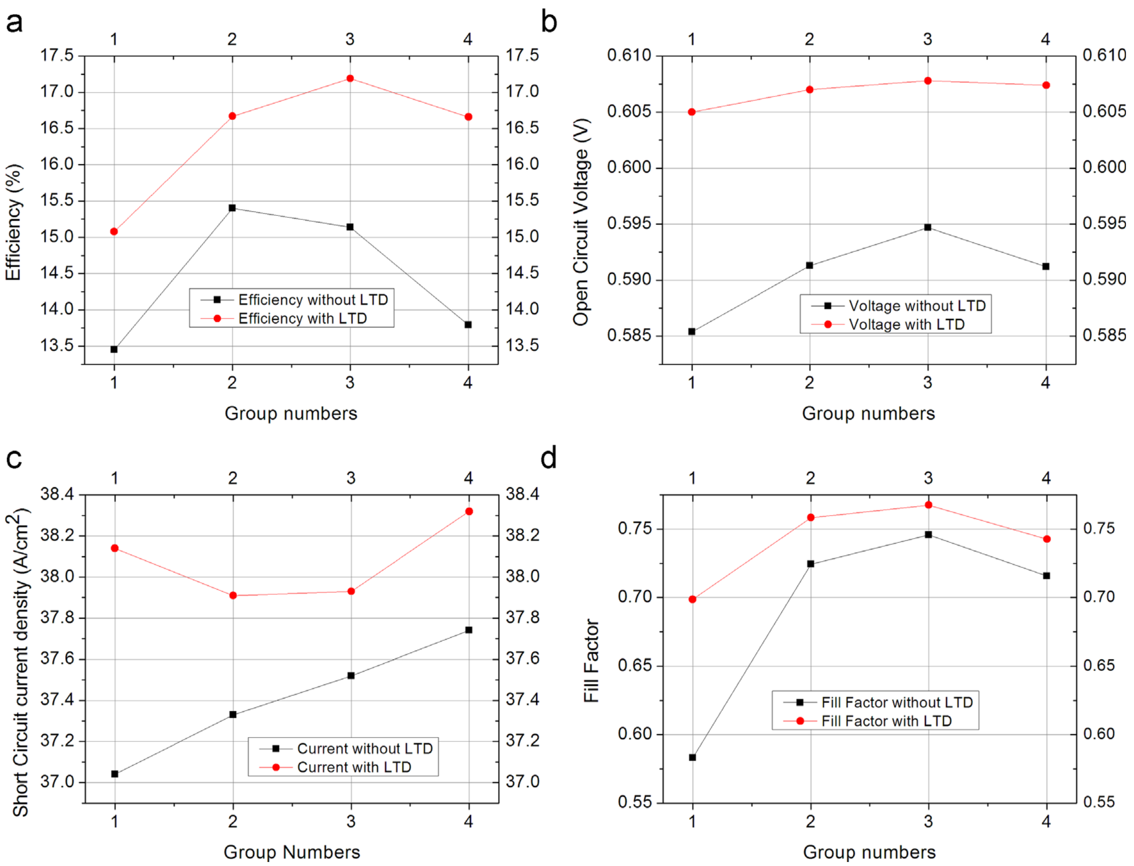

Fig. 1. The comparison of the performance of the silicon solar cells made with and without LTD.