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Description	

Effect of evacuating a chamber on the degradation rate of solar cells in a cell-level potential-induced degradation test

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In this work, we investigated the effect of evacuating a chamber on the degradation rate of solar cells in a cell-level potential-induced degradation (PID) test by which photovoltaic-module-like stacks are stressed. The degradation rate of a solar cell tested in an evacuated chamber was higher than that in air. The higher degradation rate may be due to the improvement of contacts between the stack components. From this result, evacuating the chamber was confirmed to be effective for obtaining a high acceleration factor in cell-level PID tests.

Potential-induced degradation (PID) has been considered one of the most important reliability issues of photovoltaic (PV) modules used in large-scale PV systems.[1] PID occurs owing to a high electric potential difference between the grounded frames and active circuits of solar cells, which may lead to significant performance losses of modules. PID has been found in various types of PV modules, such as conventional p-type crystalline silicon (c-Si),[2–4] front-emitter n-type c-Si,[5–7] rear-emitter n-type c-Si,[8] n-type back-contact c-Si,[9,10] amorphous Si (a-Si) thin-film,[11,12] c-Si/a-Si heterojunction,[13,14] cadmium telluride thin-film,[15,16] and copper indium gallium selenide thin-film[15,17,18] PV modules. PV modules fabricated from different types of cells are known to degrade by different mechanisms.

To investigate the root cause of PID, cell-level PID tests have been carried out. In particular, a method in which module-like layer stacks without lamination are stressed[19] is considered to be important. This is not only because typical degradation behaviors in various kinds of solar cells can be easily reproduced[20] but also because, unlike in module-level PID tests, PID-affected bare cells can be readily obtained after PID tests. In the cell-level PID tests, layer stacks are placed in a vacuum chamber and stressed. The vacuum is used to improve contacts between individual layers in the module-like layer stacks. However, the actual effect has not been clarified yet.

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In this note, we report the effect of evacuating the chamber on the degradation rate of solar cells in the cell-level PID test. On the basis of the results, we discuss the effect and importance of evacuating the chamber.

Module-like stacks composed of 0.7-mm-thick flat soda-lime glass, a 0.4-mm-thick uncured ethylene vinyl-acetate copolymer (EVA) sheet, and a PID-prone p-type c-Si solar cell were prepared. The stacks were placed on a temperature-controlled aluminum (Al) chuck in a test chamber, with the cell side down, and a 0.10-kg-weight copper block was placed on each stack. The copper blocks, glass, and EVA sheets had an area of 19.8×19.8 mm^2, whereas the solar cells had an area of 20×20 mm^2. The copper block served as both the top electrode and a weight to reduce the contact resistance within the unlaminated sample stacks. The pressure applied by the 0.10-kg-weight copper block to a sample was 2.5 kPa. The chamber was pumped with a diaphragm pump to a pressure of approximately 20 kPa during the PID tests. PID tests were performed by applying a voltage of 1000 V to the copper block with respect to the Al chuck maintained at 65 °C, using a PID insulation tester (KIKUSUI TOS7210S) with an ammeter to detect the leakage currents during the voltage application.

After each PID test, the glass and EVA sheet were carefully removed from the surface of the solar cell. To estimate the degradation, dark and one-sun-illuminated current density–voltage (J–V) measurements were performed on the PID-affected bare solar cells at 25 °C before and after the PID tests. Leakage currents were collected at elevated temperatures in a range from 55 to 85 °C at increments of 5 °C under different test conditions to obtain the Arrhenius plot.

Figure 1 shows the normalized maximum output power ($P_{\max}/P_{\max,0}$) of the solar cells tested in air and vacuum as functions of PID-stress duration. These solar cells exhibited typical PID behaviors, which are characterized by a reduced fill factor (FF) due to a reduction in their shunt resistances. As shown in Fig. 1, the degradation rate in vacuum was considerably higher than that in air. This result suggests that the atmosphere in the test chamber largely affects the degradation rate and evacuating the chamber is important to obtain a high acceleration factor.

A high acceleration factor is very important when using the cell-level PID test as a rapid method for assessing the PID susceptibility of PV module components. Therefore, evacuating the chamber is essential for this test method. If the chamber is not evacuated, the PID resistance can be overestimated.

To investigate the cause of the acceleration effect, we analyzed leakage currents flowing in the samples tested in air and vacuum during the cell-level PID tests. Figure 2 shows the

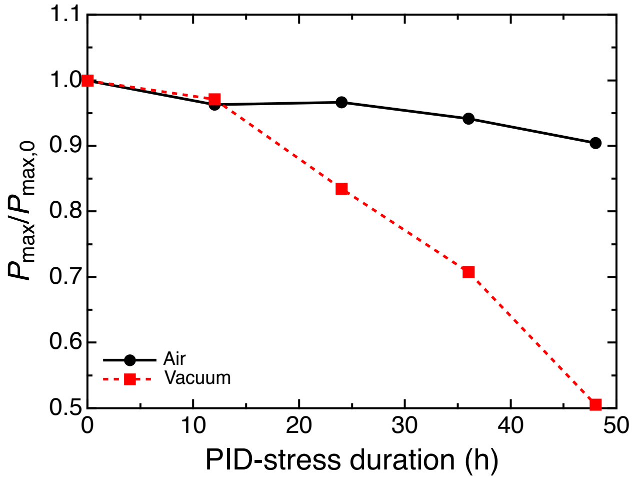

Fig. 1. (Color online) $P_{max}/P_{max,0}$ of the solar cells tested in air and vacuum as a function of PID-stress duration.

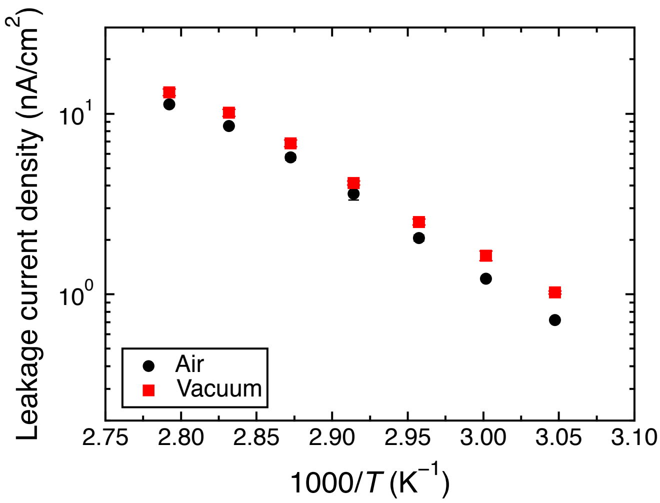

Fig. 2. (Color online) Leakage current densities during the cell-level PID tests in air and vacuum. The data points show the means of three samples, and error bars correspond to standard deviations of the means.

Arrhenius plots of leakage currents. In this experiment, three identical samples were used for each condition, and, in Fig. 2, means of three samples are shown with error bars based on the standard deviations of the means. In this experiment, we used busbarless solar cells. By using them, we can have removed the effect of currents flowing in the busbar, which do not contribute to PID. Under all the conditions, sublinear behaviors were observed in the Arrhenius plots. These behaviors have been reported to be caused by interstices existing in both surfaces of EVA sheets.[20)]

As shown in Fig. 2, leakage current densities flowing within the samples tested in vacuum

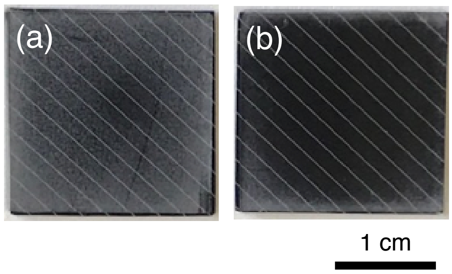

Fig. 3. (Color online) Appearances of sample stacks after the leakage current measurements in (a) air and (b) vacuum.

were higher than those in samples in air at all the temperatures tested. This suggests that the contact resistances between the cell and the EVA sheet and between the EVA sheet and the glass were reduced by introducing vacuum. This is also suggested by the appearances of test stacks in Fig. 3 after the leakage current measurements in air and vacuum. The components of the stacks adhered because they were heated at a temperature of 85 °C. In Fig. 3(a), there are many air bubbles; however, in Fig. 3(b), there are fewer air bubbles. This suggests that evacuating the chamber improves the contacts between different layers of the sample stacks by removing air bubbles existing along both sides of the EVA sheet.

On the basis of the above proposed mechanism, a high pressure applied by the top electrode might be used instead of vacuum to accelerate the degradation, because such a high pressure can contribute to the improvement of contacts between the components. We therefore used 0.05- and 0.15-kg-weight copper blocks as the top electrodes in the PID tests in air; however, the degradation rate was not significantly changed. This suggests that evacuating the chamber has a more significant effect than applying pressure under this experimental condition. We previously reported the dependence of degradation rate on the pressure applied by the top electrode under evacuation and found that the degradation is slightly accelerated by applying a high pressure.[20]

There are remaining open questions. For example, the dependence of degradation rate on the degree of vacuum is unclear and should also be investigated to understand the effect of vacuum in more detail.

In summary, we investigated the effect of vacuum on the degradation behaviors of solar cells in a cell-level PID test. Vacuum in the cell-level PID test was confirmed to accelerate the degradation of cells tested. The acceleration effect was due to the improvement of contacts between the components of test stacks. Evacuating the chamber is very important to obtain a high acceleration factor.

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