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Edition 1.1 2020-10
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INTERNATIONAL STANDARD

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colour inside

Measurement procedures for materials used in photovoltaic modules – Part 1-4: Encapsulants – Measurement of optical transmittance and calculation of the solar-weighted photon transmittance, yellowness index, and UV cut-off wavelength

Procédures de mesure des matériaux utilisés dans les modules photovoltaïques – Partie 1-4: Encapsulants – Mesurage du facteur de transmission optique et calcul du facteur de transmission photonique à pondération solaire, de l'indice de jaunissement et de la fréquence de coupure des UV

IEC 62788-1-4:2016-09+AMD1:2020-10 CSV(en-fr)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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IEC 62788-1-4 edition 1.1 contains the first edition (2016-09) [documents 82/1148/FDIS and 82/1165/RVD] and its amendment 1 (2020-10) [documents 82/1767/FDIS and 82/1791/RVD].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

International Standard IEC 62788-1-4 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

A list of all parts in the IEC 62788 series, published under the general title *Measurement procedures for materials used in photovoltaic modules*, can be found on the IEC website.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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MEASUREMENT PROCEDURES FOR MATERIALS USED IN PHOTOVOLTAIC MODULES –

Part 1-4: Encapsulants – Measurement of optical transmittance and calculation of the solar-weighted photon transmittance, yellowness index, and UV cut-off wavelength

1 Scope

This part of IEC 62788 provides a method for measurement of the optical transmittance of encapsulation materials used in photovoltaic (PV) modules. The standardized measurements in this procedure quantify the expected transmittance of the encapsulation to the PV cell. Subsequent calculation of solar-weighted transmittance allows for comparison between different materials. The results for unweathered material may be used in an encapsulation manufacturer's datasheets, in manufacturer's material or process development, in manufacturing quality control (material acceptance), or applied in the analysis of module performance.

This measurement method can also be used to monitor the performance of encapsulation materials after weathering, to help assess their durability. The standardized measurements are intended to examine an interior region within a PV module, e.g., without the effects of oxygen diffusion ~~around the edges~~ at the periphery of the cells. Subsequent calculation of yellowness index allows for quantification of durability and consideration of appearance. The change in transmittance, yellowness index, and ultraviolet (UV) cut-off wavelength may be used by encapsulation or module manufacturers to compare the durability of different materials.

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 60904-3, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

ISO 291:2008, *Plastics – Standard atmospheres for conditioning and testing*

ISO 11664-1:2007, *Colorimetry – Part 1: CIE standard colorimetric observers*

ISO 11664-2:2007, *Colorimetry – Part 2: CIE standard illuminants*

ISO 13468-2:1999, *Plastics – Determination of the total luminous transmittance of transparent materials – Part 2: Double-beam instrument*

ISO 17223:2014, *Plastics – Determination of yellowness index and change in yellowness index*

ASTM E424-71:2007, *Standard test methods for solar energy transmittance and reflectance (Terrestrial) of sheet material*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

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

NOTE In cases where definitions already exist, refer to IEC TS 61836. Calculations related to these definitions are given in Clause 8.

3.1
solar-weighted transmittance of photon irradiance
proportion of the solar spectral photon irradiance ($E_{p\lambda}$, $m^{-2}\cdot s^{-1}\cdot nm^{-1}$) optically transmitted through the specimen, throughout the range of the terrestrial solar spectrum (280 nm to 2 500 nm) (see Table 1)

Note 1 to entry: The photon irradiance ($E_{p\lambda}$, $m^{-2}\cdot s^{-1}\cdot nm^{-1}$) accounts for the wavelength-specific energy of the optical flux and should not be confused with spectral irradiance (E_{λ}, $W\cdot m^{-2}\cdot nm^{-1}$).

3.2
representative solar-weighted transmittance of photon irradiance
proportion of the solar spectral photon irradiance ($E_{p\lambda}$, $m^{-2}\cdot s^{-1}\cdot nm^{-1}$) optically transmitted through the specimen, throughout the range of the terrestrial solar spectrum (300 nm to 1 250 nm) (see Table 1)

Note 1 to entry: In the case of a PV device, the representative solar-weighted transmittance of photon irradiance is defined throughout the range of the spectrum utilized by a representative PV device (which may not include wavelengths as low as 280 nm or as great as 2 500 nm).

3.3
UV cut-off wavelength
λ_{cUV}
wavelength of light below which the encapsulation is considered optically absorbing and above which the encapsulation is considered transmitting

Note 1 to entry: In this procedure, the absolute transmittance of 10 % (corresponding to the optical absorbance of 1) is considered as the threshold of the UV cut-off wavelength. As described further in [9][1], the UV cut-off wavelength may also be used to quantify the effects of weathering.

3.4
weathering
process of subjecting specimens to environmental conditions that could include ultra-violet radiation, temperature, humidity, and ozone

Note 1 to entry: Weathering may occur in artificial or natural environments. Weathering could occur at the nominal (field) or an accelerated rate.

3.5
yellowness index
YI
calculated value identifying the yellowness of the test specimen perceived by a human observer (see ASTM E313-10)

Note 1 to entry: *YI* may be used to quantify the effects of weathering.

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1 Numbers in square brackets refer to the Bibliography.

4 Principle

The total spectral transmittance of laminated specimens, containing encapsulation material, shall be measured using a spectrophotometer equipped with an integrating sphere. Solar-weighted transmittance, yellowness index, and UV cut-off wavelength will be subsequently calculated from the transmittance measurements.

The transmittance measured using this procedure may be used in a more advanced optical analysis to improve the accuracy of PV performance analysis or distinguish between different encapsulation materials, as described in Annex A. The transmittance measured using this procedure may be used to estimate module performance (current yield) if the quantum efficiency of the PV cell is known, as described in Annex B. The method does not attempt to account for variations in transmittance with the angle of incidence, which may vary with time of day, sky conditions, and geometry of the module, especially if optical concentration is used.

5 Apparatus

The test instrument shall consist of a double beam spectrophotometer equipped with an integrating sphere. A single beam spectrophotometer may be used if the port reflectance can be properly accounted for, as in Annex A and [2]. Details regarding the construction and configurations of the test instrument may be found in ISO 13468-2 or ASTM E424-71. A measurement range of at least 280 nm to 2 500 nm is required for calculation of the solar-weighted transmittance using the AM1.5 global spectrum as in IEC 60904-3. A wavelength increment no larger than 1 nm is preferred for the measurement, however increments up to 5 nm are permitted with linear interpolation to 1 nm.

An integrating sphere of at least 100 mm in diameter with a port area of < 5 %, as in [11], is recommended to reduce the error in the measurement. The port area as in [9] should not exceed 13 %.

6 Test specimens

6.1 Nominal (and unweathered) transmittance to the cell

Specimens shall be constructed using a laminate structure of glass/encapsulation, as described in Annex A and [12].

The solar-weighted transmittance and representative solar-weighted transmittance, as calculated in Clause 8, may be used for the purpose of reporting on an encapsulation manufacturer's datasheet.

The specimens shall contain an examination region free from visible flaws including: scratches, pits, sink marks, bubbles, or other imperfections. The examination region shall be at least 50 % larger in diameter than the measurement area of the test instrument.

NOTE 1 A spot size of 1 cm × 1 cm is common in many commercial spectrophotometer instruments. Use of specimens at least 2 to 3 times this size will improve uniformity (resulting from fabrication) and handling (during measurement).

The size (length and width) should be adequate to allow the specimen to fit inside the test instrument.

The nominal thickness of the ~~encapsulation~~ encapsulant specimens shall be equal to the thickness intended for use in PV modules.

Specimens should be cured (if applicable) according to the manufacturer's specification and using a process as similar as possible to the method used in the intended manufacturing process.

The thickness of the encapsulation portion of the test specimen shall be measured after its preparation. The thickness shall be taken as the average of three measurements obtained at different locations on the test region of the specimen.

Glass plates shall be parallel with minimal edge pinch or edge flare. I.e. the encapsulation thickness at any of the corners shall not be more than 10 % different than that in the centre of the sample. In a typical bag laminator this will require the use of a frame around the samples during lamination, but any other means of accomplishing this specification is acceptable.

The back surface of the specimens (the exposed encapsulation intended to face to the integrating sphere) shall not be intentionally textured.

For additional resolution to more accurately distinguish between materials, subsequent studies may utilize a thicker encapsulation layer that may be analysed to determine the optical attenuation coefficient as described in Annex A.

If the encapsulation material is intended to be used with superstrates other than glass, the same procedure may be used in a subsequent study. Specimens using polymeric superstrates may be prone to optical polarization occurring within the instrument. As in [9] and [12], a depolarizer should be used with the instrument to minimize the effects of polarization.

NOTE 2 The effect of haze in specimens prone to optical haze can be mitigated through the use of a diffusing film, as described in [13].

6.2 Weathering studies

A glass/encapsulation/glass laminate specimen geometry is recommended.

The size (length and width) should be adequate to allow the specimen to fit inside the test instrument.

~~As described in [14], the minimum size of 5 cm × 5 cm is recommended for weathering specimens based on previous examinations of poly (ethylene-co-vinyl acetate).~~

The minimum size of 7,5 cm × 7,5 cm is recommended for weathering specimens based on previous examinations of poly (ethylene-co-vinyl acetate).

Large specimens are preferred in weathering studies, because a test region may be distinguished, where the diffusion of oxygen or moisture is limited.

Other geometries may be used with this procedure to evaluate the effects of weathering. For example, a permeable polymeric backsheet facilitates the examination of moisture ingress. Some PV modules make use of an edge seal to reduce moisture permeation.

Separate “blank” pieces of superstrate or substrate may be weathered with the test specimens to quantify the degradation of those components.

The specimens shall contain an examination region free from visible flaws including: scratches, pits, sink marks, bubbles or other imperfections. The examination region shall be at least 50 % larger in diameter than the measurement area of the test instrument.

The nominal thickness of the ~~encapsulation~~ encapsulant specimens shall be as intended for use in the PV module. Specimens should be cured (if applicable) according to the manufacturer’s specification and as similar as possible to the method used in the intended manufacturing procedure.

The thickness of the encapsulation in the laminate may be controlled by inserting a removable material around the specimen perimeter.

6.3 Glass for superstrates/substrates

Measurements of the nominal (unweathered) transmittance to the cell for the purpose of encapsulation manufacturer's datasheets shall be performed using (3 ± 0,2) mm thick silica glass. The glass shall have smooth, defect-free surfaces that are sufficiently flat and parallel such that the diffuse component of transmitted light is less than 1 % between 280 nm and 2 500 nm.

The solar-weighted transmittance of photon irradiance of silica glass, which may be used to verify that the composition of the glass is appropriate, is approximately (93 ± 1) % between 280 nm and 2 500 nm, because the reduction in transmittance comes from reflections at the surfaces. The UV cut-off wavelength for silica should be less than 225 nm. As in [1] and [12], the transmittance of the glass should be greater than 90 % at 280 nm.

The glass shall not be coated or contain antireflective layers. The glass shall not be intentionally textured.

Subsequent examination beyond that intended for the encapsulation material datasheet (including performance and weathering), such as for the purpose of quality control for production monitoring, may be performed according to this procedure using other superstrate and/or substrate materials that can incorporate other optical features, e.g., antireflective coatings, surface texture, and untempered soda-lime PV glass.

The process of solarization, where a redox reaction of trace impurities affects the UV cut-off wavelength and corresponding range of transmittance, can occur if glass other than silica is used [14]. It is therefore advised for weathering studies to UV condition substrate and superstrate materials, other than silica, prior to lamination.

NOTE Silica glass is more durable than soda-lime glass and will better resist glass corrosion in accelerated tests.

6.4 Number of specimens

A minimum of 3 replicates shall be used for the determination of the transmittance to the cell or in weathering studies. Optical characteristics, including transmittance, *YI*, and the UV cut-off wavelength shall be subsequently calculated using the average of the three separate specimens, with the range of the measurements indicated to identify their variability.

6.5 ~~Preconditioning~~ Conditioning of specimens

Specimens used for the purpose of datasheet reporting shall be maintained at (23 ± 2) °C, (50 ± ~~5~~ 10) % RH for at least 24 h, as ~~recommended~~ specified per Class 2 in ISO 291, prior to optical measurement.

The use of elevated temperature and humidity conditions in a weathering study may result in a supersaturated moisture condition within specimens, affecting their optical transmittance when they are returned to the laboratory ambient condition. In such cases, specimen conditioning, including a controlled environmental chamber, may be applied to prevent spurious effects, e.g., optical haze or moisture related absorptance. Specimen-condition effects may be verified using periodic measurements. Refer to the weathering test procedure for any specific details related to specimen conditioning and storage intermittent to weathering.

7 Measurement procedure

7.1 General

Transmittance measurements shall be performed in accordance with the procedure in ISO 13468-2.

7.2 Specimen preparation

Prior to measurement, specimens should be free of dust, grease or other contaminants. Specimens may be wiped with a solution of deionized water and mild soap for cleaning prior to measurement using a cleanroom wipe or lint free cloth. The specimens and instrument should be in thermal equilibrium prior to measurement.

7.3 Instrument calibration (baseline measurements)

Allow the instrument lamp to adequately equilibrate after it has been lighted, observing the typical warm-up period, e.g., 15 min or as recommended by the instrument manufacturer. Perform the correction scan(s) to compensate for the instrument baseline signal.

The 100 % transmittance baseline measurement should be performed in air, with no superstrate, specimen, or substrate material present. The 0 % transmittance baseline measurement should also be performed, if possible.

Periodic measurement of the baseline is recommended to minimize instrument drift and ensure the measured values are accurate. The instrument drift occurring over an extended measurement session may be instrument specific.

It is recommended to maintain the instrument drift below 0,05 % to minimize the uncertainty of measurement (Clause 9). The instrument drift should be considered in the instrument bias when the uncertainty of measurements is determined.

7.4 Specimen measurements

Perform the transmittance measurements for the test specimens over the wavelength range of at least 280 nm to 2 500 nm using a 1 nm increment.

Linear interpolation to a 1 nm increment may be used when only a coarser measurement increment (maximum of 5 nm) is available. The error associated with a coarser increment may be more influential at shorter wavelengths (where YI and the UV cut-off wavelength are determined) than at longer wavelengths (where only the solar-weighted transmittance is affected). When applied, the use of linear interpolation should be noted in the test report.

Discontinuities associated with changes in the optical components (including detector, light source, and/or monochromator) may occur during the measurement. Such discontinuities can be minimized via the instrument settings.

It may be useful to extend the range of measurement in weathering durability studies to provide insight into the results. For example, by measuring UV wavelengths as low as 200 nm, the integrity of UV absorbers and stabilizers can be confirmed from the UV cut-off wavelength.

The spectral bandwidth of the measurement should be less than or equal to the increment of the measurement, i.e., 1 nm or 5 nm.

7.5 Witness measurements

Perform the transmittance measurements on a witness specimen at the beginning of each measurement session to ensure proper operation of the instrument and minimize the measurement error. Perform the transmittance measurements of any witness specimens using the same procedure applied to the test specimen(s). The witness specimens may include a traceable standard specimen, laboratory working witness specimen, or the silica superstrate/substrate material.

7.5.1 Witness specimen(s)

The witness specimens may include a traceable standard specimen, laboratory working witness specimen, or the silica superstrate/substrate material. Witness specimen(s) for control measurements may also include a non-weathered glass working witness specimen of the same construction used in module representative test specimen(s) or reference (glass or polymeric superstrate) specimen(s). When not being used for control measurements, a working witness specimen shall be stored in the dark at 23 °C and 50 % humidity as specified per Class 2 in ISO 291.

7.5.2 Procedure for the witness specimen prior to the test specimen(s)

After instrument equilibration and baselining, perform the transmittance measurements on a witness specimen at the beginning of each measurement session to ensure proper operation of the instrument and minimize the measurement error. Perform the transmittance measurements of the witness specimen using the same procedure that will be applied to the test specimen(s).

The verification wavelengths for the working reference shall be ± 50 nm from the instrument transitions for the source, detector, and gratings. Because of the limitations of measurement, including noise from scattering at short wavelengths, the verification wavelengths shall not extend below 225 nm. In the case of many commercial instruments where the source, detector, and grating transitions occur at 350 nm, 800 nm, and 800 nm, respectively, the verification wavelengths should include the ranges 250 nm to 300 nm, 400 nm to 750 nm and 850 nm to 2500 nm (in the case of standard measurements) or 225 nm to 300 nm, 400 nm to 750 nm and 850 nm to 2 500 nm (in the case of measurements of weathered specimens).

The transmittance at each of the verification wavelengths should be within 0,25 % of the known transmittance (or laboratory running average) for the witness specimen. If the transmittance at each verification wavelength is not within 0,25 % of the known transmittance, the instrument baseline shall be performed again (including as many as three times) and the witness specimen shall be remeasured. If the transmittance at each wavelength continues to be greater than 0,25 % of the known transmittance, the instrument should be maintenanced or repaired.

7.5.3 Measurement of the test specimen(s)

After the witness specimen has been verified, the test specimen(s) shall be measured.

7.5.4 Procedure for the witness specimen after the test specimen(s)

After the test specimen(s) have been measured, perform the transmittance measurements on a witness specimen at the end of each measurement session to ensure proper operation of the instrument through the measurement session. Perform the transmittance measurements of the witness specimen using the same procedure that will be applied to the test specimen(s). The transmittance at each of the verification wavelengths should be within 0,25 % of the known transmittance (or laboratory running average) for the witness specimen. If the transmittance at each verification wavelength is not within 0,25 % of the known transmittance, the measured data for the test specimen(s) shall be considered invalid and the test specimen(s) shall be measured again in a subsequent session.

8 Calculation and expression of results

8.1 Post-processing of data

The measurements obtained from three separate specimens shall be averaged at each wavelength increment. ~~The range (difference of the maximum and minimum) shall also be determined at each wavelength increment.~~ The variability shall be reported for each characteristic (weighted transmittance, yellowness index, and UV cut-off wavelength) as the range (difference of the maximum and minimum measurements) for the three specimens.