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Firing temperature profile impact on light induced degradation in multicrystalline silicon

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Abstract

Light- and elevated temperature-induced degradation (LeTID) in multicrystalline silicon can reduce the efficiency of solar cells significantly. We analyse the influence of the firing temperature profile on the degradation behaviour of neighbouring mc-Si wafers, varying peak temperatures above 800°C (measured) as well as heating and cooling ramps. The degradation intensity is determined by the normalized defect concentrations N_t^* using spatially resolved and lifetime calibrated photoluminescence images. Wafers which were fired in a standard industrial fast firing furnace with steep ramps suffer from significant LeTID whereas samples that were subjected to the same or even higher peak temperatures but with slower heating and cooling rates hardly degrade. A spatially resolved analysis of N_t^* over the whole wafer area shows that at the beginning of the experiment, the degradation is restricted to low-lifetime areas around dislocation clusters. After several hours, a very strong degradation is observed also in initially good grains. The possible roles of metallic impurities and hydrogen in-diffusion are discussed.

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Keywords: light-induced degradation (LID); multicrystalline silicon (mc-Si); temperature profile; wafer

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1. Introduction

In 2012, a new degradation mechanism in multicrystalline PERC (passivated emitter and rear contact) silicon solar cells was observed at elevated temperatures under light exposure (“LeTID” [1]) which leads to significant efficiency losses [2]. This effect cannot be attributed to iron-boron pairs or the boron-oxygen defect [2-6]. It was shown that higher peak temperatures during the firing process lead to stronger degradation [7-9], possibly indicating that precipitates dissolve and form lifetime-killing complexes in the following. Furthermore, a second firing step at reduced temperatures decreases LeTID [8]. In addition, it was shown that the surface passivation affects the degradation behaviour [10], which suggests that hydrogen influences LeTID.

Our first experiments with boron-doped and phosphorus-gettered lifetime samples fired in a rapid thermal processing (RTP)-oven (peak temperatures of 700°C - 850°C measured) showed a surprisingly small degradation in the range of $\Delta\tau = 10\ \%_{rel}$ at $\Delta n = 10^{15}\ cm^{-3}$ compared to experiments of other groups. As the latter had been conducted in fast firing ovens (FFO), we carried out an experiment to analyse the influence of the firing process itself and the temperature profile in particular on LeTID while keeping all other influences constant.

2. Material and methods

2.1 Sample preparation

High performance multicrystalline silicon wafers with a base resistivity of ~1.0 Ωcm from neighbouring positions in the ingot were processed to lifetime samples. All wafers were processed with the same sequence: After wafer cutting (format 125 mm x 62.5 mm), saw damage etch and HNF/SC1 cleaning, the samples were $POCl_3$-diffused at 847°C for one hour (~50 Ω/sq) and the phosphorus silicate glass and the emitter were etched back. The wafers were covered with an Al_2O_3 layer (10 nm) and capped with a PECVD anti-reflective coating made of silicon nitride (100 nm). For the analysis of the effect of different firing processes on LeTID, five temperature profiles in two firing furnaces featuring different heating and cooling rates - all calibrated using identically processed sister samples - were compared (see Fig. 1a). Using FZ reference samples, care was taken to exclude other influences resulting from the use of two different furnaces. The temperature profile of the FFO fired samples (black solid line, 3 samples) is characterised by a steep heat up and cool down of the wafers. As it is known that the cooling ramps of high temperature processes can significantly influence the defect concentration by an internal gettering [11], a further variation of temperature profiles was added to the experiment. It was tried to imitate the characteristics of the FFO furnace by two standard temperature profiles of the RTP furnace with varying peak temperatures of 800°C (red dashed line) and 850°C (orange dash-dotted line), respectively. However, these standard firing profiles show a longer cool down sequence than the FFO profile. To even prolong the cooling sequence, a very slow but continuous profile of the ramp-down was used (“RTP slow ramp”, blue dotted line). The last variation (“RTP with plateau”, red dashed line) is characterised by a temperature plateau at 550°C which was hold for 10 seconds during a slow cooling process. For these profiles small deviations of the maximum firing temperature can be seen in Fig. 1(a). The trends of our results cannot be attributed to these temperature differences.

2.2 Measurements

After processing and an initial boron-oxygen degradation at 0.15suns for 48 hours, the LeTID defect was activated under halogen lamp illumination at an intensity corresponding to ~1 sun while the samples were thermostated at 75°C. Before and during the degradation, the wafers were characterised by spatially resolved and lifetime calibrated PL imaging [12] to calculate the normalized defect concentration N_t^*. For the PL imaging a 790 nm laser and a CCD camera are used. A stack of long pass filters and a 1000 nm short pass filter prevent the detection of laser light and reduce optical blurring. N_t^* is calculated with the initial and degraded lifetime at constant injection level Δn [13]: