

Guiding Principle for Crystalline Si Photovoltaic Modules with High Tolerance against Acetic Acid

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Abstract

Guiding principle for high-reliability crystalline Si photovoltaic modules, especially with high tolerance against acetic acid generated by hydrolysis reaction between water vapor and ethylene-vinyl acetate (EVA), is proposed. The most important component for high tolerance is Ag finger electrode materials if using EVA encapsulant. Pattern of dark region in electroluminescence images will be also discussed based on the dynamics of acetic acid in the module.

1. Introduction

One of the degradation factors for crystalline Si (c-Si) photovoltaic (PV) modules exposed outside for a long time over 20 years is acetic acid generated in the module by hydrolysis reaction between water vapor and ethylene-vinyl acetate (EVA) encapsulant [1,2]. Ingress of water vapor occurs thorough back sheet during a long-term exposure. It was reported that contact resistance of Ag finger electrodes increases by acetic acid at the interface between Ag and Si [3]. Dissolution of glass layer underneath Ag finger electrodes was experimentally clarified [4,5].

In this paper, guiding principle for high-tolerance c-Si PV modules against acetic acid is proposed based on experimental results. In addition, appearance and pattern of dark region in electroluminescence (EL) images due to degradation of Ag finger electrodes by acetic acid are discussed.

2. Experimental

Four types of commercial c-Si PV cells with conventional diffusion junction were employed in this study. Types of A, B and C were p-type multicrystalline Si cells and type D was p-type singlecrystalline Si cell. Cell size of these cells was almost 156 mm square. These PV cells were laminated for PV modules with the completely identical two sheets of EVA encapsulant, polyvinyl fluoride (PVF)/polyethylene terephthalate (PET)/PVF triple layer back sheet and tempered cover glass. Therefore only cells are different for these four types of PV modules. Hereafter, PV module using PV cell of types of A, B, C and D is simply called module A, B, C and D, respectively. Module size was 180 mm square. Each side of the module was not covered with Al frame nor sealant.

These modules were subjected to damp-heat (DH) test at 85°C and 85% relative humidity until 10000 h for modules A and B, until 8000 h for module D and until 5000 h for module C. Current-voltage characteristics and EL images

were periodically measured by suspending DH test. Amount of acetic acid in the module was also characterized by ion chromatography.

3. Results and Discussion

There are three key components influencing degradation by acetic acid for c-Si PV modules; back sheet, encapsulant and finger electrode materials. In our previous study, it was found that back sheet with higher water-vapor transmission rate (WVTR) brings about smaller degradation during DH test [6]. This “seemingly” surprising behavior was well explained by amount of residual acetic acid in the modules; modules with lower WVTR contain higher amount of acetic acid since it is more difficult for generated acetic acid to be released from the modules. Of course, if using back sheet with complete barrier ability, no water vapor ingress occurs. However, it is somewhat idealistic even though we ignore the fabrication cost, considering long-term exposure under severe environment over 20 years. Therefore high-barrier back sheet is not employed for appropriate guideline for highly reliable c-Si PV modules. Use of newly developed encapsulant materials, such as ionomer, polyolefin, polyvinyl butyral, etc., generating little acid by the reaction with water vapor, is the second point and quite realistic solution for highly reliable PV modules. The third point is development of finger electrode materials with high tolerance against acid. Even using EVA encapsulant, if such finger electrode materials are used, high reliability is also possibly achieved.

Figure 1 shows maximum power (P_{\max}) as a function of DH test time for modules A, B, C and D. Drastic degradation of P_{\max} is observed after DH test around 2500 h and around 5000 h for modules C and D, respectively. On the other hand, P_{\max} gradually decreases with an increase in DH test time after DH test around 4000 h for modules A and B. The amount of acetic acid in module C is shown in Fig. 2 as a function of DH test time. The amount of acetic acid on the back sheet side increases with an increase in DH test time; however, decreases after DH test around 3000-4000 h, and does not strongly depend on the location of edge, middle and center. Maximum amount of acetic acid is about 1500 μg per EVA of 1 g. The reason for the above-mentioned behavior is that generated acetic acid on the back sheet side may be also released outside the module from the back sheet. On the other hand, the amount of acetic acid on the glass side drastically increases with an increase in DH test time, especially at the location of center

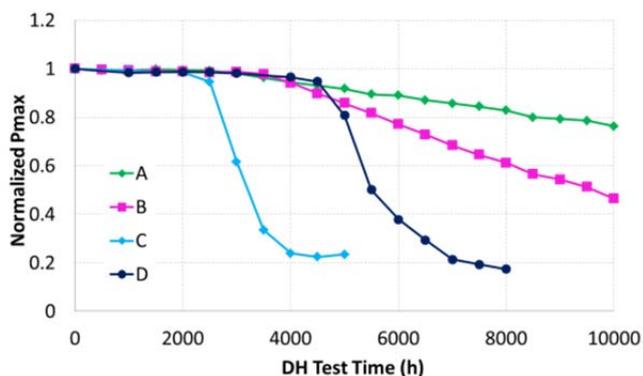


Fig. 1 Normalized P_{max} as a function of DH test time for modules A, B, C and D. P_{max} before DH test is normalized to 1.

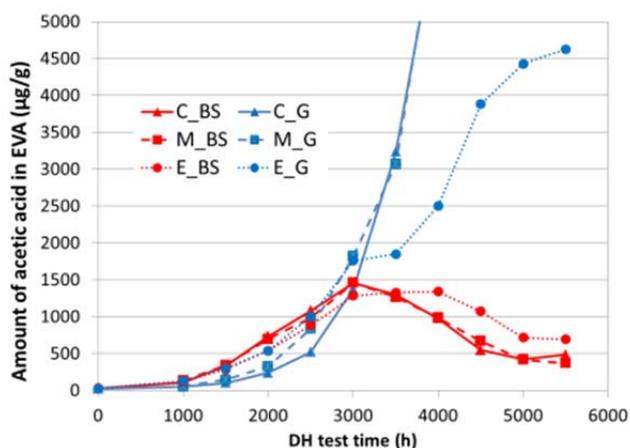


Fig. 2 Amount of acetic acid per EVA of 1 g as a function of DH test time. C, M and E denote the location of center, middle and edge on the PV cell, respectively. Middle locates between center and edge. G and BS denote glass side and back sheet side, respectively.

and middle, and reaches about 15000 μg per EVA of 1 g after DH test for 5500 h (not shown in Fig. 2). Acetic acid at the location of edge is somewhat released outside the module even on the glass side through the back sheet or the edge of the module; however, it is quite difficult for acetic acid at the location of center or middle to be released. Moreover, for conventional c-Si PV modules, Ag electrodes on the glass side are composed of fine finger patterns and have low tolerance against acetic acid in comparison with thick Al electrodes in the whole area on the back sheet side. Therefore acetic acid on the glass side much influences behavior of P_{max} during DH test. The amount of the acetic acid should be the same in those four types of modules since completely identical module materials were used other than PV cells. Therefore the different behavior of P_{max} against DH test time originates from difference in PV cells, concretely, originates from difference in Ag finger electrode materials, since it was also found by the authors' group that there is no degradation in pn junction by DH test [7,8] and less correction of photogenerated carriers due to increase in contact resistance is root cause of degradation by DH test for c-Si PV modules. Cell C was manufactured in about

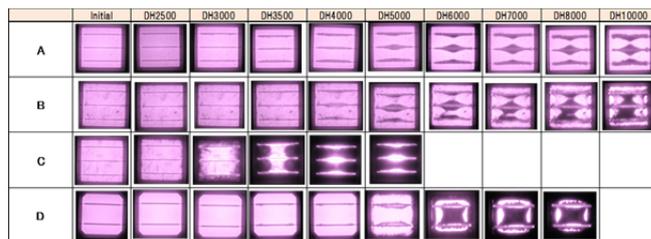


Fig. 3 EL images for modules A, B, C and D before and after DH test.

2009 and cells A, B and D were recently manufactured. Behavior of P_{max} against DH test time suggests improvement in Ag paste for finger electrodes or firing techniques.

Figure 3 shows EL images for four types of PV modules before and after DH test from 2500 h to 10000 h. Appearance and area of dark region almost correspond to decrease in P_{max} ; however, pattern of dark region in module C is much different from those in the other modules. Dark region appears from the edge of the cell in module C and from the center along the interconnector ribbons in the other modules. Such behavior is well explained as follows: Ag finger electrodes have low tolerance against acetic acid for module C and corrosion of finger electrodes occur by low amount of acetic acid in the cell edge region, on the other hand, Ag finger electrodes have high tolerance for the other modules and corrosion first occurs after much high amount of acetic acid is accumulated in the center region.

4. Conclusions

Behavior of PV performances and EL images for modules using four types of c-Si PV cells by DH test were shown. Such behavior was well explained by the amount of acetic acid in EVA on the glass side during DH test. Guiding principle for highly reliable c-Si PV modules was presented. There are two choices; use of encapsulant without generating acid or Ag finger electrode materials with high tolerance against acid.

Acknowledgements

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References

- [1] M. D. Kempe *et al.*, Sol. Energy Mater. Sol. Cells **91** (2007) 315.
- [2] A. Masuda *et al.*, Proc. 29th European Photovoltaic Solar Energy Conf. Exhib. (2014) 2566.
- [3] T. Ngo *et al.*, Jpn. J. Appl. Phys. **55** (2016) 052301.
- [4] A. Kraft *et al.*, IEEE J. Photovolt. **5** (2015) 736.
- [5] T. Tanahashi *et al.*, Proc. 43rd IEEE Photovoltaic Specialists Conf. (2016) 1075.
- [6] M. Miyashita and A. Masuda, Proc. 28th European Photovoltaic Solar Energy Conf. Exhib. (2013) 2828.
- [7] A. Masuda *et al.*, Jpn. J. Appl. Phys. **54** (2015) 04DR04.
- [8] A. Masuda *et al.*, Proc. 43rd IEEE Photovoltaic Specialists Conf. (2016) 904.