

SEMI PV94-0420

GUIDE FOR IDENTIFYING CELL DEFECTS IN CRYSTALLINE SILICON PHOTOVOLTAIC (PV) MODULES BY ELECTROLUMINESCENCE (EL) IMAGING

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1 Purpose

- 1.1 At several points in their manufacturing and installation process photovoltaic (PV) modules need to be tested regarding their performance and potential defects.
- 1.2 Such tests may be necessary to be performed during the life cycle of a module.
- 1.3 Testing modules or individual cells of them by electroluminescence (EL) imaging is a well-known method for detecting cell defects.
- 1.4 The quality of the images obtained by EL imaging depends critically on the appropriate application of this method.
- 1.5 Therefore this Guide provides users directions how to appropriately apply EL imaging of crystalline silicon PV modules.
- 1.6 It provides also guidance for the inspection of crystalline silicon PV modules regarding cell defects using EL imaging as well as for classifying the defects.

2 Scope

- 2.1 This Guide provides guidance for the inspection of crystalline silicon PV modules regarding cell defects using EL imaging.
- 2.2 This Guide also classifies the most common cell defects.
- 2.3 It is suitable for identifying cell defects in crystalline silicon PV modules indoor.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

- 3.1 None.

4 Reference Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI E89 — Guide for Measurement System Analysis (MSA)

4.2 IEC Standard¹

IEC 61215-2:2016 — Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures

4.3 ISO Standard²

ISO 12233:2014 — Photography – Electronic Still Picture Imaging – Resolution and Spatial Frequency Responses

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NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 Refer to the SEMI Standards Compilation of Terms (COTs) for a list of the current Abbreviations, Acronyms, Definitions, and Symbols.

5.2 *Abbreviations and Acronyms*

5.2.1 *EL* — electroluminescence

5.2.2 *PV* — photovoltaic

5.3 *Definitions*

5.3.1 *electroluminescence (EL)* — radiation emitted by a *p-n* junction under forward or reverse bias.

5.3.2 *defect* — the observed unwanted characteristics of PV module by EL inspections, such as concentric circles, black edges, dark spots, bright spots, cracks, and finger interruptions.

5.3.3 *defect recognition* — to distinguish and mark the characteristics of defects in EL images.

5.3.4 *exposure time* — the time for which the image sensor is exposed to the electroluminescent light from the PV module.

5.3.5 *forward current* — current flow from positive electrode of a PV module to the negative.

5.3.6 *imaging time* — the time from beginning of test to the displaying of a PV module EL image.

5.3.7 *pixel* — physical unit on the image sensor that is photosensitive.

5.3.8 *micro-crack* — micro cleavage or fracture in a cell which is mainly caused by bending or impact during manufacturing, transportation, or installation, etc.

5.3.9 *micro-defect* — the defects that cannot be identified by the naked eye, but can be observed by electroluminescence, such as micro-cracks, scratches, finger interruption, etc.

5.3.10 *stray light* — any other light source except electroluminescence that can influence the imaging results.

5.3.11 *test plane* — between the camera's test lens and the object under test, the light is transmitted through the surface, it means the glass pane on the front face of the module.

6 Summary of Test Method

6.1 The radiation emitted by a PV silicon module under forward bias is recorded by an infrared sensitive camera.

6.2 In the EL image, the defective part of the module will be darker than the active part which indicates the defects of the module.

6.3 Brief EL inspection procedure flow chart shown in Figure 1.

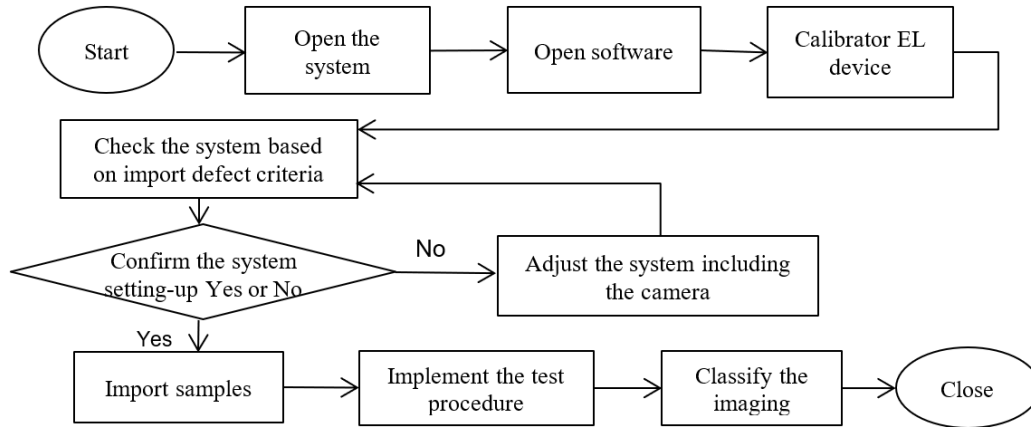


Figure 1
Summary EL Inspection System

7 Apparatus

7.1 Composition of EL Inspection Equipment — The schematic diagram of EL detection device is shown in Figure 1, which mainly includes the following parts:

7.1.1 Imaging Lens — EL imaging lens must avoid absorption of the spectral band of EL by PV module. For high-quality images, light with wavelength less than 850 nm shall be cut off by using filters or coating.

7.1.2 Imaging Detectors — Detectors must respond to light with wavelength more than 850 nm which is the electroluminescent band of the PV module.

7.1.3 DC Power Supply — DC power supply provides forward current to the PV module, capable of applying I_{sc} of the module or a serial string of modules of interest. Typically the DC power supply must be capable of applying short-circuit current I_{sc} of the PV module under standard test conditions.

7.1.4 Dark Room — It used to eliminate any stray light. Dark room imaging studio may be the box structure of the device itself, blackout curtains or an external dark environment.

7.1.5 Operating Software — The operating software used for controlling the operations of an EL inspection for a PV module, such as the powering on and off of DC power supply, the exposure control of imaging system (including imaging lens, imaging detectors, dark room, etc.), movement of PV module and imaging system.

7.1.6 Image Processing Software — The image processing software is used to process the signal of EL by PV module obtained by imaging detector. The grayscale is commonly used for an EL inspection equipment to represent the signal level measured by detector. Low EL signal shall be represented by low brightness (towards black) and high EL signal in the image shall be represented by high brightness (towards white).

7.1.7 Image Displaying System — Image display system is used to display the detected image. Basic software features include displaying, enlarging, cropping, and rotating, level range adjustment.

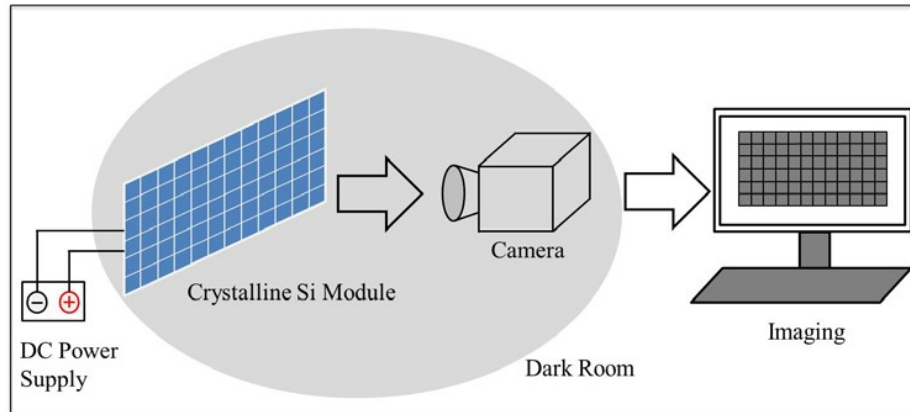


Figure 2
Diagram of EL Inspection Equipment

7.1.8 *Performance of EL Inspection Equipment* — Flow chart as Figure 3:

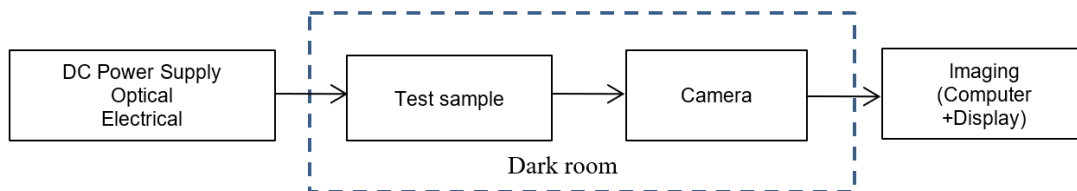


Figure 3
EL Inspection Equipment

7.1.9 *Pixel Resolution* — The pixel resolution refers to the total count of pixels in EL image of a PV module. The number of rows, M , is the height of the image. The number columns, N , is the width of the image. Then its resolution can be defined as $M \times N$. For comparisons of EL images, the pixel resolution of the EL image would be better of similar classification. The following two classifications are given for these categories:

Table 1 Classification of Pixel Resolution

Class	Pixel Resolution (R_p)
A	$R_p \geq 8,000,000$
B	$2,000,000 \leq R_p < 8,000,000$

7.1.10 *Spatial Resolution* — The spatial resolution refers to the ability to distinguish details. For the same field of view, the smallest distinguishable size of feature corresponds to the highest spatial resolution. There are many ways to characterize the spatial resolution.

7.1.10.1 For easier comparison, Line pair patterns with a single line stripe or line pair (lp) stripes which have equal width and continuous arrangement of black and white can be used for testing the spatial resolution of EL defects detection system. Therefore the spatial resolution can be expressed in line pairs per millimeter (lp/mm)

7.1.10.2 Generally speaking, the spatial resolution does not correspond to the pixel resolution due to differences in imaging systems and optical designs, according to ISO 12233 Annex H, which confirm the lp/mm classification. For comparisons of EL images, the worst result is used for rating. The spatial resolution of the EL image would better be of similar classification. The following two classifications are given for these categories:

Table 2 Classification of Spatial Resolution

Class	Spatial resolution (R_s) for $2.0\text{ m} \times 1.0\text{ m}$ field of view R_s (lp/mm)
A	$R_s \geq 0.5$
B	$0.25 \leq R_s < 0.5$

7.1.11 The total system class rate is the worse classification between Pixel Resolution and classification of Spatial Resolution works as the whole classification rate. Such as, which can be divided into four types: AA, AB, BA, BB, and the worst combination of four types as the final level of the device.

7.1.12 *Grayscale Resolution* — Grayscale resolution is the performance of EL inspection equipment for image recognition of different brightness.

7.1.13 *Contrast Ratio* — Contrast ratio represents the brightness difference of image. Parameters (such as forward current, exposure time, aperture of camera) of an EL inspection equipment which would better be appropriately adjusted for getting the EL image of a PV module without saturation. Normally, the highest brightness of EL images would be better not exceeding 80% of the saturation value of imaging detector and the lowest brightness is not less than 5%.

7.1.14 *Forward Current* — Forward current applied is usually in constant current operating mode.

7.1.15 Forward current can be divided into high current and low current. Generally, high forward current means the bias current of the PV modules connected equals to the short-circuit current under STC.

7.1.16 Low forward current refers to the bias current of the PV modules connected equals 0.1 to 0.3 times to the short-circuit current under STC. The power supply must be capable of setting (0.1 to 1.0) times of short-circuit current (I_{sc}) and 1.0 times of the open circuit voltages (V_{oc}).

7.1.17 *Exposure Time* — Exposure time must be adjusted to meet the image quality and detection efficiency.

7.1.18 *Imaging Time* — The imaging time must meet the requirements of detection efficiency. For mass production line of PV modules the imaging time of an EL inspection equipment should ideally be less than 30 s.

7.1.19 *Test Plane* — The test plane of an EL inspection equipment, where modules fixed must be clean, free of obvious scratches and foreign bodies.

7.1.20 *Imaging Angle* — The optical axis of the imaging camera shall be normal to the test surface of the PV module within $90^\circ \pm 1^\circ$.

7.1.21 *Image Stitching* — The EL image of a PV module can be obtained by stitching multiple images of the PV module; however the image stitching method shall not miss or distort information or miss identify defects.

7.1.22 *Image Information* — For comparison of EL images, information of component serial numbers, testing conditions such as, forward current values, exposure time and other notes are required.

7.1.23 *Image Orientation* — For easier comparison, the orientation of EL images is required to be consistent with human observation and the location of junction box is also required.

8 Safety Precautions

8.1 *Mechanical Safety* — If a separate cover shield is used in the EL defects detection system, the movement of the cover shield would better be made to avoid injuries to personnel. Do not endanger hands and head when opening and closing the cover shield.

8.2 *Electrical Safety* — The power supply has to be switched off before removing electrical connections to the module.

8.3 Make sure that the positive pole of the sample to be tested is connected to the positive pole, negative pole of sample to the negative pole of the power supply.

8.4 When using the system outdoors to test the power station, keep the camera in safety box and ensure the camera can take images.