

New Insights into Hydrogen Induced Degradation: A study on n- and p-type Silicon

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Hydrogen induced degradation (HID), or more commonly referred to as light- and elevated temperature-induced degradation (LeTID) has been a common point of interest within both industrial and academic circles of the photovoltaics industry [1]. On studies conducted using industrial passivated emitter and rear cell (PERC) architectures, LeTID has been associated with up to a 16% relative drop in efficiency, thus proving itself to be a significant problem if untreated [2]. Even though such degradation mechanism was initially, thought to affect multi-crystalline silicon (mc-Si) substrates, recent works have identified identical defects manifesting in a plethora of materials including p-type Czochralski-grown (Cz) monocrystalline silicon and float-zoned (FZ) wafers [3,4]. Recently, we identified HID in n-type silicon, a material which has been long believed to be free from light induced degradation [5]. Although the exact cause of recombination is still under debate, various works have postulated the involvement of hydrogen introduced into the silicon bulk during firing.

In this paper, we continue to explore the behaviour of HID in n-type silicon as an extension to the work in [5]. We start by using 6-inch n-type Cz (2 Ω .cm) wafers with symmetrically diffused phosphorus emitters and silicon nitride ($\text{SiN}_x\text{:H}$) passivation on both sides. These wafers are then fired at a temperature of approximately 740 $^{\circ}\text{C}$; a condition known to cause LeTID defect formation in p-type silicon. To investigate defect formation, we use either a) annealing in the dark at various temperatures and b) application of a 0.02-sun to 1-sun illumination at the same temperatures. Sample performance is monitored using an effective lifetime (τ_{eff}) metric extracted from photoconductance measurements and normalised to the lifetime directly after firing (prior to any defect formation). In Figure 1, the evolution in relative minority carrier lifetime is shown with respect to time for both n-type (Figure 1(a)) and p-type (Figure 1(b)).

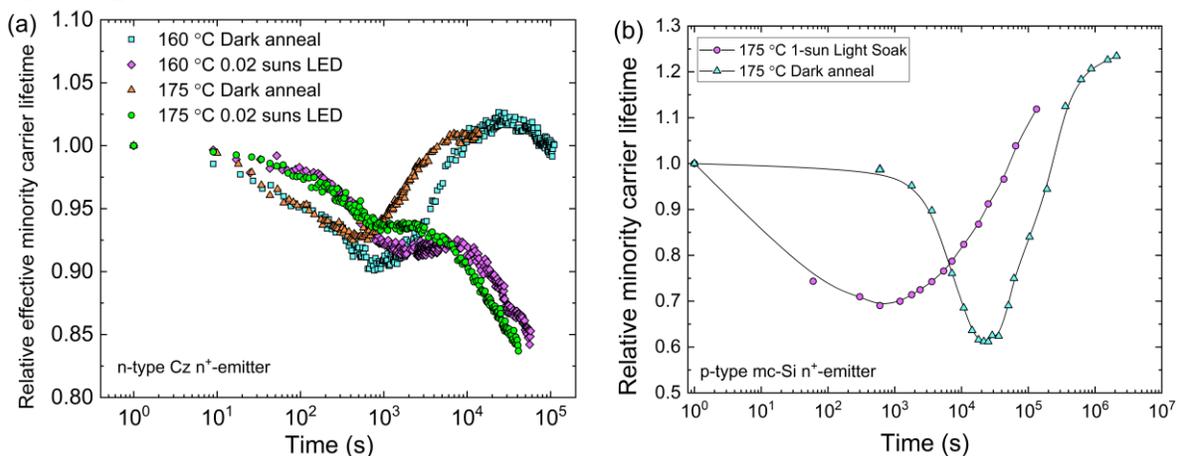


Figure 1. Relative effective carrier lifetime of n-type Cz (a) and p-type mc-Si (b) as a function of dark annealing or light soaking (0.02 or 1-sun) time.

On p-type silicon, the addition of illumination resulted in an acceleration of the degradation and regeneration reactions associated with HID. Both conditions, however, result in a recovery of the carrier lifetime beyond its starting value. In n-type silicon, the behaviour seen in the dark is follows closely with p-type, albeit the reaction kinetics are 2.5 orders of magnitude faster [5]. After an initial degradation and recovery of the bulk, a subsequent decline of the surface quality is observed. With

added illumination, however, a secondary surface degradation mechanism is observed prior to any onset of bulk regeneration. Interestingly, the time scale required for the initial bulk degradation to occur appears to be longer, in contrary to the behaviour derived from p-type whereas the onset of surface degradation appears to be near a similar time. In the work presented in [5], we concluded that the recovery of HID was related to the diffusion of a hydrogen species towards the surface of the silicon wafer during dark annealing. A build-up of significant concentrations of interstitial hydrogen in the negative charge state (H^-) near the surface would then lead to a subsequent surface deterioration due to the formation of hydrogen induced defects and dislocations. The rate at which this diffusion occurs, however, may be heavily reliant on the diffusivity of the hydrogen species. If we consider the bulk of the silicon (Figure 2(a)), the addition of 0.02 suns of illumination increases the fraction of H^+ by over an order of magnitude and above the H^- concentration. Since the diffusivity of H^+ is lower than H^- , this may result in a retarding effect. In the surface (Figure 2(b)), however, the higher phosphorus dopant density maintains a high fraction of H^- which may facilitate the formation of defect leading to surface degradation.

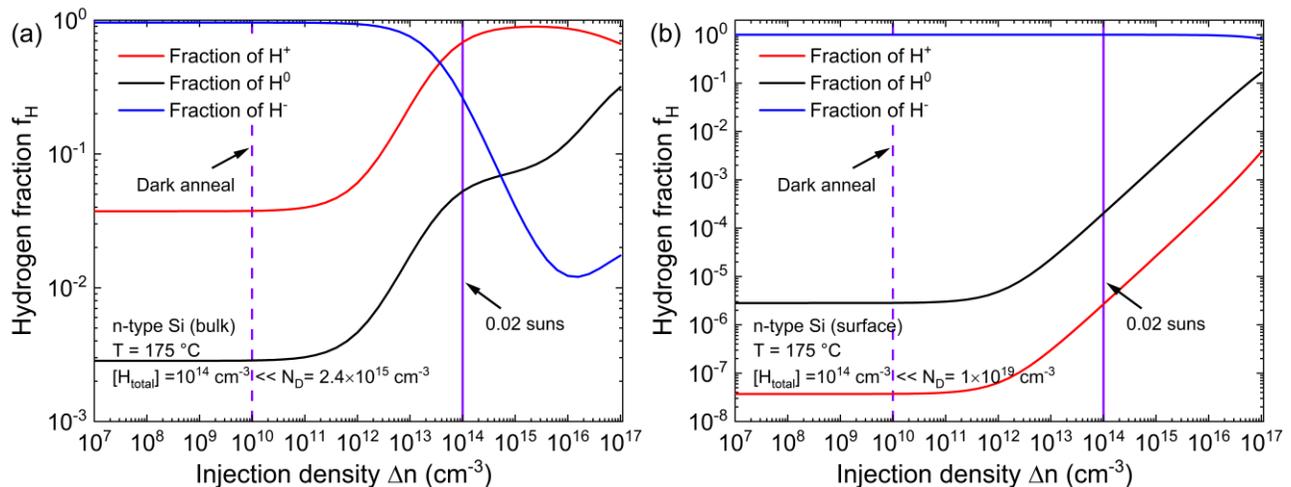


Figure 2. Hydrogen fraction charge state as a function of injection level in the a) bulk and b) emitter regions of an n-type silicon wafer.

In the final paper, we will be presenting further investigations on the dependence of illumination intensity in addition to further comparisons to the behaviours observed on n-type and p-type mc-Si

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