Lifetime Degradation in Multicrystalline Silicon under Illumination at Elevated Temperature: The Role of Hydrogen

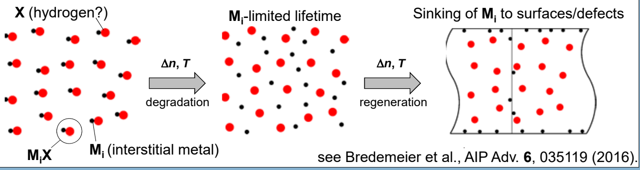
Dennis Bredemeier[1], Dominic C. Walter[1], and Jan Schmidt[1,2]

[1] Institute for Solar Energy Research Hameln (ISFH), Germany

[2] Department of Solar Energy, Institute of Solid State Physics, Leibniz Universität Hannover, Germany

LeTID: Pronounced lifetime degradation under illumination at elevated temperature

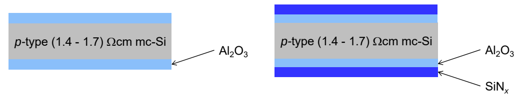
- Pronounced degradation of multicrystalline silicon (mc-Si) solar cells under illumination at elevated temperature [1]
- Frequently denoted LeTID (Light and Elevated Temperature Induced Degradation) [2]
- LeTID strongly affects the bulk lifetime of mc-Si wafers [3]
- Lifetime evolution (degradation and subsequent regeneration) is triggered by a high-temperature firing step [3,4]



see Bredemeier et al., AIP Adv. **6**, 035119 (2016).

Sample processing

- We use block-cast high-performance boron-doped mc-Si with base resistivities in the range (1.4 – 1.7) Ωcm



I. Variation in passivation scheme: Al_2O_3 single-layers or Al_2O_3/SiN_x-stack passivation, each fired at 900°C.

II. Variation in phosphorus diffusion step:

i. Phosphorus diffusion and subsequent removal of n^+-layers

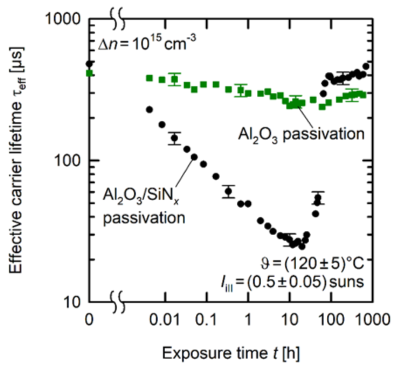
ii. No phosphorus diffusion step

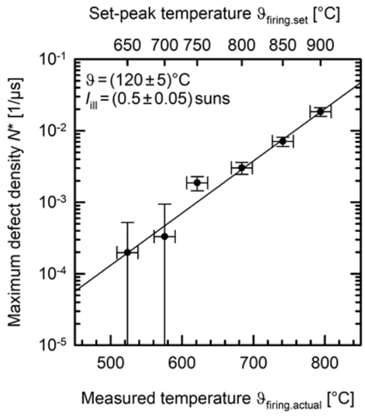
III. Variation in peak-firing temperature in the range from 650°C to 900°C with Al_2O_3/SiN_x-stack surface passivation.

Impact on the degradation extent: Passivation schemes, phosphorus diffusion and fast firing

- LeTID degradation extent 20 times more pronounced on Al_2O_3/SiN_x-stack passivated samples than on samples with Al_2O_3 single-layers.
- Our SiN_x layers contain ≈12-20 at.% hydrogen and the Al_2O_3 single-layers contain ≈1-2 at.% hydrogen.
- Hydrogen from SiN_x layers diffuses into the silicon bulk during the high-temperature firing step.
- Maximum defect density increases approx. exponentially with increasing peak firing temperature

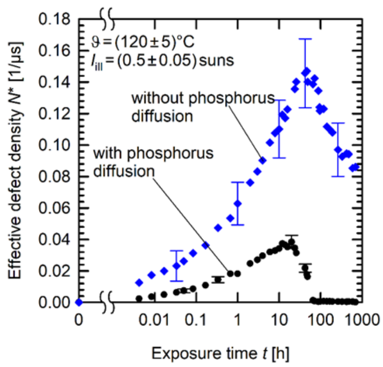
➢ Indication for **hydrogen** playing a major role in the LeTID effect

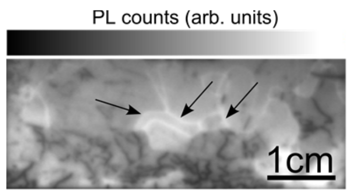




- Samples that received a phosphorus diffusion show a less pronounced degradation than samples with no phosphorus diffusion
- Significant decrease of metal contaminants in the silicon bulk by phosphorus diffusion due to segregation gettering
- Grain boundaries appear brighter in a PL image and are less affected by the degradation than the intra-grain area, because of metal gettering by grain boundaries.

➢ Indication for a **metal** impurity being involved in the LeTID effect





Enlarged section of a PL image of a fully degraded mc-Si sample. The arrows point towards grain boundaries in the mc-Si material, which appear brighter in the PL image than the PL signal within the grains.

Conclusions

- LeTID strongly depends on the applied passivation scheme with pronounced degradation only observed for hydrogen-rich passivation layers such as SiN_x (cf. [5]).
- A phosphorus gettering step significantly decreases the degradation extent in comparison to a non-diffused sample (cf. [6])
- The degradation extent increases approx. exponentially with increasing peak firing temperature

➢ **Metal-hydrogen complexes** are strong candidates for the root cause of LeTID

References and Acknowledgments

[1] Ramspeck et al., in *Proceedings of the 27th European Photovoltaic Solar Energy Conference* (WIP, Munich, 2012), p.861.

[2] Kersten et al., Sol. Energ. Mat. Sol. Cells. **142**, 83 (2015).

[3] Nakayashiki et al., IEEE J. Photovolt. **6**, 860 (2016).

[4] Bredemeier et al., AIP Adv. **6**, 035119 (2016).

[5] Kersten et al., Energy Procedia **92**, 828 (2016).

[6] Zuschlag et al., Prog. Photovolt: Res. Appl. **25**, 545 (2016).

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Institute for Solar Energy Research Hameln (ISFH)

Am Ohrberg 1, D-31860 Emmerthal, Germany, Tel.: +49 (0) 5151 999-100, Fax: +49 (0) 5151 999-400