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TECHNICAL SPECIFICATION

colour inside

Photovoltaic cells –
Part 2: Electroluminescence imaging of crystalline silicon solar cells

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CONTENTS

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PHOTOVOLTAIC CELLS –

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IEC TS 63202-2 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
82/1912/DTS	82/1951/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 63202 series, published under the general title *Photovoltaic cells*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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PHOTOVOLTAIC CELLS –

Part 2: Electroluminescence imaging of crystalline silicon solar cells

1 Scope

This part of IEC 63202 specifies methods to detect and examine defects on bare crystalline silicon (c-Si) solar cells by means of electroluminescence (EL) imaging with the cell being placed in forward bias. It firstly provides guidelines for methods to capture electroluminescence images of non-encapsulated c-Si solar cells. In addition, it provides a list of defects which can be detected by EL imaging and provides information on the different possible methods to detect and differentiate such defects. When EL imaging alone cannot provide conclusive information for the presence of a type of defect, suggestions are also made to utilize a combination of other methods.

Finally, this document provides some information on potential effects when using cells with specific EL features in module assembly. Although this document mainly addresses bare c-Si solar cells, it is generally applicable to all wafer solar cell technologies.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC TS 60904-13:2018, *Photovoltaic devices – Part 13: Electroluminescence of photovoltaic modules*

IEC TS 61836:2016, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC TS 62446-3, *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 3: Photovoltaic modules and plants – Outdoor infrared thermography*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836, together with the following, apply.

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
electroluminescence
EL
light emission by radiative recombination of excited charge carriers in a semiconductor device resulting from electrical voltage applied to the semiconductor in forward bias

3.2
open circuit
for a given terminal pair, electric circuit without a continuous path between the two terminals of the pair

Note 1 to entry: A cell exhibits an “open circuit” if defective or damaged so that no current can flow through it when attached to an external circuit at the cell electrical connection points.

Note 2 to entry: A PV cell itself is in open circuit condition if one or all of the cell electrical connection points are not connected to electrical terminations or current is not flowing as defined in IEC TS 61836:2016,3.4.56.

3.3
forward bias
forcing current flow with a power supply where the leads are connected to those of the same polarity (+ and -) on the solar cell

3.4
barrel distortion
geometric distortion of a rectangular raster causing its boundaries to appear convex

3.5
vignetting
reduction of an image's brightness at the periphery compared to the image centre caused by the lense of the imaging system

3.6
dynamic range
DR
ratio between the maximum output signal level and the noise floor

Note 1 to entry: Noise floor is the root mean square noise level in a black image.

3.7
sharpness
S
minimum real dimension from the darkest black to the point which could provide a contrast of 50 % over the brightest white in terms of EL brightness

Unit: mm

Note 1 to entry: The sharpness is used as the index of the resolvable object size.

3.8
gray-scale value
numeral used to define the different levels between the brightest white and the darkest black

Note 1 to entry: EL images will correspond to a weighted average value (mean gray value).

3.9
modulation transfer function
MTF
ratio of contrast of input images over the output image’s contrast

Note 1 to entry: MTF is a function of spatial frequency.

Note 2 to entry: MTF is applied to evaluate the resolution of the images in terms of frequency over the test area.

Note 3 to entry: MTF is also referred to as spatial frequency contrast sensitivity function.

3.10
field of view
FOV
area of a scene that is imaged on the camera sensor

Note 1 to entry: The geometry of a field of view is usually rectangular and corresponds to the camera sensor shape.

3.11
angle of incidence
angle between the normal to the reference surface of the FOV (the cell) and the camera optical axis

3.12
angle of view
maximum angle between any two incident rays from the detector camera to any arbitrary points on the FOV

Unit: dimensionless, usually expressed in degrees

Note 1 to entry: FOV describes the angular extent of a given scene that is imaged by a camera.

4 Imaging

4.1 Apparatus

4.1.1 General

A general description of an EL imaging system and its required apparatus is given in this clause. Figure 1 shows a typical setup for EL imaging. It consists of a camera detector with appropriate lens or filters that senses the EL emission from the device under test, a power supply connected to the DUT which injects current into it for EL emission, a dark chamber that reduces stray light from ambient and a computer that controls all the components. Under normal test conditions, the device under test shall be forward biased in the dark such as to achieve a current flow, similar to the AM1.5G short-circuit current. The resulting radiative recombination causes a light emission of the cell which is captured by the camera detector.

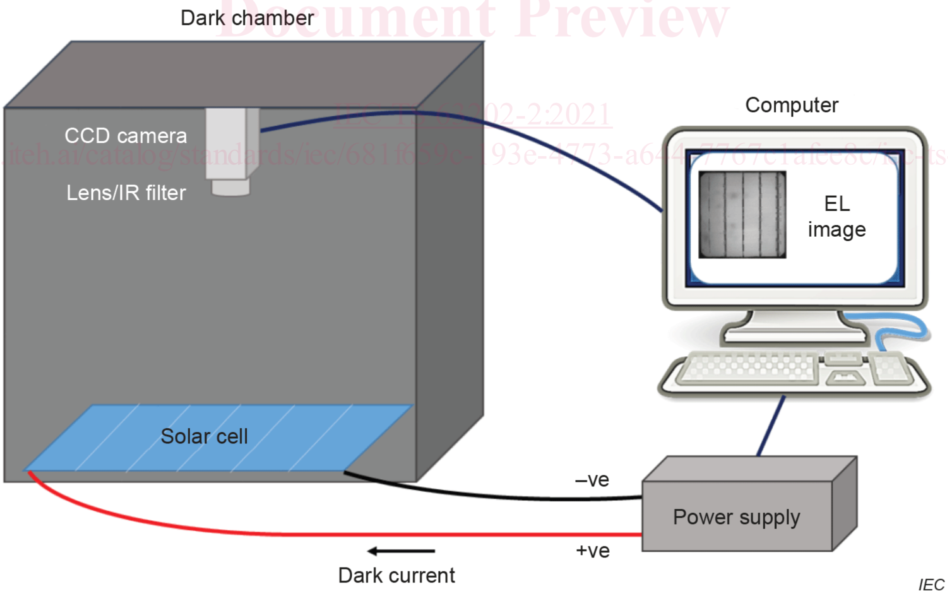

Figure 1 – Typical setup of an electroluminescence imaging system

4.1.2 Electroluminescence imaging camera

4.1.2.1 Camera detector

Detectors are typically light-sensing pixels consisting of charge coupled devices (CCD) or complementary metal oxide semiconductor (CMOS) devices arranged in a focal-plane array. To achieve better signal-to-noise ratio (SNR) by means of reducing device dark current originating from thermally generated charges, they may be cooled, usually with thermoelectric cooling. Semiconductor light absorber materials in the detector shall be sensitive to the EL emission of the device under test. For crystalline silicon the detector shall be sensitive in the wavelength range between 900 nm and 1 100 nm and able to achieve SNR_{50} of 45 or better, determined using the method detailed in IEC TS 60904-13:2018,4.3. An example image with SNR_{50} of 45 is given in Figure 2. Images with SNR_{50} below 45 are not suitable to be qualitatively interpreted. Determined SNR for images obtained shall be reported per Clause 6.

SNR_{50} = 45

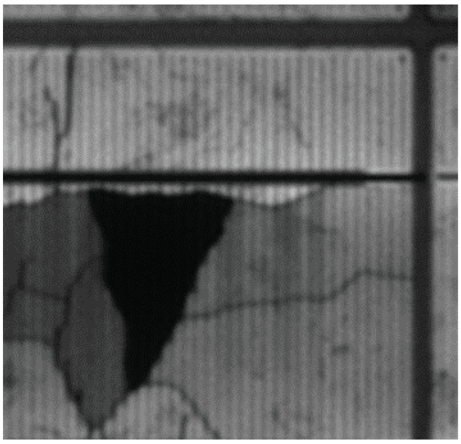

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Figure 2 – Image of multi-crystalline silicon solar cell with SNR_{50} value of 45

4.1.2.2 Lens

Lenses shall be free of absorption filters or coatings that remove the infrared near the band-gap of the semiconductor material to be examined. For crystalline silicon this means: wavelengths between 900 nm and 1 100 nm shall not be attenuated by absorption filters or coatings. Optical glass is generally suitable when measuring Si based solar cells. Lenses vary from telephoto to wide-angle in focal length. Choices will depend on the specific application and geometric considerations when capturing the image. Wide-angle lenses that have short focal lengths used in conjunction with the higher resolution cameras capture a larger FOV. The camera may be placed much closer to the solar cell under test, which is useful when space is a consideration. Some wide-angle lens optics, however, may cause undesirable barrel distortion in the images that will require correction by post-processing.

Lenses with longer focal lengths generally have less barrel distortion and can therefore more accurately image a solar cell, in which case the resulting images may not require correction by post processing. Lenses may feature components that correct for the difference between visible and infrared wavelengths, which can facilitate focusing.

NOTE Lenses typically have adjustable aperture with their size generally referred to by a *f*-number. Ignoring differences in light transmission efficiency, a lens set to a greater *f*-number has less light gathering area and projects less electroluminescence signal to the image sensor. Depth of field increases with increasing *f*-number. Image sharpness is related to *f*-number through two different optical effects; aberration, due to imperfect lens design, and diffraction, which is due to the wave nature of light. Many wide-angle lenses will show significant vignetting at the edges when using a smaller *f*-number.

4.1.2.3 Filters

Filters on the camera lens may be used to help cut light of extraneous wavelengths from being detected. Long-pass filters above 850 nm may be used when imaging near band-edge EL from silicon.

4.1.3 Dark room imaging studio or environment

While not mandated, a darkened environment is favoured for high quality images. Precautions should be taken to eliminate stray light entering the imaging studio, such as with use of hard walls, curtains, baffles, and sealing of any gaps with material that are of light absorbing nature (black). If a filter is used on the camera, then LED lighting may be used that emits light only in