Area 1: Crystalline and Thin Film Silicon PV

IMPROVED UNDERSTANDING OF LIGHT-INDUCED DEGRADATION AND REGENERATION IN MULTICRYSTALLINE SILICON SOLAR CELLS

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In 2012, Ramspeck et al. reported on an unexpectedly strong light-induced degradation of solar cells fabricated on block-cast multicrystalline silicon (mc-Si) [1]. They observed that the cells degraded up to 6% relative in their efficiency under illumination at elevated temperature (above ~50°C), hence, frequently the phenomenon is denoted “LeTID” (Light and elevated Temperature Induced Degradation). Since Ramspeck et al. were not able to explain this effect by known light-induced degradation processes such as the boron-oxygen defect activation or the iron-boron pair dissociation, they attributed the efficiency loss to a new type of degradation mechanism. Based on a series of lifetime experiments, we recently proposed a multi-step defect model [2]. In this model, first, the high-temperature firing step (used to form the metal contacts as last step in the cell process) dissolves metal precipitates. The resulting free metal atoms attach to non-metal atoms, forming non-recombination-active defect complexes, which change their configuration during minority-carrier injection (i.e. during illumination) at elevated temperature and finally dissociate. The resulting (highly recombination-active) interstitial metal atoms limit the lifetime in the mc-Si bulk after complete degradation. However, on very long timescales, a perfect regeneration of the cell efficiency is observed. This regeneration is – in our model – explained by the diffusion of the interstitial metal atoms to the wafer surfaces, which act as a ‘sink’ for the metal atoms [2]. In this study, we perform lifetime measurements on mc-Si lifetime samples with different thicknesses. Since in our model, the lifetime regeneration in mc-Si is attributed to the diffusion of interstitial metal atoms to the wafer surfaces, the thinner the wafer, the faster the regeneration should take place, which we indeed observe.

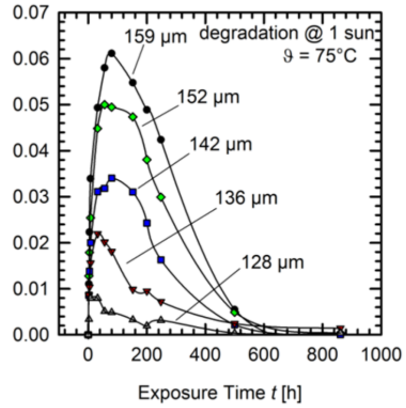

Figure 1: Evolution of the normalized defect density N^* at 75°C and 1 sun, determined from the measured carrier lifetime of neighboring mc-Si samples of different thicknesses. The thinner the mc-Si wafer is, the less pronounced is the magnitude of degradation, i.e. the smaller is the maximum defect concentration. Also, the thinner the wafers the faster the regeneration is.

We extract the lifetime $\tau(t)$ of our Al_2O_3/SiN_x-passivated mc-Si wafers at a fixed injection level of 10^{15}cm^{-3} using a Sinton WCT-120 lifetime tester and calculate the normalized defect density $N^*(t) = (1/\tau(t) - 1/\tau_0)$, with the initial lifetime being denoted τ_0. As can be seen from Fig. 1, the normalized defect concentration for the sample with a thickness of 159 µm increases within the first 80 hours of illumination, corresponding to a pronounced degradation in the lifetime. During prolonged illumination, N^* decreases again, which is the mentioned lifetime regeneration effect. The most important result of our study is the observation that the sample thickness has indeed a pronounced impact on the lifetime evolution. On the one hand, the maximum N^* decreases with decreasing wafer thickness. On the other hand, the lifetime regeneration is happening much faster in thinner wafers. Both observations are in good agreement with our defect model. The detailed analysis of our data even provides an estimate of the diffusion coefficient of the mobile species, which is found to be in the range $(3.5\pm1.5)\times10^{-11}$ cm^2/s. This value of the diffusion coefficient fits with reported values for the diffusion coefficients of ***cobalt*** and ***nickel*** in silicon at a temperature of 75°C, but would also be consistent with the diffusivity of ***hydrogen***, which in fact requires a slight modification of our model. Importantly, we observe a linear increase of the maximum defect density with increasing sample thickness, leading to the conclusion that there is *no degradation* taking place in mc-Si wafers and in solar cells thinner than 120 µm, which we in fact experimentally confirm.

[1] K. Ramspeck et al., *Proc. 27th EUPVSEC* (2012), p. 861.
[2] D. Bredemeier et al., *AIP Advances* **6**, 035119 (2016).