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Power degradation caused by snail trails in urban photovoltaic energy systems

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Abstract

In recent years, a discoloration defect called as the snail trials emerged on crystalline silicon solar module in urban photovoltaic energy systems. It resulted in power degradation, and caused a serious concern about effects of this phenomenon on crystalline silicon solar modules, but very few publications have dealt with this phenomenon. In this paper, the crystalline silicon solar modules with snail trials are investigated by I-V and P-V characteristics, electroluminescence (EL) technique, thermography analysis, and energy production in photovoltaic power plant. The obtained results show that the snail trails may affect output of power for crystalline silicon solar modules compared with reference module, the energy production measured was about 9.1% lower than the normal array.

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Keywords: Photovoltaic; power plant; reliability; Degradation; Snail trails

1. Introduction

The photovoltaic (PV) energy will provide a substantial contribution to low-carbon cities and urban energy. The crystalline silicon solar module is a workhorse for photovoltaic energy in a long time. It is a key system component that converts solar radiation directly to electricity. The reliability of crystalline solar modules is critical to the cost effectiveness and the commercial success of photovoltaic energy. In recent years, a discoloration defect called as the snail trials emerged on crystalline silicon solar module in photovoltaic power plant. This snail trail appearing as small, dark lines or partial cell-discolorations on PV modules, has drawn considerable attention from researchers and manufacturers in the solar industry Previous works focused on the elements and formation mechanism of snail trail. They argued that the snail trail is silver nanoparticle [1], silver oxide or silver carbonate nanoparticles [2] and the silver

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element is from the silver finger of solar cells [1-2]. Some authors think that the snail trail discolorations within the cells are strongly correlated with cell micro-cracks. Other authors think that there is no indication that they cause a significant decrease in module efficiency.

Because the thickness of crystalline silicon solar cells is only 190 um, and silicon is very brittle, cracks can be easily induced by vibrations, impact during transportation and installation. And heavy snow pressure also caused the cracks. According to the above authors, there are a lot of snail trials in every photovoltaic power plant. But there is no snail trial in some photovoltaic power plant. According to our investigations, the snail trials phenomenon is random. It is not directly correlated with cell micro-cracks. It indeed caused power degradation in urban photovoltaic energy systems. In this work, the relationship between snail trails and micro-cracks is studied. Electroluminescence and infrared thermometer are used to find out the influence of snail trails on cell structure and performance. In order to clarify the origin of silver element of snail trail, Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometry (EDS) were used to observe the morphology and silver element content difference of silver fingers between common modules and degraded modules affected by snail trails.

2. EXPERIMENTAL

2.1. Sample preparation

PV modules affected by snail trails in urban photovoltaic energy systems are prepared for study. Figure 1 shows the outdoor scene of urban photovoltaic energy systems affected by snail trails phenomenon.

Fig. 1. Phenomenon of snail trials in urban photovoltaic energy systems

2.2. EL analysis

Electroluminescence (EL) is a good means to exam whether the PV modules have the cells with micro-cracks or not. So the problem of micro-cracking in Silicon PV has recently been investigated in [3-7] with the aid of the electroluminescence (EL) technique.

2.3. SEM analysis and EDS analysis

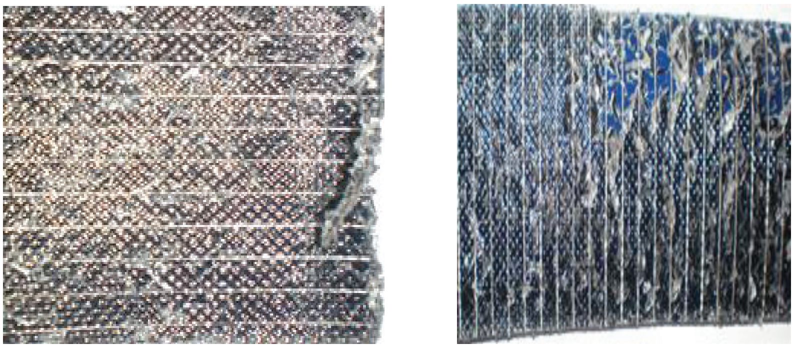
Scanning Electron Microscopy (SEM) is a good method for sample surface topography and microstructure inspection. It is able to inspect both plan view and cross-section view of sample. With an extra installed EDS (Energy Dispersive Spectrometry), it is possible for this machine to conduct qualitative and semi-qualitative analysis for specified microstructure.

2.4. Thermography analysis

Electric measurement of PV module performance was combined with a thermal analysis of modules surface to find out potential hot spots. The same module with different temperatures would have various performances in output power.

3. Results

The samples description is as figure 2, the top EVA above the cell finger in snail affected and non-affected area were removed and analyzed respectively. There are obvious darken lines discovered within the affected EVA area when the EVA was stripped mechanically from the top of the cell with snail trails.

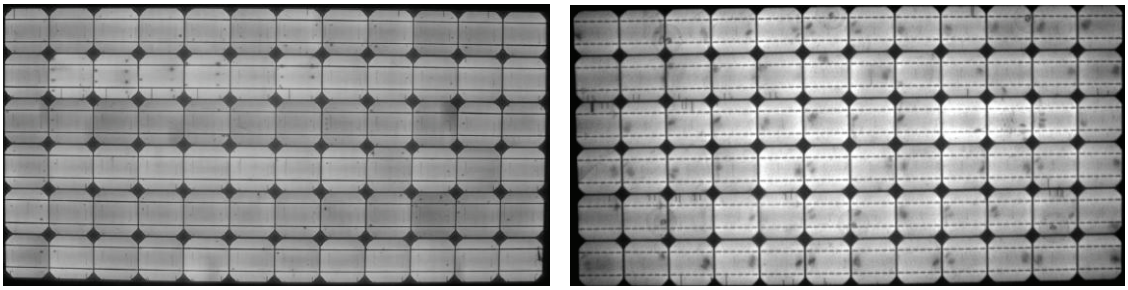


(a) (b)

Fig. 2. The affected sample with cell and EVA (a) and the stripped EVA within snail trial area (b)

3.1. Results of EL analysis

The module with snail trails was checked by electroluminescence technique to discover the micro-cracks in solar cells. A comparison of EL imaging between module with snail trails and module without snail trails had been done to identify the impact of micro-cracks on snail trails. The result is shown in figure 3. Through looking at both EL images carefully, there is no micro-crack in both modules and the characters of modules EL images are nearly same. The micro-cracks didn't play a key role in the formation of snail trails. The gap between two cells is nature cracks, according to previous works, there must be many snail trails on gap areas. However, a surprising result has been found that there is no snail trails discoloration in the gap areas (figure 4). So the idea held by those authors that the snail trail discolorations within the cells are strongly correlated with cell micro-cracks is not correct.



(a) (b)

Fig. 3. EL images of module with snail trails (a) and module without snail tails (b)

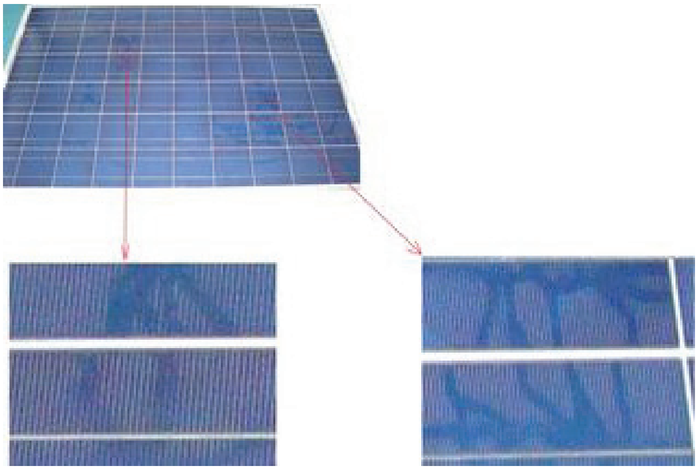


Fig. 4. Module with snail trails. All the snail trails appear on solar cells. There is no snail trails discoloration in the gap areas

3.2. Results of SEM and EDS analysis

The cross sections of silver finger in affected areas of cell with snail trails are observed by SEM. The morphology of the scanned silver lines is normal and no corrosion could be identified. The SEM image is shown in figure 5 below.

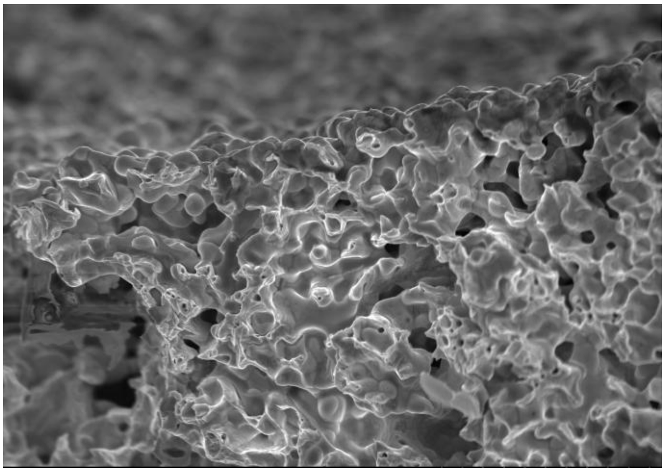
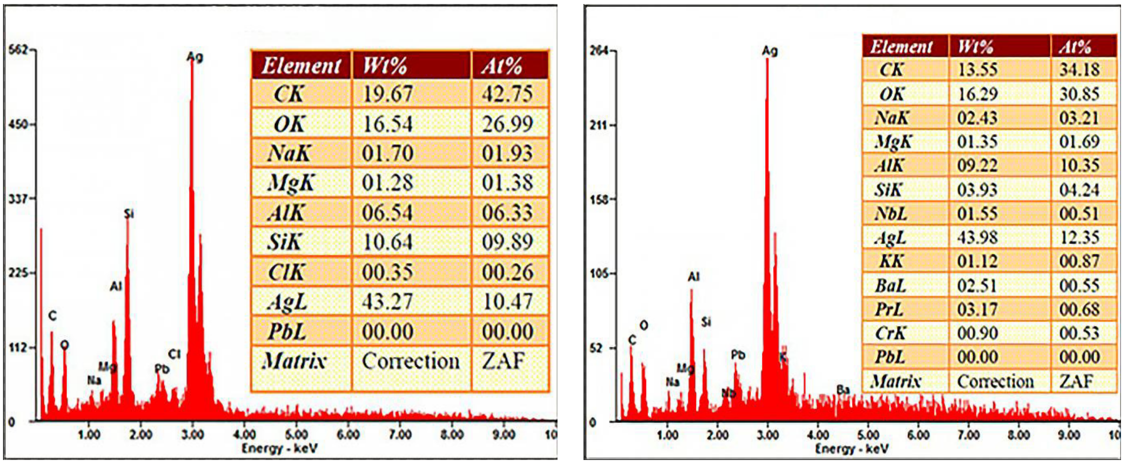


Fig. 5. SEM. image of cross section of silver finger in non-affected areas

EDS (Energy Dispersive x-ray Spectrometry) is used to exam the elements and relevant content in cell fingers. In the finger areas of cell, the key elements C, O, and Ag were detected in both affected and non-affected silver lines areas. There is no striking difference in the content of silver in both fingers. This result implies that the silver element of snail trails didn't come from silver finger. The result is shown in figure 6.



Element	Wt%	At%
CK	19.67	42.75
OK	16.54	26.99
NaK	01.70	01.93
MgK	01.28	01.38
AlK	06.54	06.33
SiK	10.64	09.89
ClK	00.35	00.26
AgL	43.27	10.47
PbL	00.00	00.00
Matrix	Correction	ZAF

Element	Wt%	At%
CK	13.55	34.18
OK	16.29	30.85
NaK	02.43	03.21
MgK	01.35	01.69
AlK	09.22	10.35
SiK	03.93	04.24
NbL	01.55	00.51
AgL	43.98	12.35
KK	01.12	00.87
BaL	02.51	00.55
PrL	03.17	00.68
CrK	00.90	00.53
PbL	00.00	00.00
Matrix	Correction	ZAF

(a) (b)

Fig. 6. EDS analysis for affected cell finger areas (a) and non-affected cell finger areas (b)

3.3. Results of thermography analysis

According to the results of thermography analysis, we found that the local temperature of affected areas by snail trails is nearly same as that in normal areas. The snail trails didn't increase the leakage currents. The results are shown in the figure 7 below.

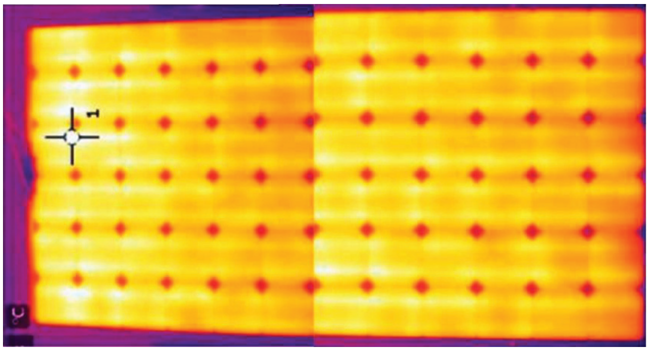


Fig. 7. Temperature difference between affected and non-affected areas

3.4. Power degradation caused by snail trails in PV modules

Many experiments about power degradation have been performed to find the influence caused by snail trails in PV modules. The results reveal that the degradation in power output of PV plants affected by snail trails is about 9.1 percent. The specific data is put in the Table 1.

Table 1. Degradation caused by snail trails in power output of PV modules

Serial number of Modules	Vm(V)			Im(A)			Pmax(W)		
	Before delivery	With snail trails	Degradation rate (%)	Before delivery	With snail trails	Degradation rate (%)	Before delivery	With snail trails	Degradation rate (%)
199BC2EB0	36.52	35.12	-3.83	5.09	4.804	-5.62	185.82	168.72	-9.2
199BC2EB2	36.89	35.47	-3.85	5.04	4.786	-5.03	185.96	169.78	-8.7
199BC567A	36.36	35.43	-2.56	5.06	4.691	-7.28	183.66	166.21	-9.5
199BC5408	36.44	35.29	-3.16	5.07	4.768	-5.95	184.92	168.28	-9.0

4. Conclusions

According to some papers, the darkened lines of snail trails mainly consist of metallic silver nanoparticles. These authors considered that the silver in snail trails stemmed from the Ag fingers of solar cells. However, through lots of experiments and analysis, the content of Ag in silver fingers had none difference between affected and non-affected fingers. So in this work, a proposed model is that the source of metal silver in snail trails is not from the silver fingers but the impurities (silver phosphate) of additives in EVA. Silver phosphate impurities in EVA were added by chance in the process of manufacture of EVA. Because the existence of silver phosphate in EVA is accidental, so the snail trails is an accidental phenomenon. So this work can explain why the snail trail is not a common phenomenon. Micro-cracks were not a key factor for snail trails. The impurities would undergo some chemical reactions and finally form the darkened silver nanoparticles which are visible to the naked eyes. And the procedure of the snail trail's formation would be accelerated under high temperature, intense incident light and other factors. The results show that the snail trails affect power output for crystalline silicon solar modules, the energy production measured was about 9.1% lower than the common modules. Owing to the snail trails above solar cells are dark, this influence on power output mainly results from the reduction of irradiance absorbed by solar cells.

Acknowledgements

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Biography

He Wang was born in China on May 1969. She received her BS degree in the department of physics from the National University of Defense Technology in 1991 and MS degree in Microelectronics Engineering from Xidian University in 1994. She received her PhD degree in 2005 from Xi'an Jiaotong University. She is working in the Institute of Solar Energy of Xi'an Jiaotong University. Her research interests lie in photovoltaics.