

## **Studying Degradation in Multicrystalline Silicon by Modulating the Thickness of Dielectric layer**

Utkarshaa Varshney<sup>1</sup>, Malcolm Abbott<sup>1</sup>, Shaoyang Liu<sup>1</sup>, Daniel Chen<sup>1</sup>, Moonyong Kim<sup>1</sup>,  
Chandany Sen<sup>1</sup>, David Payne<sup>1</sup>, Stuart R. Wenham<sup>1</sup>, Bram Hoex<sup>1</sup>, Catherine Chan<sup>1</sup>

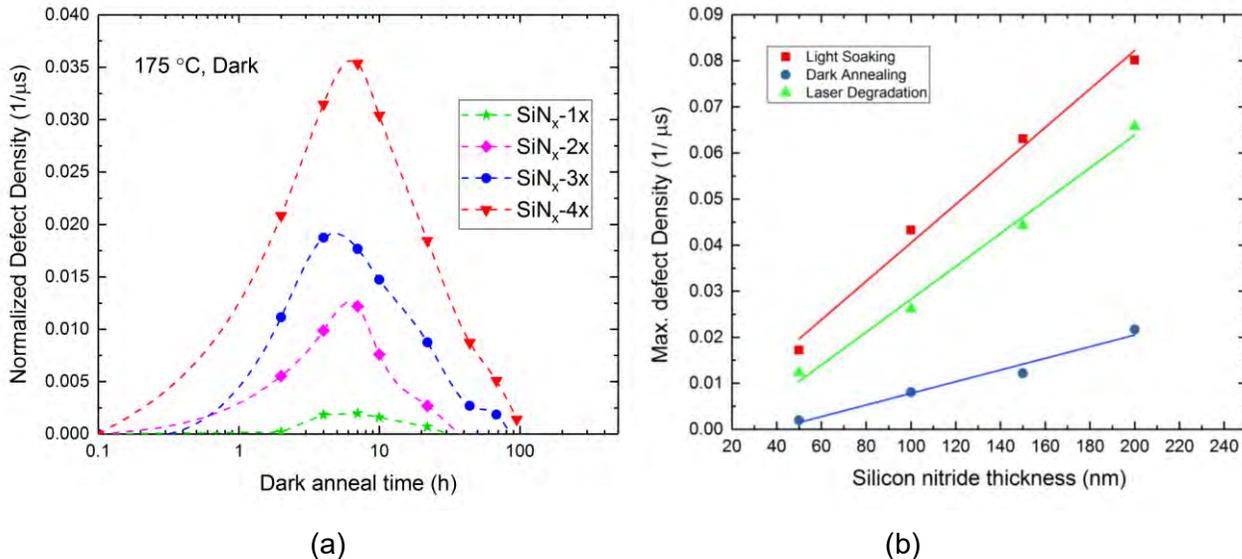
<sup>1</sup>*School of Photovoltaics and Renewable Energy Engineering, The University of New South Wales,  
Sydney, NSW, 2052, Australia  
E-mail: u.varshney@student.unsw.edu.au*

Light and elevated temperature induced degradation (LeTID) is a serious concern for multicrystalline silicon (mc-Si) solar cells. Since it was first observed in 2012, it has been under intensive research both within academia and industry, however, its actual cause is still unidentified. More recently, some studies have proposed the involvement of hydrogen in LeTID, however its true role is still debated [1-4]. On the other hand, the positive role of hydrogen in passivating both crystallographic and chemical defects in silicon is well-known. It is widely accepted that the regeneration of the light-induced boron-oxygen (B-O) defect that forms predominantly in boron-doped Czochralski (Cz) silicon is due to the passivation of the defect by hydrogen, and Wilking *et al.* [5] were able to show a dependence of the B-O regeneration rate on the amount of hydrogen available in the bulk. Plasma enhanced chemical vapour deposition (PECVD) based hydrogen-rich silicon nitride (SiN<sub>x</sub>:H) is the industry standard dielectric layer for phosphorus diffused *p*-type silicon solar cells due to its inherent positive charge density and excellent antireflection properties. Although the role of hydrogen diffusion from SiN<sub>x</sub>:H during high-temperature contact firing is recognized in providing surface and bulk passivation, its impact on activating LeTID is not well understood and is the focus of this work.

In this work, *p*-type mc-Si wafers from neighbouring ingot positions (sister wafers) were used as substrates. All the samples underwent phosphorus diffusion to form an *n*<sup>+</sup> emitter on both sides. Subsequently, the samples were symmetrically coated with a SiN<sub>x</sub>:H film in the 50 to 200 nm thickness range on both sides at 400 °C using remote PECVD. For quantitative analysis, Cz silicon samples were coated with SiN<sub>x</sub>:H with the similar thickness range. In parallel, some polished FZ wafers were used for Fourier transform infrared (FTIR) spectroscopy. The samples were then laser cleaved into small tokens and fired in a fast firing furnace at a set peak firing temperature of 855 °C. The samples were tested for LeTID under dark annealing at 175 °C, annealing at 75 °C under 1 sun illumination, and annealing at 130 °C under 44.2 kW/m<sup>2</sup> illumination.

The results show a strong dependence of degradation in mc-Si with SiN<sub>x</sub>:H thickness. The sample with the thinnest SiN<sub>x</sub>:H film showed the least degradation. The extent of degradation increased with increasing thickness of SiN<sub>x</sub>:H and the sample with the thickest SiN<sub>x</sub>:H film showed the strongest degradation amongst all investigated samples [Figure 1 (a)]. Although the extent of degradation under illumination was higher than that in case of dark annealing, the trend of increase in degradation with increasing SiN<sub>x</sub>:H thickness was consistent for all considered degradation conditions. These results can be explained with thicker SiN<sub>x</sub>:H films releasing greater amounts of hydrogen into the bulk, which possibly acts as a catalyst for the reaction which is responsible for causing LeTID in mc-Si. Further, monocrystalline silicon wafers with thicker SiN<sub>x</sub>:H showed a faster rate of B-O regeneration, which indicates a higher hydrogen concentration in the bulk to passivate the B-O defect and accelerated rate of regeneration consistent with the findings in [5]. Analysing FTIR results, an increase in N-H bond density was observed with increase in SiN<sub>x</sub>:H thickness. Also, a reduction in the intensity of N-H bonds after firing was observed, which can be explained by the loss of hydrogen from the film at high-temperature. No considerable variation in *J*<sub>0</sub> was observed for the samples, which confirms that the degradation was in the bulk and surface passivation was stable throughout the experiment.

In the examined range, a linear dependence of the defect concentration with the SiN<sub>x</sub>:H thickness was observed for all tested conditions [Figure 1 (b)], which is consistent with hydrogen being involved in LeTID in mc-Si.



**Figure 1. (a) Evolution of defect concentration with time in dark at 175 °C and (b) linear dependence of defect density with silicon nitride thickness.**

## References

- [1] Chan, C., T. H. Fung, M. Abbott, D. Payne, A. Wenham, B. Hallam, R. Chen and S. Wenham, 2017, 'Modulation of Carrier-Induced Defect Kinetics in Multi-Crystalline Silicon PERC Cells through Dark Annealing', *Solar RRL* 1(2): 1600028
- [2] Bredemeier, D., Walter, D., Herlufsen, S., Schmidt, J., 2016, 'Understanding the Light-induced Lifetime Degradation and Regeneration in Multicrystalline Silicon', 92, 773
- [3] Ciesla A., 2017, 'Advanced laser processing for next-generation silicon wafer solar cells', PhD Thesis UNSW Sydney, Australia
- [4] Nakayashiki, K., Hofstetter, J., Morishige, A. E., Li, T.-T. A., Needleman, D. B., Jensen, M. A., Buonassisi, T., 2016, 'Engineering Solutions and Root-Cause Analysis for Light-Induced Degradation in p-Type Multicrystalline Silicon PERC Modules', *IEEE J. Photovoltaics*, 6, 860.
- [5] Wilking S., Herguth A., Hahn G., 'Influence of hydrogen on the regeneration of boron-oxygen related defects in crystalline silicon', 2013, *Journal of Applied Physics*, 113, 194503.