Research Article

PID Testing Method Suitable for Process Control of Solar Cells Mass Production

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Voltage bias of several hundred volts which are applied between solar cells and module frames may lead to significant power losses, so-called potential-induced degradation (PID), in normal photovoltaic (PV) installations system. Modules and minimodules are used to conduct PID test of solar cells. The test procedure is time consuming and of high cost, which cannot be used as process monitoring method during solar cells fabrication. In this paper, three kinds of test including minimodule, R_{sh} , and V-Q test are conducted on solar cells or wafers with SiN_x of different refractive index. All comparisons between test results of R_{sh} , V-Q, and minimodule tests have shown equal results. It is shown that R_{sh} test can be used as quality inspection of solar cells and V-Q test of coated wafer can be used as process control of solar cells.

1. Introduction

In standard photovoltaic (PV) installations system, PV modules are exposed to voltage bias of several hundred volts with respect to the module frames/mounting [1–3]. Due to those high voltages, solar modules may suffer so-called potential-induced degradation (PID) which may lead to significant performance loss [4–6]. It is reported that high voltages may lead to leakage currents through the encapsulating material, being responsible for degradation effects [7]. Some investigation revealed that soda lime glass, ethylene vinyl acetate (EVA), and the solar cell's antireflective coating (ARC) play important roles in the formation of PID [8–10].

Among those factors, antireflective coating (ARC) was the important part and was widely studied to avoid PID [11, 12]. Solar cells with SiO_2/SiN_x double coating layer or SiN_x with high reflective index all have great improvement. At present, most PID test methods about solar cells are conducted on modules [13] or minimodules [9, 14]. Solar cells firstly should be made into module and then placed in an environmental chamber under defined conditions, finally connected to a power supply in order to generate a typical bias

voltage for defined times. The test procedure is time consuming and of high cost, which cannot be used as process monitoring method during solar cells fabrication.

The purpose of this work was to provide simple and fast PID test methods about solar cells which are suitable for quality inspection of solar cells and process control of ARC deposition during mass production.

2. Experimental

Solar cells based on p-type multicrystalline wafers with resistivity of 1–3 $\Omega\cdot\text{cm}$ and thicknesses of about 190 μm were used as test samples. Solar cells with different SiN_x refractive index were divided into different groups according to various anti-PID properties. The PID performances of solar cells were evaluated by three methods, including minimodule test, shunt resistance R_{sh} test, and voltage-corona charge (V-Q) test for solar cells. Same EVA and glasses were used for minimodule test and R_{sh} test. The test results of three different methods were compared to each other to investigate the substitutability of those methods.

FIGURE 1: Different PID power loss of cells with ARC of different refractive index.

Frameless minimodules (one mc-Si cell, dimensions $30 \times 30 \text{ cm}^2$) were used for the lab testing with a self-adhesive aluminum tape as a substitute for the frame. Some water was dropped on the surface of glass and then another aluminum foil was applied on the top of glass to ensure full contact between glass and aluminum tape. The PID test was conducted in environment chamber with temperature of 85°C , humidity of 85%, applied voltage of 1000 V, and time of 96 h. The electrical parameters and EL image were measured to evaluate the PID performance of solar cells.

R_{sh} test was performed using PIDcon which was developed by Fraunhofer CSP and now is commercially available by Freiberg Instruments [15] as follows: the solar cell was placed on a temperature-controlled aluminum chuck to achieve a constant temperature throughout the testing process. On the front side, a sheet of EVA and glass were placed on top of the solar cell. The front surface of the solar cell was connected to a needle to measure the solar cell parameters. A solid metal block was then placed on top of the front glass to achieve a uniform high voltage across the glass surface within the test area. A voltage of 1000 V was then applied between the front metal block and aluminum chuck. During the degradation, the shunt resistance of the solar cells was measured to indicate the performance change of solar cells. Cells of different group with similar initial R_{sh} were chosen as test samples.

V-Q characteristics of ARC films were also measured to evaluate the conductivity of these films using WT-2000 PVN from Semilab [8]. After ARC coating, silicon wafers are charged by corona continuously. Kelvin Probe was used to measure the surface voltage of silicon wafer under different charged electric quantity. Generally, the surface voltage initially increases with the charged electric quantity and then is gradually saturated with a certain voltage which was named V_{limit} . The value of V_{limit} can be used to evaluate the conductivity of ARC film.

3. Results and Discussion

3.1. Minimodule Test. Figure 1 shows the different PID power loss of cells with ARC of different refractive index. The

thickness of film was controlled to the same (85 nm), and different refractive index is produced by adjusting the flow rate of silane and ammonia in the process of deposition. It can be seen from the figure that the PID power loss decreases from 29.27% to 2.83% while the refractive index changes from 2.0 to 2.2. The results show that the PID decreases by the increasing of refractive index of SiN_x , especially when the refractive index increases from 2.0 to 2.15, and the PID shows sharply downward trend and then comes to a slightly decreased trend. By the increasing of refractive index of SiN_x , the brightness in EL is enhanced gradually before PID test. After PID test, the point of darkness in EL picture increases for the low refractive index. When the refractive index increased to 2.2, the testing results show it is stable after the PID, indicating a good anti-PID performance. The EL images also verified that higher refractive index of SiN_x can weaken PID of solar cells and even eliminate this phenomenon (Figure 2).

3.2. PIDcon Test. Figure 3 shows the degradation of R_{sh} of different SiN_x refractive index. In order to make accurate comparison, solar cells with R_{sh} of 100–300 Ω were chosen to apply PIDcon test. It can be seen that, in the process of refractive index changing from 2.0 to 2.2, the R_{sh} degradation rate varies from being rapid to almost stable. It indicates that the R_{sh} degradation rate decreases by the increasing of refractive index of SiN_x . Plenty of reports claim that the decrease of R_{sh} is a very important parameter in evaluation of the PID problem. When R_{sh} of solar cells decreases to an extremely low level, for example, lower than 5%, it will have an obvious negative effect on solar cell output parameters.

3.3. V-Q Test. Figure 4(a) shows the relation between the surface voltage of silicon with SiN_x films and the deposited corona charge density under different refractive index of SiN_x . The surface voltage increases with more positive corona charge on the surface. For samples with high refractive index, such as 2.1, 2.15, and 2.2, the voltage is easy to become saturate. And for samples with low refractive index, such as 2.0 and 2.05, it seems that it needs higher corona charge density to lead the voltage to saturation. It can be seen that, by

Refractive index of SiN_x	2.0	2.05	2.1	2.15	2.2
Before test
After test

FIGURE 2: Different EL images of cells with ARC of different refractive index before and after PID test.

FIGURE 3: Degradation of R_{sh} of different SiN_x refractive index.

the increasing of the refractive index of SiN_x , while positive corona charge was applied on the ARC surface, the voltage may reach the saturation state more easily. Once the voltage reached the saturation state, the voltage does not change by more corona charging. It can be explained by the leakage current through ARC. Continuous positive charging will leak out because of the electrical conductivity of ARC film. The saturation voltage was extracted from Figure 4(a) and plotted with refractive index of SiN_x in Figure 4(b). It has to be mentioned that, for samples with refractive index of 2.0 and 2.05, the saturation voltage is extracted by the voltage of the maximum corona charge density (3000 nC/cm^2).

The saturation voltage decreases with the increasing of refractive index. When the refractive index increased from 2.0 to 2.1, the saturation voltage decreased from 29.1 V to 6.6 V rapidly. Then the value of V_{limit} changes slightly by increasing refractive index. Low V_{limit} indicates an increased electronic

conductivity, arising from more mobile electrons, in the silicon rich SiN_x layer with higher refractive index. In comparison of the minimodule, R_{sh} , and V-Q result, the function of represented parameter with refractive index takes the same trend. Then they are the equal test tool to evaluate the performance of PID in silicon solar cells.

4. Conclusion

Modules or minimodules PID tests are quite time consuming and of high cost. In this paper two sample methods for checking the PID performance of solar cells and ARC coating were provided to solve the monitoring problem during mass production of anti-PID solar cells. All comparisons between R_{sh} , V-Q test of silicon solar cell, and minimodule tests in climate chambers have shown equal results. And R_{sh} and V-Q test are much simpler than minimodule test. It is shown that

FIGURE 4: Testing results of V-Q and V_{limit} with different refractive index of SiN_x.

R_{sh} test can be used as quality inspection of solar cells and V-Q test of coated wafer can be used as process control of solar cells. Those two methods can be helpful to eliminate PID in mass production level.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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