THIN-FILM BARRIERS FOR DURABLE THIN-FILM PV MODULES

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ABSTRACT: This contribution describes thin-film barrier coatings to enhance the stability of silicon thin-film solar modules. Thin-film barriers are applied to protect the modules from degradation in humid environment. Demonstrator modules were exposed to indoor and outdoor tests to evaluate failure modes by electrochemical corrosion during operation. Test results reveal some major failure modes, but we demonstrate long lifetimes under operational conditions for certain modules without conventional encapsulation. These modules without conventional encapsulation showed less than 1% relative degradation during 1000 hours of damp-heat tests with light exposure at open circuit voltage. These promising results will guide the way to new encapsulation concepts for longer lifetimes and/or new low-cost concepts. This approach might be applied to any thin-film technology and will be an important aspect for consumer electronics with less strict requirements for very long-term operation.
Keywords: stability, solar modules, thin-film barriers

1 INTRODUCTION

Standard encapsulation schemes for thin-film modules such as glass/glass have two drawbacks: (1) EVA often used as an encapsulant/adhesive releases acetic acid, which may react with the cell or its contacts, if water ingress is not sufficiently suppressed. (2) Standard encapsulation is optimized for wafer-based technology and devices with lower efficiency suffer from relatively high area cost of the encapsulation material. Though several delamination failures of thin-film PV modules have been reported [1], more recent solar modules do not suffer from such degradation anymore due to different solutions [2]. Lab tests have demonstrated non-protected thin-film Si cells/modules that survived damp-heat exposure without major degradation [3].
The PV market is dominated by silicon wafer-based technology. Thus, standards regarding measurements, regulations and standard encapsulations are defined for this technology but consequently are imposed on thin-film technologies. Unlike wafer-based technology, thin-film PV modules consist of uniform coatings on large area substrates. Thus, thin-film barrier coatings might serve as protection against moisture ingress. This is especially interesting to enhance the lifetime of PV devices or being an alternative e.g. for consumer electronics or for silicon thin-film PV modules that have demonstrated inherent stability against damp-heat environment [3].
This contribution presents functional modules on rigid glass superstrate tested under operational conditions using indoor and outdoor degradation tests. Similar approaches have been followed by other groups using barrier coatings in OPV technology [4].

2 EXPERIMENTAL

2.1 Module preparation and encapsulation

Small area modules (10x10 cm²) were prepared using our base line process at Jülich. The silicon thin-film modules consist of sputtered aluminum doped zinc oxide (ZnO:Al) or Asahi VU type fluorine doped tin oxide (SnO_2:F) front TCO, amorphous-microcrystalline silicon tandem junction solar cells and a ZnO:Al/silver back reflector. All modules were series connected via laser scribing. The P3 scribe line (back contact) reveals parts of the front contact by simultaneous ablation of the absorber and back contact. The front contact material is known to degrade under exposure to moisture. Thus, parts of the modules were protected by additional barrier coatings, namely sputtered ZnO:Al or silicon oxynitride (SiO_xN_y), plasma enhanced chemical vapor deposited amorphous silicon (a-Si) or silicon oxide (a-SiO_x), or they were left blank.

Figure 1: Photographs of solar modules on thermal insulating building materials (left) and the modules under consideration on the outdoor measurement setup (right).

In order to check the concept and get insight into the effect of the atmosphere on the various parts of the (non-encapsulated) module (such as cell itself, interconnection area and bus bar area) medium area (30x30 cm²) solar modules with a special “quasi”-encapsulation were designed. An air-space of about 7 mm between the front glass with the active layers on the back surface and the back glass enabled the air to penetrate the active layers during operation. The top and side edges of the module were sealed by a water tight glue tape. As a reference standard glass/glass encapsulation was applied. All modules were separated by laser scribing into three separate sections (A, B, C) and can be individually measured. For more details the reader is referred to the images on the poster (available for download). These modules were exposed to our outdoor test setup (see Figure 1). The center row represents the quasi-

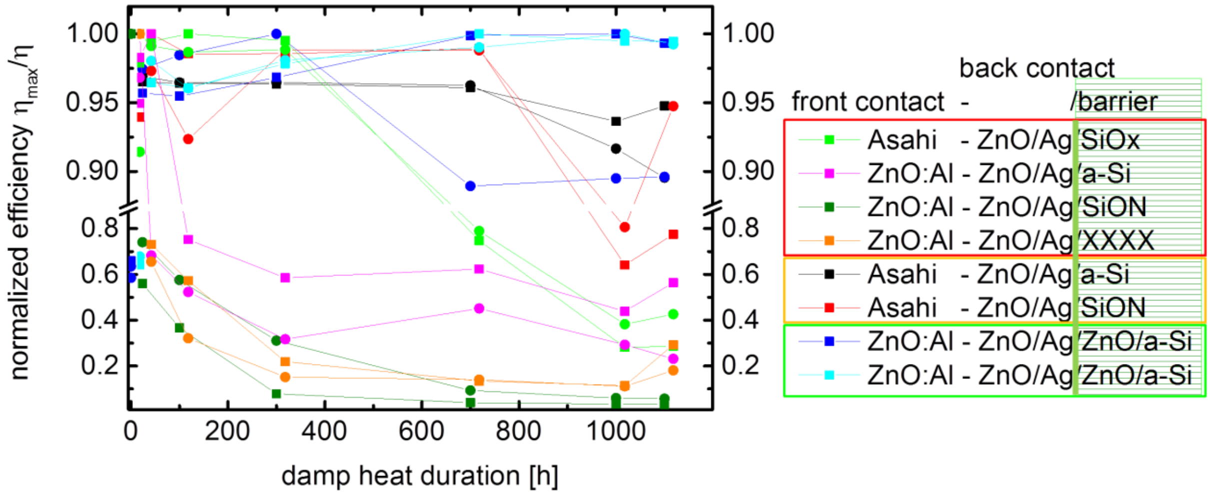

Figure 2: Normalized efficiency of solar modules with different protective barrier coatings as function of damp heat exposure time.

encapsulated modules (with air-gap and without barrier coating) and the bottom right one with glass/glass encapsulation serves as reference. The other modules, visible in the photograph, are not encapsulated at all and some of them reveal their back surface fully open to the environment, including rain runoff.

3 DAMP HEAT DEGRADATION TESTS

On small area solar modules (10x10 cm²) thin-film coatings were deposited to protect the solar modules from environmental influences. In previous studies such modules had been exposed to damp heat in the dark without electrical bias, so the modules have not been subject to electro-corrosion. To evaluate this further, new damp-heat tests were performed under AM1.5 type irradiation with ~60° inclined irradiation angle. Figure 2 shows the efficiency values of the modules as function of damp heat treatment duration measured indoors with a class A sun simulator.

The remarkable result is that some of the modules survived this harsh test for 1000 hours. Unfortunately, several modules degraded (marked in red) or nearly died after about 300 hours of irradiated damp-heat test (yellow). This was mainly the case for protective coatings that had been deposited directly onto the silver back contact. Adhesion on silver is known to be a critical issue, thus a ZnO layer between silver and the silicon protection layer led to very stable modules. Interestingly the type of front contact (Asahi U type SnO2:F or sputtered ZnO:Al) did not influence the stability to a large extent. This suggests that the main degradation occurred at the back reflector. As a result of handling issues some of the modules might have degraded due to mechanical damage rather than by corrosion during the test. This was obvious when analyzing the results of individual cells (not shown).

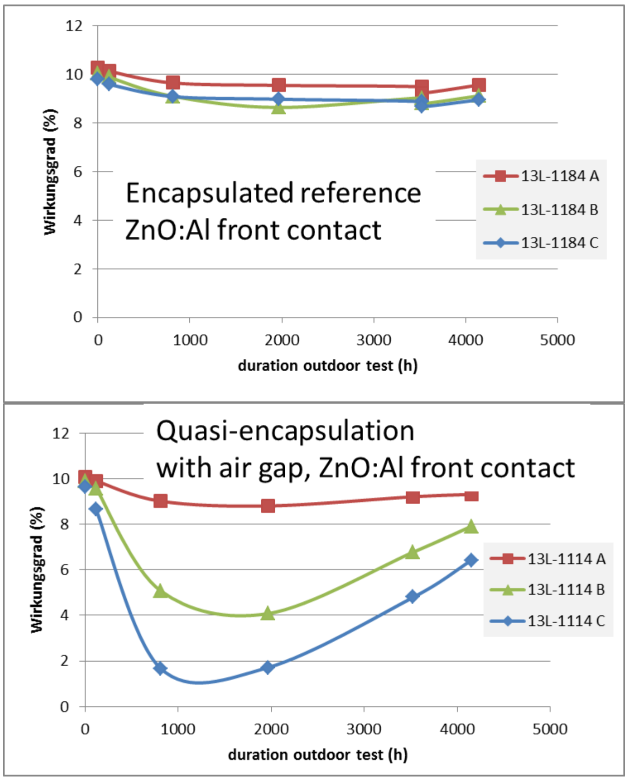

Figure 3: Efficiency of solar modules with standard and quasi-encapsulation as function of outdoor exposure time.

4 OUTDOOR DEGRADATION TESTS

Further evaluation of outdoor tests of 30x30 cm² modules has been performed. **Figure 3** shows absolute module efficiency measured indoors using a flash light sun simulator during consecutive outdoor tests that started in Dec. 2015 at the Jülich site. The encapsulated modules exhibit about 10% relative degradation during the first 1000 hours as assigned to the Staebler Wronsky effect. For the quasi-encapsulated modules the different sections can be distinguished. The section A, at the longest distande to the opening degrades to a similar extent as the encapsulated reference module. However, the module sections B and C, which are much closer to the opening, show strong degradation during the first 1000 hours of the test. These might be related to corrosion of the active layers or contacts, though their efficiency started to increase after about 2000 h. This interesting result was not investigated further due to time constrains, but the effect might be related to the maximum temperature at each day, which exceeded 10°C only for a few days during the first 2000 h and was on average 20°C for the time between May and June 2016 (see **Figure 4**).

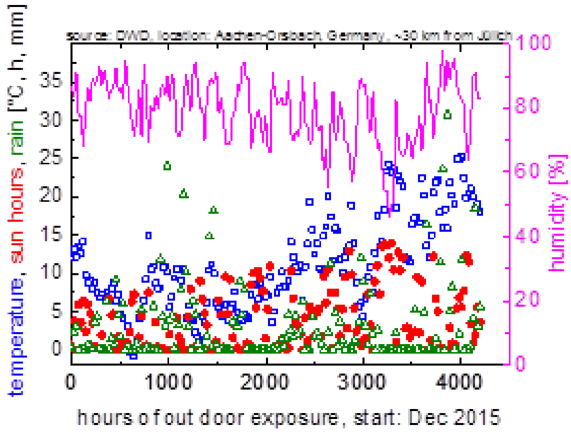

Figure 4: Weather data of the location Aachen-Orsback, at about 30 km distance to the Jülich site maximum day temperature, sun hours for each day, amount of rain and relative humidity.

5 CONCLUSIONS

We have demonstrated amorphous silicon based silicon solar modules using thin-film barrier coatings for environmental protection. Apart from some module failures, several barrier coatings provided sufficient protection against damp-heat degradation and electro-corrosion. The modules showed less than 1 % degradation after 1000 hours of damp-heat treatment. These are very promising results to enhance module lifetime and might stimulate further research on new encapsulation concepts for thin-film PV technologies including OPV.

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