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Light- and Elevated Temperature-Induced Degradation (LeTID): The Past, the Present and what Lies Ahead

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Introduction

Light- and elevated temperature-induced degradation (LeTID) has, in recent years, captured the attention of the global silicon photovoltaics industry. With over 180 publications and countless conference presentations from more than 40 universities, research institutes and manufacturers alike (see Fig. 1), there has been a range of studies conducted to understand the behaviours, kinetics, mitigation strategies and root cause of the defect. **In this talk, we will provide a condensed review of the current global progress on LeTID research, highlighting recent theories, models, mitigation strategies and implications on the future of commercial silicon solar cells.**

Figure 1. A figure of logos of the many publishing institutes underaking LeTID studies.

The History of LeTID

A new flavour of light-induced degradation (LID) was first observed in 2012 on the newly emerging passivated emitter and rear cell (PERC) structures fabricated using multi-crystalline silicon (mc-Si) materials [1]. Initial testing of such devices demonstrated a 16%$_{rel}$ loss in solar cell efficiency with a projected time-scale of many decades for natural recovery out in the field [2]. Further testing by Kersten *et al.* observed that the degradation was accelerated by increasing temperature and illumination, thus the phenomena was coined LeTID [3]. In 2016, Bredemeier *et al.*, Nakayashiki *et al.* and Chan *et al.* uncovered a correlation between degradation and the peak metallization firing temperature, suggesting that the defect may be process-induced [4–6]. Further work by Chan *et al.* showed that defect formation may occur at elevated temperatures in the absence of illumination and that the formation and recovery kinetics may be modulated via thermal annealing [7]. This understanding paved the way for identifying LeTID on materials usually susceptible to multiple other forms of LID such as boron-oxygen related degradation Czochralski-grown (Cz) monocrystalline silicon. In 2017, Chen *et al.* and Fertig *et al.* reported the susceptibility of Cz silicon to LeTID [8,9], which in turn, linked various works observing degradation on high-quality float-zone wafers to the same defect [10]. In 2018, Chen *et al.* and Sio *et al.* uncovered identical behaviours in n-type Si materials, long believed to be free from LID, cementing the notion that LeTID is a problem universal to all silicon materials [11,12].

Possible Candidates and Root Cause

Over the years, numerous candidates for the defect behind LeTID have been proposed. The most commonly discussed candidates are metallic impurities [4,13]. Bredemeier *et al.* postulated the involvement of Co and Ni whereas other works from UNSW and MIT utilized lifetime spectroscopy to speculate the involvement of Ti, W and Mo [13,14]. In more recent years, there has been increasing evidence to suggest that hydrogen introduced into the silicon bulk plays a major role in causing recombination [11,15–17]. Given our recent explanations of hydrogen and its interactions with bulk impurities we will present both a model of hydrogen diffusion and kinetics (Fig. 2) to explain the observed behaviours of LeTID in both n- and p-type silicon. This model will highlight the key roles played by individual layers within solar cells and the impact of temperature and illumination.

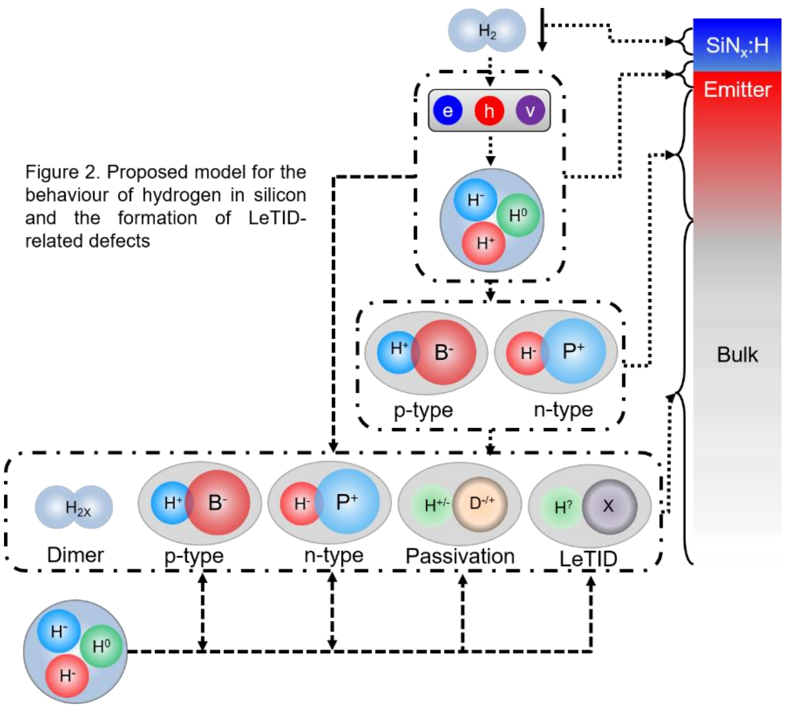

Figure 2. Proposed model for the behaviour of hydrogen in silicon and the formation of LeTID-related defects

Mitigation Strategies

The global race to solve LeTID has led to a wide range of methods for mitigating or supressing the effects of LeTID. Given the increasing agreement behind the involvement of hydrogen, a reduction in hydrogen content introduced during firing has shown much promise. Tuning of the SiN_X:H layer density, thickness and composition for reduced hydrogen content in addition to firing at reduced temperatures have all shown success but at a compromise of hydrogen passivation and metal contact formation [17,18]. In addition, annealing and current injection processes on wafers and finished cells to accelerate degradation and recovery kinetics have also proved a worthy alternative [19].

Summary

With much research and development being undertaken globally in the area of LeTID, it is important to bring the puzzle together every so often. In this work, we piece together the work of the global community to assess the current standpoint of LeTID. In our presentation we will address the current progress in not only understanding LeTID but also developments out in the industry to mitigate the defect. With this, we will assess where we believe LeTID lies in the future of photovoltaics.

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