Metastabilities in thin-film modules due to pre-treatment

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INTRODUCTION

Electrical properties of thin-film photovoltaic modules exhibit metastable behavior when exposed to light or when kept in the dark after light exposure. This reversible effect, which can be observed after pre-treatment, varies in magnitude, depending on the cell and module technology. It also depends on other factors such as irradiance, temperature and bias on the module.

Experiments with various thin-film technologies were conducted in this study and showed that the power output increases after weak irradiance light exposure. This observation is mainly due to a rise in the fill factor (FF) and in the open circuit voltage (V_{OC}). The time constants between the excitation and relaxation processes match for all investigated thin-film technologies except for CIGS, where the relaxation phase is roughly 500 times longer than the light-soaking period.

EXPERIMENTAL SETUP

In this study, light-soaking effects under different irradiances (50-1000 W/m²) as well as dark-soaking effects were analyzed for various thin-film technologies such as CIGS, CdTe, a-Si:H and a-Si/a-Si. The modules were illuminated for 2-3 hours and afterwards left in the dark for at least the same period of time, while kept in open circuit or short circuit conditions or in the maximum power point.

The temporal influence of electrical parameters on the module power as well as on IV-curves was investigated during both the light-soaking and the dark-soaking periods. In a controlled indoor setup, the modules were pre-treated under the illumination of a lamp array and characterized in a pulsed sun simulator or pre-treated and characterized in-situ in a static sun simulator.

RESULTS

All investigated thin-film modules (CIGS, CdTe, a-Si/a-Si, a-Si) exhibited an overall increase in P_{MPP}, FF and V_{OC} due to light-soaking (LS), as well as a decrease during dark-soaking (DS). The graphs in Figure 1a-d indicate that the increase in P_{MPP}, FF and V_{OC} follow a logarithmic law.

It is noteworthy that for CdTe the P_{MPP} fell below the initial value after 1100 minutes of dark-soaking (Figure 1b). While the temporal behavior of the light-soaking effect is equivalent to the relaxation time during dark-soaking for CdTe and amorphous silicon modules, this could not be observed with the CIGS modules. Figure 1a shows, that 12 hours of relaxation did not reset the module to its primary power level. Further measurements showed that the initial values were reached only after two months of dark-soaking. In contrast to the other investigated thin-film technologies, the CIGS module (Figure 1a) showed a slight decrease in power and the FF in the first minute of light-soaking.

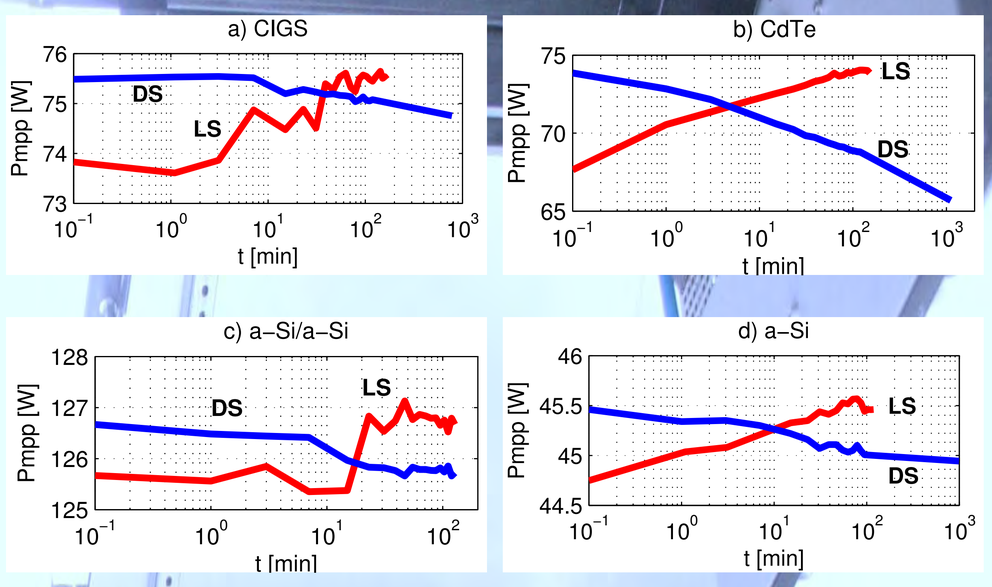


Figure 1a-d: Power increase of CIGS (a), CdTe (b), a-Si (c) and a-Si/a-Si (d) modules due to light-soaking (LS) at 50 W/m² and realxation during dark-soaking (DS).

Figure 2a-b: Changes in the IV-curves during light-soaking for a CIGS module (a) and a CdTe module (b).

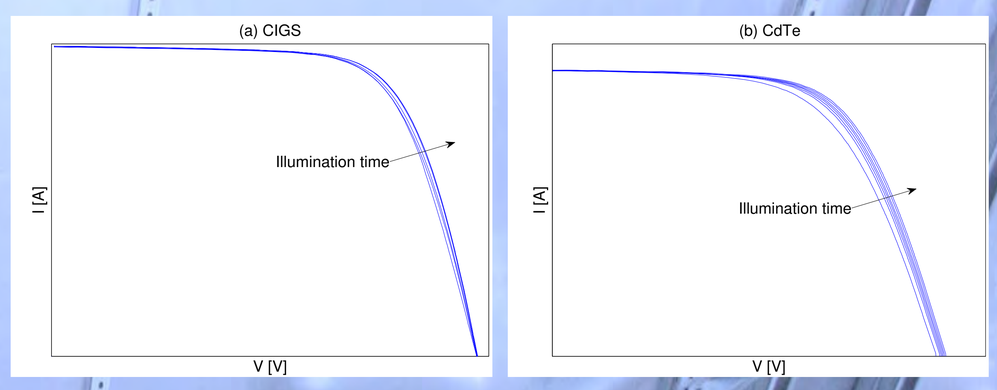
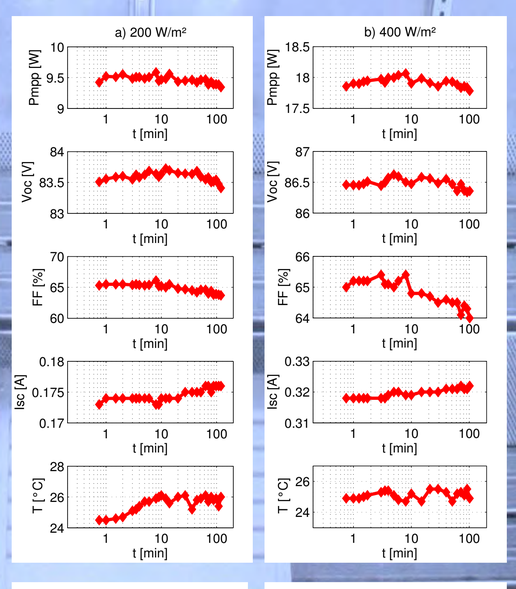


Figure 2a and 2b show how the increase in power due to light-soaking can be attributed to different electrical parameters of the thin-film module. While in the CIGS module the effect is almost entirely due to a change in the FF (Figure 2a), the CdTe module (Figure 2b) shows an increase in both the FF and the V_{OC}.

Different irradiances also influence the metastabilites. Figures 3a-d show, that irradiances above 200 W/m² largely inhibit a rise in V_{OC}, FF or P_{MPP}, however, the I_{SC} may increase.

The influence of a load on the light-soaking effect can be seen in figure 4. While the effect is strongest under open circuit conditions, it diminishes with higher loads.



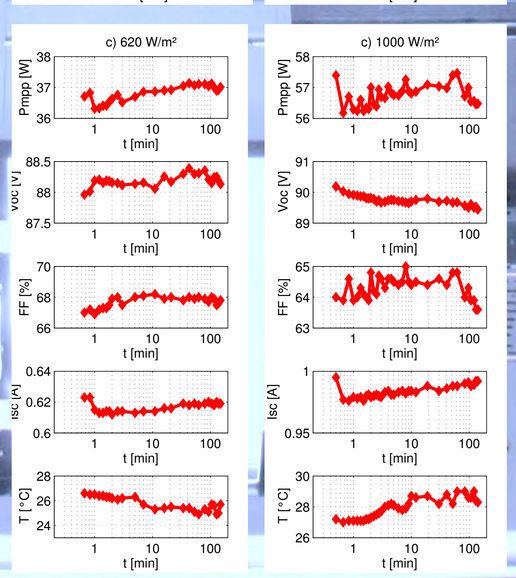
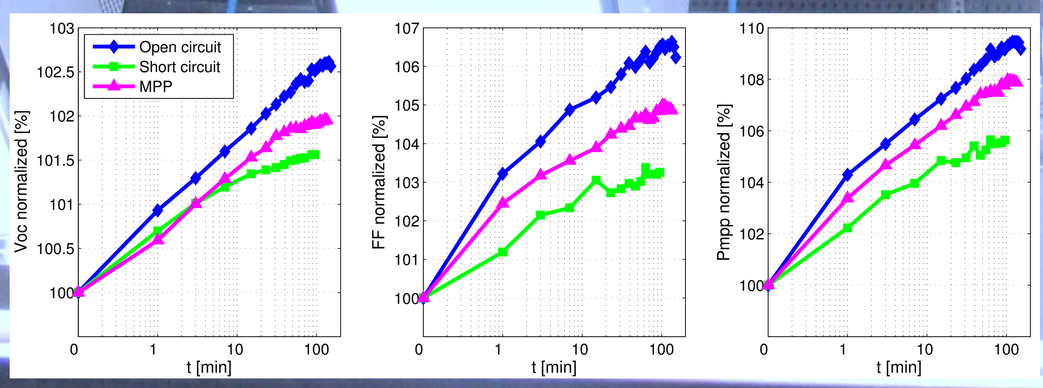


Figure 3a-d: Influence of different light-soaking irradiances (200 W/m² (a), 400 W/m² (b), 620 W/m² (c), 1000 W/m² (d)) on P_{MPP}, U_{OC}, FF and I_{SC} for a CdTe module.

Figure 4: Relative increase in V_{OC}, FF and P_{MPP} for different loads (OC, SC, MPP) during light-soaking at an irradiance of 50 W/m² for a CdTe module.



CONCLUSION

Metastable behavior could be observed in all investigated thin-film technologies (CdTe, a-Si and CIGS) at low light-soaking irradiances (50 W/m²), while higher irradiances do not seem to affect the electrical parameters. The intensity of the observed effect varies among different technologies with the amorphous silicon technologies exhibiting the weakest changes. For CdTe and the amorphous technologies, it could be verified that a gain in P_{MPP} results from a simultaneous rise of the FF and V_{OC} due to LS, while I_{SC} remains mostly unaffected. For CIGS modules a slight increase in I_{SC} could also be observed, but the rise in the P_{MPP} is mainly due to the FF. The time constants between light- and dark-soaking match for all investigated thin-film technologies except for CIGS, where the relaxation phase is roughly 500 times longer than the LS period.

Under a load or in SC conditions light-soaking diminishes the metastability effect.