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Influence of light illumination on the potential-induced degradation of n-type interdigitated back-contact crystalline Si photovoltaic modules

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Abstract

We investigate the effect of light illumination on the potential-induced degradation (PID) of n-type interdigitated back-contact (IBC) crystalline Si (c-Si) photovoltaic (PV) modules. IBC PV modules show PID characterized by reductions in short-circuit current density (J_{sc}) and open-circuit voltage (V_{oc}) under negative bias stress. The degradation may originate from sodium (Na) introduction into c-Si and resulting enhancement of carrier recombination on the cell surface. 1-sun light illumination during a PID test results in less severe reductions in J_{sc} and V_{oc}. A reduction in an electric field in the surface Si nitride (SiN_x) film due to carrier generation in the SiN_x and resulting increase in its conductivity is one possible explanation for the mitigation of the Na-related PID.

1. Introduction

n-type crystalline Si (c-Si) solar cells generally have higher efficiency than conventional p-type c-Si ones, and their widespread use is thus expected in the near future [1]. In particular, interdigitated back-contact (IBC) solar cells are known as high-efficiency solar cells because all the electrodes are formed on the back surface of the cells and the light incident area can thus be enlarged, resulting in the higher current compared to conventional solar cells with electrodes on the illumination side [1].

It is important to clarify the behavior and mechanism of the long-term reliability of photovoltaic (PV) modules with IBC cells. Potential-induced degradation (PID) is a performance degradation of PV modules triggered by a voltage between a grounded Al frame and cells, and is one of the most important reliability issues because of its severity [2, 3]. The mechanism of the PID of c-Si PV modules with conventional p-type cells has been considerably clarified [2], which show a reduction in fill factor (FF) under a negative bias stress, originating from the formation of shunting paths due to sodium (Na) introduction. On the other hand, there have been relatively fewer previous studies on the PID of n-type c-Si PV modules. Regarding the PID of the IBC PV modules, reductions in open-circuit voltage (V_{oc}) and short-circuit current density (J_{sc}) occur when a positive bias is applied to the cells with respect to the grounded Al frame [3]. This can be explained by the accumulation of negative charges in the front silicon nitride (SiN_x) and resulting acceleration of carrier recombination on the surface. On the contrary, the PID of IBC PV modules under negative bias has not been fully clarified yet. Furthermore, since PID occurs only under sunlight illumination in the field, it is also important to clarify the influence of light illumination on the PID of IBC modules. In this study, we investigate the PID of IBC PV modules under negative bias and the influence of light illumination on their PID.

2. Experimental Procedures

We laminated 12.5×12.5 cm^2-sized commercial IBC cells to fabricate one-cell modules with a structure of glass/ethylene vinyl acetate copolymer (EVA)/cell/EVA/backsheet. The size of the cover glass was 18×18 cm^2, and the EVA has a relatively low resistivity of 1.5×10^{15} Ω·cm. Al tape was attached around the four sides of the modules to mimic the Al frame of a PV module. A PID test was conducted by applying −2000 V to the cells with respect to the grounded Al tape at a temperature of 85 °C. No intentional humidity stress was applied during the PID test. A thermocouple was attached to the back side of the modules during the test in order to check the temperature of the modules. The PID test in the dark was performed by connecting IBC modules in parallel. We also performed the PID test under 1-sun light illumination to investigate the effects of light illumination. The PID test under light illumination was performed separately for each module.

For the evaluation of the performance degradation of the IBC PV modules by PID, current density–voltage (*J*–*V*) characteristics were measured before and after the PID tests in the dark and under 1-sun illumination. We also measured external quantum efficiency (EQE) spectra and obtained electroluminescence (EL) images of the modules before and after the PID test.

3. Results and Discussion

Fig. 1 shows the J_{sc}, V_{oc}, FF, and maximum power (P_{max}), normalized by their initial values, of the IBC PV modules as a function of PID-stress duration. The results both for the PID test in the dark and under 1-sun illumination are shown. The modules do not show any degradation within the first 30 minutes. J_{sc} and V_{oc} then start to reduce simultaneously, and their reductions are saturated at ~72 hours. FF does not deteriorate at all. The modules receiving 1-sun light illumination during the PID test clearly show less significant PID compared to the modules undergoing PID test in the dark. Although the degradation tendency is quite similar to the previous study in which the positive bias was applied to the cells and J_{sc} and V_{oc} reductions are seen due to negative charge accumulation in the front SiN_x [3], their degradation mechanisms must be different from each other. This is because the accumulation of negative charges in SiN_x never occurs under the negative bias application, and positive charge accumulation, which possibly occurs in this experiment, does not deteriorate the performance of the IBC cells with n-type c-Si near the surface. The degradation observed in this study is thus due to the introduction of mobile ions, such as Na, into the surface of the IBC cells, like in the case of conventional p-type c-Si PV modules.

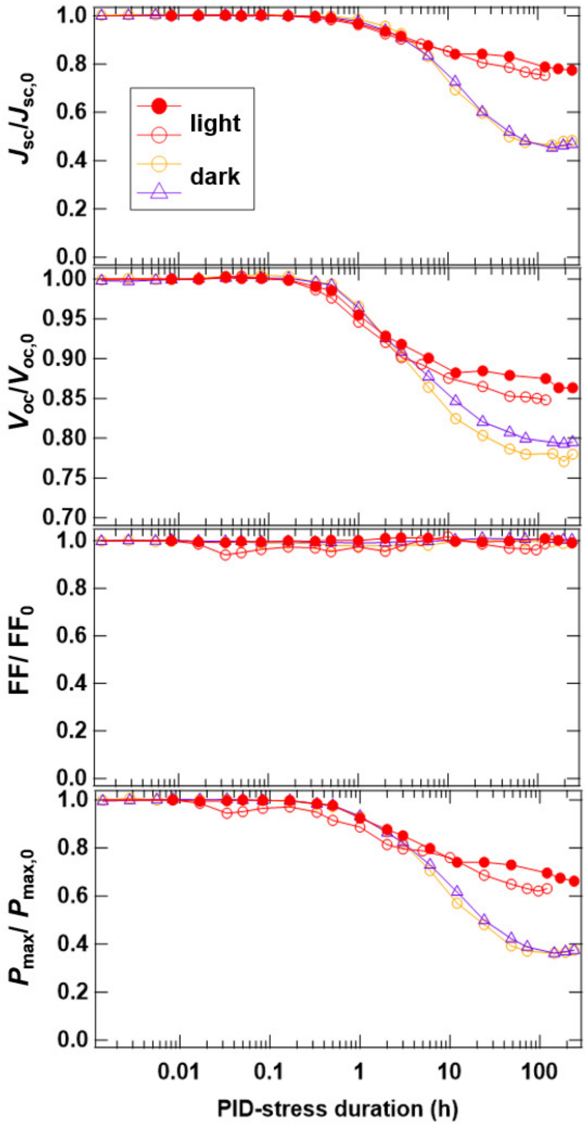

Fig. 1 J_{sc}, V_{oc}, FF, and P_{max}, normalized by their initial values, of the IBC PV modules as a function of the duration of PID test performed in the dark and under 1-sun illumination.

Fig. 2 shows the EQE spectra of the IBC modules before and after the PID test in the dark state and under light illumination. Decreases in EQE in a whole wavelength region are confirmed, even though the IBC cells receive Na introduction only near the surface. This can be explained by the sufficiently long carrier diffusion length in the IBC cells. Minority carriers, holes, generated by long wavelength light far from the surface can reach the surface and recombine there. The mitigation of PID by 1-sun illumination can be clearly confirmed also in the EQE spectra. The delay of PID by light illumination has also been confirmed in conventional p-type c-Si PV modules [4,5]. An increase in the conductivity of SiN_x by carrier generation due to light illumination and resulting reduction in electric field is believed to be the reason for the delay of the PID under light illumination. This can also be the reason for the mitigation of the PID of IBC modules under 1-sun illumination. These findings are useful to evaluate the long-term reliability of IBC PV modules in the field where the modules receive PID stress with light illumination.

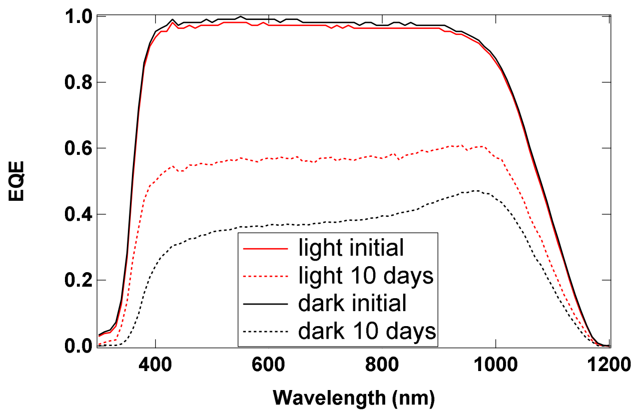

Fig. 2 EQE spectra of the IBC modules before and after the PID test in the dark and under 1-sun light illumination.

4. Summary

We investigated the PID of the IBC modules under negative bias and the effect of light illumination on their PID. As a result of a PID test for ~10 days, J_{sc} and V_{oc} decrease simultaneously, whereas FF is unchanged. The reductions in J_{sc} and V_{oc} are probably because of Na introduction into the cell surface and enhanced surface recombination of minority carriers. We also observed the mitigation of PID by light illumination.

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