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Thermally Induced- and Passivated- Meta-stable Defects in Mono-Crystalline Silicon By Rapid Firing Processes

Moonyong Kim[1], Stuart Wenham[1], Veysel Unsur[2], Abasifreke Ebong[2], and Brett Hallam[1]

[1]*School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, NSW 2052, AUSTRALIA*
[2]*Department of Electrical and Computer Engineering University of North Carolina at Charlotte, Charlotte, NC, USA*
E-mail: moonyong.kim@unsw.edu.au

Boron-doped Czochralski-grown silicon (Cz-Si) is one of the common wafer types that is used for the fabrication of crystalline silicon solar cells [1]. However, this type of wafer is susceptible to boron-oxygen (B-O) related light-induced degradation (LID) [2]. An effective way to permanently suppress the negative impact of B-O defects is to use illuminated annealing [2]. Subsequent studies have identified a key role of hydrogen in the permanent passivation process [3], although that understanding is still disputed.

An alternative approach to reduce the extent of B-O related LID is by a thermal approach such as rapid thermal processing [4], which is required process for contacting metallization on typical commerical solar cell structures. Increasing the cooling rate after the rapid firing process can also reduce the B-O extent [5]. These results demonstrated an alternative pathway to eliminate B-O defects, whereby thermal processing can modulate the equilibrium concentration of B-O defects. Therefore, this approach can minmise LID without any additional process.

It has been shown recently that this high-temperature firing process can also introduce and vary the extent of another meta-stable defect causing Light- and elevated Temperature- Induced Degradation (LeTID) [7,8], which strongly affect multi-crystalline silicon PERC cells. The defects, however, could also be induced in different types of crystalline silicon in p-type [8] silicon. Furthermore, the defects can also be induced by thermal annealing or during the rapid firing process [8]. In this paper, we further investigate the impact of the rapid thermal processing on the meta-stable defect concentrations responsible for two common LID mechanisms, B-O related LID, and LeTID.

Lifetime structures were fabricated on p-type Cz-Si wafers. All Samples were then $POCl_3$ diffused with sheet resistance of 65 Ω/sq. After phosphosilicate glass removal in dilute HF, hydrogenated silicon nitride (SiN_x:H) with a refractive index of 2.08 was deposited onto both surfaces of the wafers using a plasma- enhanced chemical vapour deposition system [9]. The samples were fired at different peak firing temperatures, and different belt speeds in an inline fast-firing furnace. The effective lifetime that is measured using quasi-steady state photo-conductance method [10] Using Sinton WCT-120 Lifetime Tester. Normalised defect density (NDD) is calculated using the equation below.

$$\mathrm{NDD}=\frac{1}{\tau_{\mathrm{LS}}}-\frac{1}{\tau_{\mathrm{FD}}}$$

Where τ_{LS} and τ_{FD} are effective lifetime after 48 hours of light soaking and after firing with different conditions and subsequent dark annealing at 200°C for 10 mins, respectively. Lifetime analysis method by Nampalli *et al.* [11], has been used to isolate the bulk recombination and surface recombination after process.

Fig. 1a. Shows the firing profiles with different belt speeds and peak temperatures. the cooling rates from 750 °C to 815 °C with different firing conditions are shown in Fig. 1b. Increasng belt speed or peak firing temperature (T_{peak}) increases cooling rates.

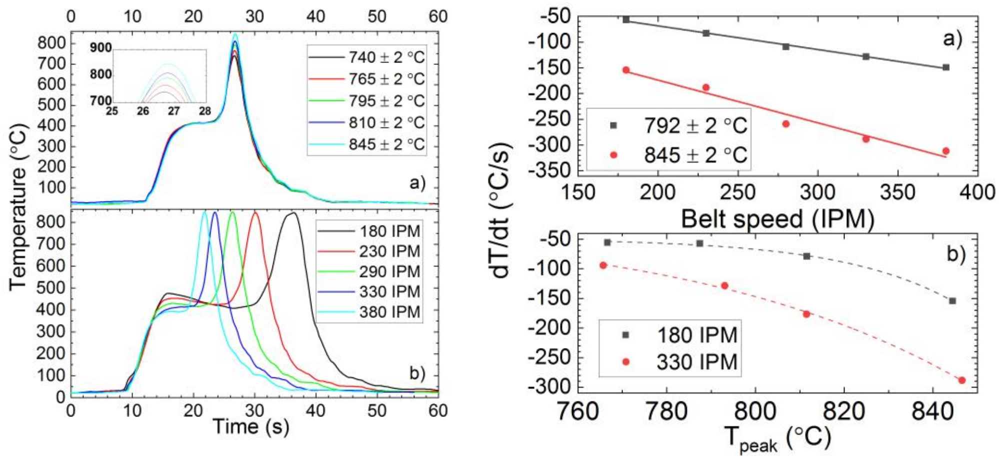

Figure 1. Thermal profiles of the rapid firing processes a) with different peak firing temperatures at belt speed of 330 inch per minutes (IPM) and b) different belt speeds with a peak temperature of 845 ± 2 °C.

Increasing T_{peak} decreased the effective lifetime after firing (see Figure 2-a). The reduction in lifetime at higher peak firing T was more severe for faster belt speeds, with faster associated cooling rates. The reduction in the effective lifetime after firing indicates the pre-formation of LeTID. Lifetime analysis method was performed to ensure the reduction in lifetime was due to bulk recombination only. Figure 2b. shows the NDD with different firing conditions. Increasing T_{peak} showed an increase in NDD, which indicates the increase of the extent of B-O defects. It is unclear why the faster belt speed showed increase then decrease in NDD. The results showed how meta-stable defects in Cz-Si can be modulated with firing conditions. This must be considered to not only achieve higher bulk lifetime but to be more stable under an illumination.

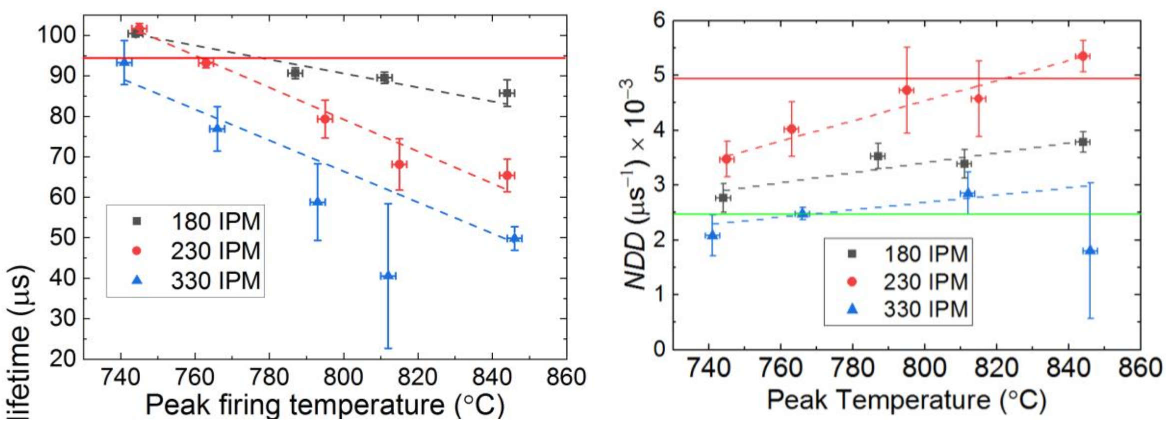

Figure 2. a) Effective lifetime and b) NDD with different T_{peak} and belt speeds

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