Classification and Inspection Methods of Cracks in Photovoltaic Cell -- Induced by Transportation Vibration

Yi-Ting Chen [a], *Kuang-Han Ke* [a], *Shu-Tsung Hsu* [b], *Tsung-Chun Hsu* [a], *Yean-San Long* [b]

[a] Gran Systems Co., Ltd., Taipei, Taiwan, 110, info@gransystems.com

[b] Industrial Technology Research Institute, Hsin-Chu, Taiwan, 300

Abstract

Photovoltaic cells (PV cells) and modules are sent to customers worldwide. The vibration by different transportation modes might induce cracks and crack propagation, making micro scale crack larger in the millimeter or larger scale. These larger cracks affect the solar cell product quality and performance. Classification of these cracks and understanding of ones is very important for the ability to define higher-quality and better-yielding PV cell products. Crack observation tools and inspection methods in the manufacturing lines, en-route transportation and customer site are discussed. Related crack propagation mechanism is also addressed.

Introduction

It was found that shipping damage is always one of the top PV failure issues in the field. This calls for detailed research by the SEMI Standards PV Vibration Test Method Task Force [1]. In this program, it shows that cell breakage mostly depends on the stresses induced in the processing, handling and transportation, and the presence of defects such as micro-cracks. Thus, detail study and inspection tool of micro-cracks is necessary to be developed.

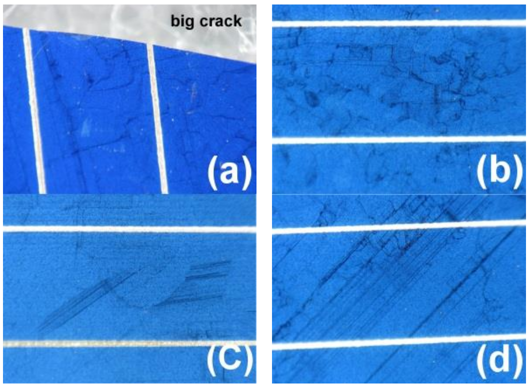

Figure 1

Microscopic Image Analysis

After the vibration experiment [1], we looked at the broken cells in detail. In Figure 1-(a), micro-cracks extending out from the major crack/breakage. The finding of these micro-cracks is important. After external excitation and stress, it might lead to big crack or even cell breakage, according to previous paper [2]. Figure 1-(b) shows a very clear picture of vibration-resulted cracks and micro-cracks of several-teens of μm wide. These cracks were not there before the vibration. Figure 1-(c) is a clear image to see scratches on PV cells. These scratches might be caused by friction between cells. In Figure 1-(d), we can also see scratches and micro-cracks co-exist in the same photograph, therefore we caution that these scratches might potentially have some contribution to micro-cracks, if cells are mishandled. Figure 1-(a), (b), and (d) were previously not noticed in production lines.

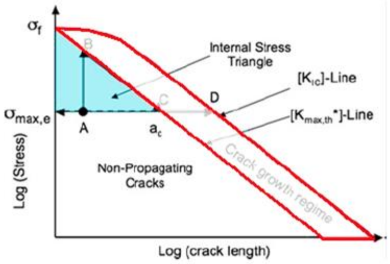

Figure 2 Modified Kitagawa Diagram [3] for Fatigue – Describing the Point at Which a Crack Becomes a Propagating Crack.

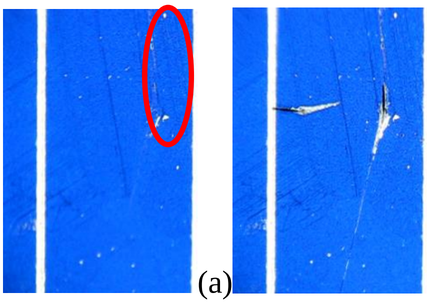

Figure 3 (a) A crack is shown. (b) A crack propagated. There is a big chipping lying beside the crack.

Crack Definition and Classification

Through above image analysis, we can see many different cracks. How to define these cracks and classify them is very important for the ability to define better quality and higher yield PV cell products. Therefore, to define a crack or micro-crack, one must first describe by

(1) its length and width; a non-visible crack of < ~30-50 μm is called micro-cracks.

(2) single simple crack, branch, multiple branches, tree-like cracks, web-like cracks, shatter-like cracks, etc.;

(3) point defect, fissure, line cracks, angled cracks, zig-zag cracks, curved cracks, etc.

Based on typical industry quality control specification, we progress further with a draft classification. (Table 1)

Item	Specification	Classification
Break	Unacceptable	Major
Crack	Unacceptable	Major
Chip	Length≦X mm, Depth≦Y mm ≦Z per wafer; V-shape chip unacceptable	Major
Crystallinity	Multi-crystalline	Major
Micro-grain	【1】Grain≥nXn mm^2 【2】If grain<nXn mm^2， Area≤n^2cm^2	Major
Scratch	Free	Minor
Surface quality	As cut, cleaned contamination free	Minor
Saw mark	≦XX μm	Minor

Table 1 Classification of Defects of PV Cells - Typical Quality Control Specification

Crack Propagation Mechanism

According to Sadananda, et. al. [3], a crack or micro-crack will remain dormant when the threshold stress is not reached. For a given material, the modified Kitagawa diagram in fatigue (Figure 2), defines the conditions under which a crack initiated at the threshold stress becomes a propagating crack, by satisfying the threshold stress intensity. The processes underlying the crack nucleation and the crack growth of a material require building up of internal stresses by local plasticity. The process involves crack tip blunting and micro-crack nucleation until the crack becomes unstable under the applied stress.

An example of crack propagation is presented. Before the application of stress, a crack on the PV cell is represented in figure 3-(a), correspond to state A in figure 2. As mention above, direct AC state transition path in figure 2 is not allow. The stress would be piled up until the threshold stress is reached. When the stress overcome the threshold stress, corresponding to state B in figure 2, the crack burst out just in a sudden, reaching state C, as shown in figure 3-(b). The crack propagation follows the path ABC in figure 2. Its behavior conforms to the physics mechanism illustrated in Modified Kitagawa Diagram.

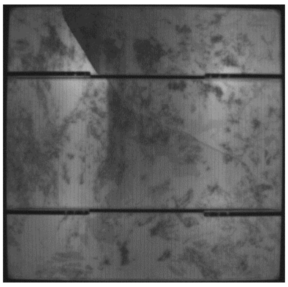

Figure 4 EL image of a break PV cell

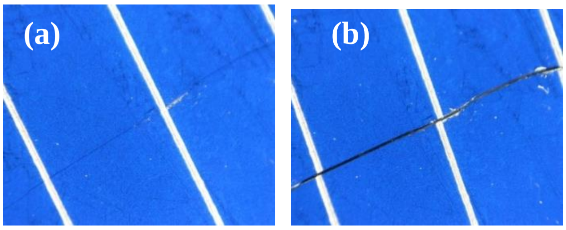

Figure 5 Broken cell suspects

Inspection Tool (Electroluminescence + Optical microscope)

Electroluminescence (EL) is widely adopted by factory as a quality verification tool. Both breakages and defects are plainly visible under EL (Figure 4). But revealing apparently breakages is not enough. In figure 5-(a), a micro-crack is stretching from the upper right to the bottom left, with about 5μm in width which is invisible to naked eye or even EL but visible to OM. As remote stress applied, stress piles up around the micro crack. When the threshold is reached, PV cell breaks (Figure 5-(b)).

In transportation, PV cells are subjected to vibration, clash, and shock. If stress is higher than the threshold, which is very likely to happen, PV cells would break, just like the case in figure 5-(a), (b). This experiment provides evidence that not only cracks can influence the performance of PV cells, micro cracks, typically invisible to EL, may also result in non-negligible damages and cause considerable losses.

EL has now been commonly used in the PV industry due to its high-speed, which can meet the standard of industry requirement. But the disadvantage is its inability of detecting detailed condition of PV cell. For example, it cannot explore micro-cracks, which can lead to potential breakage.

We recommend an inspection method combining the convenience of EL and optical microscopy (OM) into a tool set, because they are readily available in the factory floor and can provide both the speed (by EL) and the high magnification in finding defects on the PV cells (by OM). However, the non-mobility of the OM makes this inspection method not able to be implemented across solar production lines, with the same reference method from wafer to cells and module production lines. Hence, we introduce the portable digital microscope to resolve this problem.

Portable Digital Microscope

Portable digital microscope (Figure 6) is one type of OM. The main feature is that it provides mobility while also with good magnification (300X). At this magnification, the minimum-size crack on PV cells we can see is down to ~1.5μm in width. These micro-cracks are very likely to be the factor leading to cell breakage, especially when micro-cracks can propagate into larger cracks under stress.

It can serve as a consistent and convenient crack observation and inspection tool set from wafer, cell, and module production lines to field implementation, during en-route transportation to customer site, and after installation. This is a good tool to assist the existing EL and PL methods used in current PV cell factories.

Figure 6 Portable digital microscope

Automatized Crack Inspection

Crack location and analysis are laborious works which takes a lot of time and manpower. Small cracks and micro-cracks are apt to be overlooked. The difficulty of crack identification lies in the intense blue color (Figure 7-(a)), which is the nature of PV cells, reducing contract between cell surface and cracks. Also, the spot texture of PV cells sometime lead to misjudgment. By image processing and establishing selection rules, automatized inspection is realized (Figure 7-(b)).

By image process algorithm, not only the cracks are located, but the information of crack size and shape are also obtained. These crack information can be used to classified cracks, using the criterion mentioned in crack classification section. Furthermore, instead of analyze images and evaluate PV cell one by one, a large amount of crack inspection works can be done in a short time using this algorithm, saving a considerable amount of time and money.

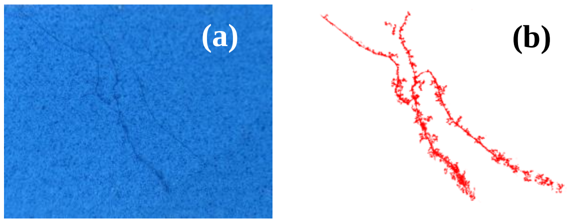

Figure 7 Illustration of image processing

Conclusions

In this paper, crack classification is made, which is important to define better quality and higher yield PV cell products. Experiments are done to verify that micro-cracks do induces crack propagation and serious breakages. EL, serving as a common tool for crack inspection, typically doesn't have ability to detect these crack scale. We propose a method combing EL and portable OM, making a good solution. Automatization of crack inspection is also proposed, which has potential for high speed crack inspection, classification and quality quantification.

Reference

[1] Kuang-Han Kea, Shu-Tsung Hsub, Tsung-Chun Hsua, Kun-Da Leec, Yean-San Long *China PV Technology International Conference* (2012)

[2] Tanga C.A., Koub S.Q., *Engineering Fracture Mechanics* **61** 311-324 (1998)

[3] Sadananda K., Vasudevan A.K., *Metallurgical and Materials Transactions A* **42A** 296-303 (2011)