Microstructure analysis of snail trails in photovoltaic modules

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Abstract. Snail trails on photovoltaic modules are a source of enormous concern to the solar industry as few scientific reports on the mechanisms producing this global phenomenon were previously available. The samples surface were treated with CH₃OH/CH₂Cl₂ and used the SEM and Raman for material analysis. The size of the discoloration silver grid is about 80-200 nm. From the Raman spectroscopy can be seen snail trails and the surrounding discoloration of silver on the Ag₃CO₃ generation.

1. Introduction

The investigation of defects and degradation in photovoltaic modules has become an important subject since reliability and product lifetime are keys to system performance [1, 2]. One of the degradation effects that has been observed increasingly during recent years is “snail trails” or “earth worms”, thus called because of their visual and power appearance [3, 4]. However, long-term negative influences [5] cannot be excluded and require further study.

The main goal of the work presented is to uncover the chemical and microstructural nature of discoloured grid fingers. It can be investigated thoroughly several PV modules affected by snail trails after outdoor exposure, as well as mini modules with snail trails induced after treatment in the damp-heat chamber. It can be shown that the same chemical mechanism is underlying the grid finger discoloration in both the real modules and the model system. This enables us to set up a model for the formation of snail trails and to develop strategies for their prevention.

2. Material and methods

Samples of EVA encapsulation about 400×400 mm² in glass size were incubated under accelerated conditions. PV modules with snail trails were disassembled mechanically to obtain the cell and encapsulation foil surface after earthworms appear. As shown in figure 1, select the snail trails section or around the gate line discoloration of the module, and heat on the heating table for 5 minutes at 80 °C temperature. After heating, the EVA film with cell use the blade directly to the battery chip with shovel. Using of tweezers on the surface of the battery chip stripped of EVA, and then cut into small 1×1cm² with scissors. Raman test samples no longer need other treatment, direct focus test can be tested. The microstructure snail trails analysis were prepared for field emission scanning electron microscope (SEM, JSM-7001F) and Laser Raman Spectrometer (USA, ThermoFisher, DXR).
3. Results and discussion

3.1. Sample preparation

Figure 2 shows the snail trails appear in the physical map and EL (Electro Luminescence) under the test picture. Figure 2(a) is an enlarged view of figure 2(b). The small gray particles is the snail trails in figure 2(a). The Snail trails are generally appear next to the silver gate line. This is a familiar phenomenon in the industry. It can be seen from the figure 2, snail trails appear similar to the yellow floral color of small particles. The samples were treated separately using water and CH$_3$OH/CH$_2$Cl$_2$, respectively. And figure 3 shows the SEM image before and after CH$_3$OH/CH$_2$Cl$_2$ washing. Samples for SEM testing require spray treatment. In view of the test found that Ag oxide generation control below 80 °C to peel off, the sampling temperature of the heating platform can not be too high, otherwise it will form silver oxide. As shown in figure 3, an oxygen peak occurs at 145 °C and no at 80 °C [6, 7]. EVA stripping material on the test results will have a great impact [8, 9]. The CH$_3$OH/CH$_2$Cl$_2$ of snail trails on the sample surface treatment, organic matter is dissolved and the surface nanoparticles still exist, which as a method of testing the following particles. It can be seen that the particle size does not change.

Figure 1. Sample drawing.

Figure 2. (a) appear snail trails; (b) EL test.
3.2. SEM and EDS
It can be seen from figure 4 that there are a large number of particles on the snail trails grain, and the particle size is about 80 nm. There is also a small amount of particles on the normal grid lines at the discoloration. The particles are larger in relation to the snail trails, which is about 100-200 nm.

3.3. Raman spectroscopy
Figure 5 is the Raman spectra of normal grating line and the discolored line. It can be seen from the figure 5 that there is a significant $\nu_{\text{O}-\text{C}-\text{O}}$ absorption vibration peak at 1375 cm$^{-1}$ and 1128 cm$^{-1}$. Ag-O characteristic vibration peak appears in the 462 cm$^{-1}$, 583 cm$^{-1}$ and 966 cm$^{-1}$. And the peak of the bending of the CO$_3^{2-}$ appears at 1052 cm$^{-1}$, 1438 cm$^{-1}$ and 709 cm$^{-1}$ [10] peaks. From the Raman spectroscopy can be seen snail trails and the surrounding discoloration of silver on the Ag$_2$CO$_3$ generation.
4. Conclusion
At present, the emergence of snail trails can be reproduced through different experimental conditions. The CH$_3$OH/CH$_2$Cl$_2$ of snail trails on the sample surface treatment, organic matter is dissolved and the surface nanoparticles still exist, which as a method of testing the following particles and the particles will not be destroyed by oxidation. The particle size of snail trails and discoloration lines is about 80-200 nm. From the Raman spectroscopy can be seen snail trails and the surrounding discoloration of silver on the Ag$_2$CO$_3$ generation. In this paper, the specific material of snail trails has been analyzed. According to the generated material in this paper, and the matching material performance can prevent the emergence of snail trails. With the reduction of snail trails phenomenon, the modules power attenuation is reduced. And the rigid quality control would be executed and therefore optimize the energy output of the PV module over 25 years lifetime.

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