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Assessing power degradation and reliability of crystalline silicon solar modules with snail trails

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ABSTRACT

Reliability and lifetime of crystalline silicon solar modules are very important for photovoltaic system performance. That the snail trails occasionally occurred on photovoltaic modules has not yet been solved. In this paper, the influence of the snail trails on the power degradation was investigated in detail by six years' tracking test and the extended reliability tests. The results show that the average power degradation of the modules with snail trails is 5.90%, while the average power degradation of modules without snail trails is 5.64% over a 6-year operation period. This reveals that the snail trail has a little impact on the performance of solar modules because the snail trail only affects the transmission of the sunlight. Electroluminescence images prove that there is no relationship between snail trails and micro-cracks. To assess the impact of snail trails on the long-term reliability of solar modules, we applied extended reliability tests based on the international standard IEC 61215. The extended reliability tests of solar modules with snail trails reveal that the average power degradation is 1.77% and 0.68% after the damp heat test over 1250 h and the thermal cycling test of 500 cycles, respectively. These results suggest that the long-term reliability and durability of solar modules are not affected by snail trails. The SEM and EDS prove that Ag finger below snail trails has no change, and no corrosion could be identified. The result of XPS indicates that there exists the silver oxide in the EVA affected by snail trails. The results obtained in this paper prove that the warranty period up to 25 years for solar modules with snail trails may be realized under real conditions.

1. Introduction

Because the feed-in tariff policy and payback were made on the basis of service lifetime of 25 years in many countries, the reliability and lifetime of crystalline silicon solar modules are very important for owners of power plant and module producers [1–4]. Over the past decade or so, the installed capacity of photovoltaic (PV) modules has experienced tremendous growth, and low-priced materials for module encapsulation have been used widely. A new degradation phenomenon, which appears as irregular dark stripes on the surface of solar cells of the crystalline silicon solar modules, emerged in crystalline silicon solar modules occasionally [5,6]. This apparent defect is different from the EVA discoloration and the discolored silver grid lines in crystalline silicon solar modules studied by other authors [7–10]. This phenomenon was first reported by photon in 2012, and called as “snail trails” [11]. Then possible causes and formation mechanisms of snail trails on solar modules were intensively investigated and discussed by many papers [12–15]. Some authors thought that the micro-cracks, moisture and oxygen were the essential conditions for the formation of snail trails [9–11,13,16]. But other authors thought that the additives like glass frits of silver paste or peroxide additives in the ethylene vinyl acetate (EVA) were root cause to form snail trails [14,17]. Up to now, the true reason and formation mechanism of snail trails have not been revealed thoroughly because of diversity of encapsulation materials and difficulty of reproduction for snail trails. In recent years, the crystalline silicon solar module producers have received more and more complaints from owners of photovoltaic power plants about snail trails. According to the published papers, the owners of power plant claimed that the snail trails on photovoltaic modules will expand as time goes on; the output power of solar modules with snail trails would not reached 80% of the initial output power after the expected 25 years. The reliability and lifetime of solar modules with snail trails will be seriously affected [13,18].

In this work, the influence of the snail trails on the performance and

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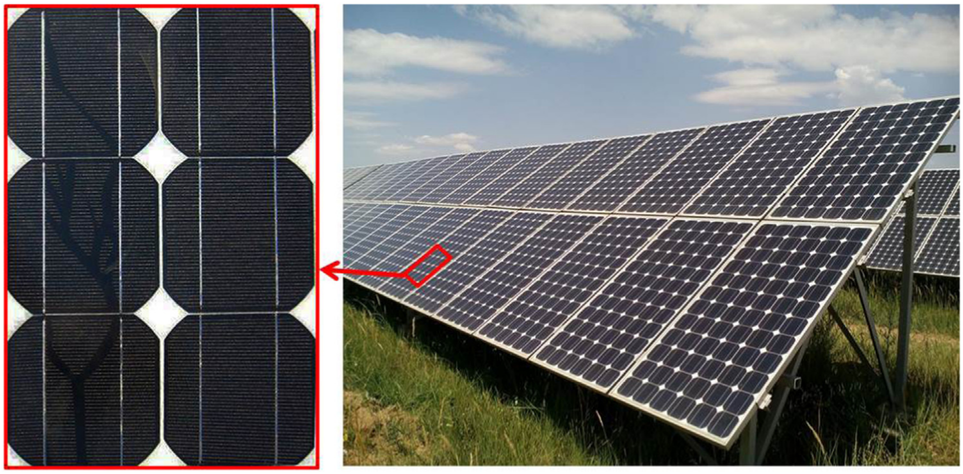

Fig. 1. Photovoltaic power plant with snail trails.

long-term reliability of solar modules were investigated in detail by six years' tracking test and the extended reliability test. We find that the snail trails is not a certain failure mode, but an occasional apparent defect. The average power degradation of the modules with snail trails is 5.90%, while the average power degradation of modules without snail trails is 5.64% over a 6-year operation period. This reveals that the snail trails has a little impact on the performance of solar modules. This result agrees with the previous work [19]. Electroluminescence (EL) images prove that there is no certain relationship between snail trails and micro-cracks. This finding is different from other authors' work [20]. To assess the impact of snail trails on the long-term reliability of solar modules, the extended reliability tests were carried out for solar modules with snail trails based on the international standard IEC 61215 [21,22]. The experimental results show that the average power degradation of solar modules with snail trails is 1.77% and 0.68% after the damp heat test over 1250 h and the thermal cycling test of 500 cycles, respectively. The area of snail trails on solar modules did not enlarge after the extended reliability tests. The SEM and EDS prove that Ag finger below snail trails has no change, and no corrosion could be identified. The result of XPS indicates that there exists the silver oxide in the EVA affected by snail trails. The conclusions obtained in this paper prove that the reliability and lifetime of solar modules are not affected by snail trails. And the warranty period up to 25 years for solar modules with snail trails may be realized under real conditions. It also provides some hints for further uncovering the formation mechanism of snail trails.

2. Experimental details

The experimental solar modules were dismounted from the photovoltaic power plant, as shown in Fig. 1. This photovoltaic power plant was connected to the grid in October 2010 with the installed capacity of 2 MWp. The peak power of the solar modules used in this power plant is 185Wp, which has a tolerance from 0 to +5%. The solar modules were encapsulated with the same materials, which consists of a glass superstrate, crystalline silicon solar cells, different polymer layers and tinned copper ribbons. The backside of the module is a white TPT (Tedlar/Polyster/Tedlar). In September 2011, the four solar modules with snail trails and four solar modules without snail trails, which dismounted from the power plant, were installed on the roof of the laboratory building for tracking study. These solar modules were marked S1, S2, S3, S4 (modules with snail trails), and N5, N6, N7, N8 (modules without snail trails) in sequence.

In order to assess power degradation and reliability of crystalline silicon solar modules with snail trails, the performance of these solar modules was measured by solar simulator (PASAN Sunsim 3C) under standard test conditions (STC: 1 kW/m^2 irradiance, 25 °C module temperature and AM1.5 global spectrum) at regular intervals from 2011 on. Thermography images of solar modules were often obtained by T420 (FLIR Systems Inc.) under forward bias on the roof of lab. The electroluminescence images of the solar modules were acquired time and again by an EL measurement system in our lab. In 2016, the extended reliability tests were carried out for these solar modules experienced outdoor exposure over six years according to the flow chart shown in Fig. 2.

Temperature and humidity are the main factors that affect the performance of solar modules [23,24], so these two factors are mainly considered in the extended reliability test. As shown in Fig. 2, these 8 solar modules were subjected to visual inspection, maximum power determination, insulation test and wet leakage current test in turn, respectively. Then, the solar modules S1, S2, N5, N6 were carried out for the damp heat test of 1000, 1250 h under the condition of 85 °C and 85% relative humidity, while the solar modules S3, S4, N7, N8 were carried out for the thermal cycling test of 50, 200 and 500 cycles under the condition of temperature from −40 °C to +85 °C.

After the extended reliability tests, the solar cell with snail trails was

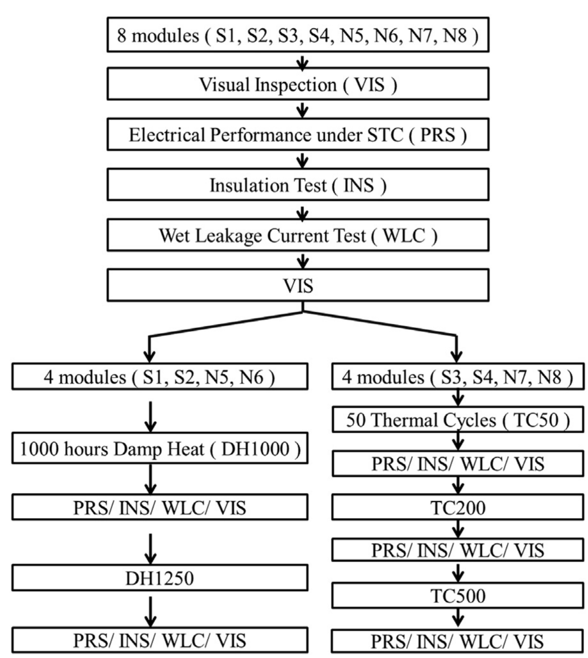

Fig. 2. The diagram of extended reliability test sequence.