IEC 62899-203

Edition 2.0 2024-05

INTERNATIONAL STANDARD

colour inside

Printed electronics –
Part 203: Materials – Semiconductor ink

IEC 62899-203:2024-05(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.045; 87.080

ISBN 978-2-8322-8931-0

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PRINTED ELECTRONICS –

Part 203: Materials – Semiconductor ink

FOREWORD

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IEC 62899-203 has been prepared by IEC technical committee 119: Printed Electronics. It is an International Standard.

This second edition cancels and replaces the first edition published in 2018. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) addition of 6.3.1.2.2 – Normalised on-current measurement of the TFT device;
b) in 6.3.2, correction of formula for calculation of permittivity.

The text of this International Standard is based on the following documents:

Draft	Report on voting
119/485/FDIS	119/489/RVD

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 International Standard 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/publications.

A list of all parts in the IEC 62899 series, published under the general title *Printed electronics*, 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- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The IEC 62899 series deals mainly with evaluation methods for materials of printed electronics. The series also includes storage methods, packaging and marking, and transportation conditions.

The IEC 62899 series is divided into several parts according to each material. Each part is prepared as a generic specification containing fundamental information for the area of printed electronics.

This part of IEC 62899 is prepared for inks containing semiconducting materials used in printed electronics and contains the test conditions, the evaluation methods and the storage conditions.

PRINTED ELECTRONICS –

Part 203: Materials – Semiconductor ink

1 Scope

This part of IEC 62899 defines terms and specifies standard methods for characterization and evaluation of semiconductor inks and semiconductive layers that are made from semiconductor inks.

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 62860, *Test methods for the characterization of organic transistors and materials*

ISO 5-2, *Photography and graphic technology – Density measurements – Part 2: Geometric conditions for transmittance density*

ISO 5-3, *Photography and graphic technology – Density measurements – Part 3: Spectral conditions*

ISO 124, *Latex, rubber – Determination of total solids content*

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

ISO 489:2022, *Plastics – Determination of refractive index*

ISO 758, *Liquid chemical products for industrial use – Determination of density at 20 °C*

ISO 1183-1, *Plastics – Methods for determining the density of non-cellular plastics – Part 1: Immersion method, liquid pycnometer method and titration method*

ISO 2555, *Plastics – Resins in the liquid state or as emulsions or dispersions – Determination of apparent viscosity using a single cylinder type rotational viscometer method*

ISO 2592, *Petroleum and related products – Determination of flash and fire points – Cleveland closed cup method*

ISO 2719, *Determination of flash point – Pensky-Martens closed cup method*

ISO 2811-1, *Paints and varnishes – Determination of density – Part 1: Pycnometer method*

ISO 2811-2, *Paints and varnishes – Determination of density – Part 2: Immersed body (plummet) method*

ISO 2884-1, *Paints and varnishes – Determination of viscosity using rotary viscometers – Part 1: Cone-and-plate viscometer operated at a high rate of shear*

ISO 3219, *Plastics – Polymers/resins in the liquid state or as emulsions or dispersions – Determination of viscosity using a rotational viscometer with defined shear rate*

ISO 3251, *Paints, varnishes and plastics – Determination of non-volatile-matter content*

ISO 3664, *Graphic technology and photography – Viewing conditions*

ISO 3679, *Determination of flash point – Method for flash no-flash and flash point by small scale closed cup tester*

ISO 13468-1:2019, *Plastics – Determination of the total luminous transmittance of transparent materials – Part 1: Single-beam instrument*

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

ISO 13655, *Graphic technology – Spectral measurement and colorimetric computation for graphic arts images*

ISO 14488, *Particulate materials – Sampling and sample splitting for the determination of particulate properties*

ISO 14782, *Plastics – Determination of haze for transparent materials*

ISO 15212-1, *Oscillation-type density meters – Part 1: Laboratory instrum*ents

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62860 and the following apply.

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

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

NOTE The terms in italic font are those defined in Clause 3.

3.1
semiconductive material
ingredient of a printing or coating material, which itself is electrically semiconductive

Note 1 to entry: The ingredient can be one or more small molecules, precursors, polymers, or particles.

Note 2 to entry: The ingredient can require post treatment to provide semiconductive properties.

3.2
semiconductor ink
liquid in which one or more inorganic particles, ions, salts, organic small molecules or organic polymers are dissolved or dispersed, and which becomes an electrically *semiconductive layer* (3.3) through solvent removal or post treatment such as UV, photonic, or thermal processing

[SOURCE: IEC 62899-101:2019, 3.121]

3.3
semiconductive layer
film-like semiconductive body of material made of *semiconductor ink* (3.2), which is printed or coated on a substrate, followed, as necessary, by using a post treatment such as UV, photonic, or thermal processing

[SOURCE: IEC 62899-101:2019, 3.119]

3.4
semiconductor film
substrate (sheet or roll) with *semiconductive layer* (3.3)

[SOURCE: IEC 62899-101:2019, 3.120]

3.5
solid content
mass fraction of an ingredient which effectively functions as a *semiconductive material* (3.1) dissolved or dispersed in a solvent to form a *semiconductor ink* (3.2)

Note 1 to entry: In some instances the ink can include insulating materials, sometimes referred to as binders, or other additives included to improve the film formation during coating or printing.

3.6
non-volatile content
mass fraction of residue obtained by evaporation of the volatile solvent under specific conditions, in *semiconductor ink* (3.2)

3.7
dispersion
heterogeneous system in which fine separated materials are distributed uniformly in other materials

3.8
flash point
lowest liquid temperature at which, under certain standardized conditions, a liquid gives off vapours in quantity such as to be capable of forming an ignitable vapour/air mixture

[SOURCE: IEC 60050-212:2010, 212-18-05]

3.9
field effect mobility
majority carrier mobility of *semiconductive material* (3.1) derived through the transfer curve measurement of a fabricated *TFT* (3.10) device

Note 1 to entry: The field effect mobility is usually derived from either saturation or linear approximations.

Note 2 to entry: Field effect mobility is given in units of $cm^2/V·s$.

3.10
thin-film transistor
TFT
switching device made from three electrodes (source, drain and gate) and semiconducting and insulating layers, wherein potentials applied to a gate electrode modulate charge carriers on the opposite side of the insulating layer situated between the gate and *semiconductive layer* (3.3)

Note 1 to entry: The change in charge density in the *semiconductive layer* changes its conductivity, and this in turn allows a modulation in current flow between the source and drain electrodes for a given source-drain potential difference.

Note 2 to entry: TFTs are found in a wide variety of electronic devices such as integrated circuits and display backplanes.

4 Atmospheric conditions for evaluation and conditioning

The standard atmosphere for evaluation (test and measurement) and storage of the specimen shall be a temperature of (23 ± 2) °C and relative humidity of (50 ± 10) %, in accordance with standard atmosphere class 2 as specified in ISO 291. If a polymer substrate is used for a test piece coated with a semiconductive layer, the standard atmosphere for evaluation shall be a temperature of (23 ± 1) °C and relative humidity of (50 ± 5) %, in accordance with standard atmosphere class 1 as specified in ISO 291.

If conditioning is necessary, the same standard atmosphere as specified above shall apply.

5 Evaluation of properties of semiconductor ink

5.1 Specimen

The specimen for evaluation shall be prepared in accordance with ISO 14488 or an equivalent method. If necessary, dilution by a compatible solvent is permitted. For semiconductor inks, in many cases the properties to be evaluated can be influenced by the choice of solvent and method of deposition. Consideration of the likely effects of solvent choice and ink deposition should be made in light of the semiconductor chemistry, the ink composition or both.

5.2 Contents

5.2.1 Solid content

5.2.1.1 Determination of solid content

Solid content of semiconductive materials and non-semiconductive materials shall be determined by the theoretical mass fraction (expressed as a percentage) of functional ingredients to the total ink mass. Functional ingredients include semiconductive materials, their precursors or binders, or any additives.

5.2.1.2 Report of the results

The report shall include the following items:

a) unique specimen identification;

b) date of test;

c) atmospheric conditions of test;

d) solid content.

5.2.2 Non-volatile content

5.2.2.1 Principle

Non-volatile content is determined by measuring the mass of residue after evaporation of the volatile ingredients and calculating the mass fraction (expressed as a percentage) to the total ink mass.

5.2.2.2 Test method

The test method shall be as specified in ISO 3251 with the following exceptions:

a) Air pressure: 86 kPa to 106 kPa.
b) If specified by the manufacturer, the test can be performed under reduced pressure. The conditions and procedures for reducing the pressure shall be as specified in ISO 124 or by the manufacturer.
c) Materials which do not react with the ink during an examination shall be used.
d) Repeat the test until the weight becomes constant within 5 %.

5.2.2.3 Report of the results

The report shall include the following items:

a) specimen identification;
b) test conditions (air pressure if reduced, drying temperature and time);
c) specimen mass;
d) results.

5.3 Physical properties

5.3.1 Density

5.3.1.1 Measurement method

The measurement method shall either be the pyknometer method as specified in ISO 758, ISO 1183-1 and ISO 2811-1, the method using oscillation-type density meters as specified in ISO 15212-1, or the immersed body (plummet) method as specified in ISO 2811-2. The detailed product specifications shall specify the measurement method to be used.

5.3.1.2 Equipment

Equipment shall be as specified in the measurement method (see 5.3.1.1) or shall be equipment considered equivalent or superior.

5.3.1.3 Report of the results

The report shall include the following items:

a) specimen identification;
b) measurement method;
c) measurement atmosphere (temperature and relative humidity);
d) results.

5.3.2 Rheology

5.3.2.1 Measurement method

Viscosity shall be measured using a Brookfield type rotational viscometer as specified in ISO 2555, cone-and-plate viscometer as specified in ISO 2884-1, or rotational viscometer as specified in ISO 3219.

The detailed product specifications shall specify the measurement method and measuring temperature to be used.

5.3.2.2 Report of the results

The report shall include the following items:

a) standard number of the measurement method;

b) specimen identification;

c) measuring temperature;

d) viscometer model;

e) viscosity expressed in millipascal second (mPa·s) at (a) shear rate(s) appropriate to the printing method(s) for which the ink is proposed to be used by the supplier.

5.3.3 Surface tension

5.3.3.1 Measurement method

Surface tension can be measured using the drawing up liquid film (Wilhelmy) method as specified in ISO 304 with the following exceptions:

a) equipment considered equivalent to that in ISO 304 can be used;

b) the test jig shall be made of platinum;

c) the equipment shall be calibrated using pure water and a hanging weight.

Other methods of measuring surface tension can be used such as the Du Noüy method and the pendant drop method.

5.3.3.2 Report of the results

The report shall include the following items:

a) specimen identification;

b) measuring temperature;

c) measurement method used to evaluate the surface tension;

d) surface tension expressed in millinewton per metre (mN/m).

5.3.4 Flash point

5.3.4.1 Measurement method

Flash point shall be measured in accordance with ISO 2592 in the case of an open system. The method of "open system" is preferable for safety, however "closed systems" are also widely used. The measurement method based on ISO 2719 (closed system) and ISO 3679 (closed system) can be applied if a closed system is required.

5.3.4.2 Report of the results

The report shall include the following items:

a) specimen identification;
b) test conditions (temperature, humidity and atmospheric pressure);
c) sampling conditions (type of ink used, dispersive media and concentration);
d) results;
e) others (special items).

5.3.5 Evaporation rate

5.3.5.1 General

The evaporation rate is a property which is necessary for the printed electronics ink, but the details of the evaluation condition and the measurement method are significantly different for the ink. In this document, a common framework for the method is specified as a guideline. The detailed conditions and measurements can be determined between trading partners depending on the properties of the ink.

5.3.5.2 Measurement method

The evaporation rate of solvent from an ink formulation can be determined by measuring the time taken for 90 % of the mass of the solvent content of the ink formulation to evaporate.

A flat absorbent material (such as a filter paper) is positioned on a sensitive mass balance located inside a dry air (< 5 % relative humidity) or nitrogen cabinet at atmospheric pressure. A known volume of ink (such as 1 ml) is dispensed in a straight line on the absorbent material to produce a repeatable area of wetted film on the filter paper. Dried air or nitrogen is passed through the cabinet at a controlled temperature and flow rate. The temperature and flow rate can be determined between trading partners depending on the properties of the ink, but these conditions shall be included in the report. The location of the entry and exit ports for the dry air or nitrogen should be chosen so as not to disturb the mass balance readings throughout the test.

The evaporation rate can be calculated by measuring the difference in mass over a period of time. It is recommended that sufficient measurements be made to allow five or more points to be plotted on a graph of mass loss versus time for values of between 10 % and 90 % loss of solvent from the ink. The test should be repeated a total of three times and the evaporation rates averaged for that ink. In order to make a comparison, the procedure should be conducted with a known solvent such as n-butyl acetate and the evaporation rate normalised to this solvent.

In the case of an ink comprising a solvent mixture, an increased number of measurements shall be made in order to clearly show how the evaporation rate changes over time. It is recommended that a balance with automated data logging be used in order to facilitate the capture of sufficient data to describe the detailed behaviour. The results can be presented in graphical form for the case where the solvent evaporation rate is varying with time in a complex manner. These results can also be compared with those for n-butyl acetate by plotting both data on the same graph.

5.3.5.3 Report of the results

The report shall include the following items:

a) specimen identification;
b) test conditions (mass of ink, flow rate of air/nitrogen, solvent used for comparison);
c) results (normalised to the solvent used for comparison).

6 Properties of semiconductive layer

6.1 Semiconductor classification

The methods described in IEC 62860 are applicable to the evaluation of printed semiconductors. However, for the purposes of this document the test methods for organic or inorganic printable semiconductors will be the same. No distinction between the two classes of material is necessary.

6.2 Test piece

6.2.1 General

Test pieces are used for evaluating the semiconductive layer.

6.2.2 Substrate

The substrate for the test piece shall be clean and of smooth-surface non-alkali glass which will not affect the ink. Other substrate materials can be used if agreed between the trading partners (supplier and purchaser).

6.2.3 Semiconductor ink

According to 5.1, except no dilution is allowed.

6.2.4 Dimensions of test piece

The dimensions of the test piece shall be as specified in each test method. If evaluation is possible, a test piece with smaller or thinner dimensions, or both, than specified can be used.

6.2.5 Preparation of test piece

The test piece shall be prepared according to the following procedure:

a) Prior to ink printing or coating, the substrate surface shall be cleaned by appropriate means using one or more of an organic solvent such as acetone, an aqueous detergent solution, diluted tetramethylammonium hydroxide (TMAH), and water.

b) Print or coat the ink onto the substrate surface using an appropriate method to form a uniform layer of ink.

c) Solidify the ink by appropriate means to produce an electrically semiconductive layer.

6.3 Electrical properties

6.3.1 Charge mobility

6.3.1.1 General

The method of direct charge carrier mobility measurement should be described for measurement of the semiconductive layer. Depending on the carrier concentration the appropriate method should be selected amongst the measurements of field effect mobility, Hall mobility, time of flight (TOF) mobility, and space charge limited current (SCLC) mobility.

6.3.1.2 TFTs

6.3.1.2.1 Field effect mobility of the TFT device

TFT field effect mobility measurements can be used to give an indication of the performance of the ink in a particular application. In this case measurements should be made in accordance with IEC 62860. Charge mobility should be calculated in the linear or saturated regime, or both, and presented graphically as a variable for a range of gate voltages in the accumulation mode. This will enable the gate voltage dependence of the mobility to be seen for a given material. TFTs should be constructed with channel lengths covering a factor of 5 from smallest to largest in order to illustrate any variation in performance arising from short channel effects. Ideally the smallest channel length tested should be less than < 10 µm since these dimensions are where the channel length shortening effects have the greatest effect upon device performance. The field effect mobility often varies as a function of gate voltage and can, on occasion, be extracted inaccurately due to contact resistance effects. Therefore, other methods to evaluate semiconductor ink performance in a TFT should be employed in addition to field effect mobility. One method is to use a normalised on-current measurement as shown in 6.3.1.2.2.

6.3.1.2.2 Normalised on-current measurement of the TFT device

Measurement of the TFT on-current (I_D) at a defined set of gate and drain voltages can be an effective way to evaluate the performance of the semiconductor ink and determine if it is able to provide enough current for an application. To evaluate devices produced with different geometries channel length (L), width (W) and dielectric capacitance (C_i), it is necessary to normalise the on-current with respect to these parameters (i.e. the current that would flow in a TFT with $W = L = 1$ µm and at $C_i = 1$ nF/cm^2). The normalised drain current (NI_D) is calculated according to the following formula:

$$NI_\mathrm{D} = I_\mathrm{D} \cdot L \cdot \frac{1}{WC_i}$$

The voltages for the TFT should be agreed between trading partners (supplier and purchaser). As an example, for a p-type TFT the NI_D could be measured for the drain set at −15 V and the gate voltage at −22 V. N-type TFTs would require positive gate and drain voltages. As in 6.3.1.2.1, the NI_D shall be measured on a range of TFT channel lengths covering a factor of at least 5 from smallest to largest to identify any short channel effects. The C_i of the TFT is often in the range of 2 nF/cm^2 to 20 nF/cm^2 for printed devices. Values above this range could be obtained if the relative permittivity of the insulator in the device is very high or the insulator is very thin, or both. Values below this range can be achieved due to the use of a very thick insulator. The dielectric thickness, and hence gate capacitance, should be agreed between the trading partners at a level relevant for the intended application.

6.3.1.2.3 Current hysteresis

IV characteristics for drain current versus gate voltage at fixed drain voltage shall be made in accordance with IEC 62860. This measurement shall be made at the same drain voltage as used to calculate the NI_D value. Forward and reverse scans shall be plotted in a graph to show the level of current hysteresis throughout the transfer scan. In this way the semiconductor ink's performance can be measured without any effects of ion migration or slow polarization that can affect the value.

6.3.1.3 Diodes

Charge mobility measurement through TOF or (SCLC) measurements can also be used to evaluate the performance of the semiconductive layer in a metal-semiconductor-metal configuration. The test method should be described, detailing the preparation method for the device contacts and the voltage measurement regimes used to conduct the study.

6.3.2 Dielectric properties

The dielectric properties of the semiconductor film can be measured by forming a capacitor structure using the semiconductor as a dielectric in between two metal plates. The metal plates can be formed by thermal evaporation or sputtering and patterned by shadow masking or photolithography. The semiconductor ink can be coated by spin, slot die coating, or printing and dried using a hot plate or oven. Film thickness should be measured using a stylus profileometer or similar equipment with the required accuracy for the film thickness. Measurement of the capacitance of a known thickness of the semiconductor (at a frequency of 1 kHz) will enable the relative permittivity ε_r to be calculated using the formula:

$$\varepsilon_r = \frac{C \cdot d}{\varepsilon_0 \cdot A}$$

where

d is the semiconductor thickness,

ε_0 is the vacuum electric permittivity,

A is the area of the capacitor,

C is the measured capacitance.

For applications where the semiconductor is operating at higher frequencies, the capacitance can be measured at different frequencies to establish the variation of the permittivity with frequency. For the capacitance measurement either a capacitance meter, LCR meter or frequency analyser can be used. Any parasitic capacitance in the measurement leads or test fixture should be accounted for. The dimensions of the electrodes and thickness of the film should be reported, and these should be chosen so as to avoid any edge effects that would alter the accuracy of the measurement. It is recommended that the diameter of the capacitor plates (or length for the case of a square device) be at least 1 000 times larger than the thickness of the semiconductor film. If a large dielectric loss is measured in the film, due to a high charge concentration in the semiconductor, then the frequency of the measurement can be increased from 1 kHz to 10 kHz or 100 kHz. Alternatively, the capacitance-voltage CV technique can be used to vary the applied bias across a metal-insulator-semiconductor-metal structure during capacitance measurement. The applied DC bias can be used to compare the capacitance values of the structure for both depletion and accumulation of charges in the semiconductor.

6.3.3 Ionization potential

Ionization potential can be measured using photoelectron spectroscopy in air. The test method and the film preparation conditions should be described, including the atmospheric conditions in the laboratory.

6.3.4 Band-gap of semiconductor film

The band-gap of the semiconductor film can be measured using the Tauc method applied to a UV-Vis absorption plot of the film or absorbance spectrum fitting (ASF) method. The test method and the film preparation conditions should be described, including the atmospheric conditions in the laboratory.

6.4 Optical properties

6.4.1 Overview

The tests specified in 6.4.2 through 6.4.6 shall be used for transparent or equivalent materials.

6.4.2 Luminous transmittance

6.4.2.1 General

Luminous transmittance is presented as total luminous transmittance.

6.4.2.2 Measurement method

Luminous transmittance shall be measured using the single-beam method as specified in ISO 13468-1, or the double-beam method as specified in ISO 13468-2, with the following details. If agreed between the trading partners (supplier and purchaser), another method which is considered equivalent can be used.

The detailed product specifications shall specify the applicable measurement method.

6.4.2.3 Measuring equipment

Measuring equipment shall be as specified in ISO 13468-1:2019, Clause 4, for single-beam instruments or ISO 13468-2:2021, Clause 4, for double-beam instruments, as appropriate. Measuring equipment according to ISO 13655 or ISO 5-2 can be used.

6.4.2.4 Wavelength or wavelength range used in the test

Luminous transmittance shall be measured either at a particular wavelength or a wavelength range, as agreed between the trading partners (supplier and purchaser) considering factors such as material characteristics or application.

6.4.2.5 Report of the results

The report shall include the following items:

a) measurement method and equipment;
b) measuring wavelength or wavelength range;
c) specimen thickness;
d) luminous transmittance.

6.4.3 Chromaticity

6.4.3.1 General

According to ISO 11664-4, chromaticity is presented as CIE (1976) $L^*a^*b^*$ colour space.

6.4.3.2 Measurement method

The measurement method shall be the reflected light method or the transmitted light method, depending on the application and the purpose.

If the reflected light method is used, a reflecting diffuser shall be placed on both the surface to be measured and the other surface, with the specimen in between.

The reflecting diffuser shall be a perfect reflecting diffuser or a reference diffuser used for calibrating measuring equipment.

6.4.3.3 Measuring equipment and auxiliaries

The measuring equipment and light source shall be in accordance with at least one of the following: ISO 5-2, ISO 5-3, ISO 3664 or ISO 13655, and shall be specified in the detailed product specifications.

6.4.3.4 Expression of the results

The results shall be presented as the numerical values of each of the $L^*a^*b^*$ coordinate axes, or shall be plotted in the $L^*a^*b^*$ colour space. If agreed between the trading partners (supplier and purchaser), the results may be presented instead by the numerical value of a specific coordinate axis or the numerical values of two specific coordinate axes of the $L^*a^*b^*$ colour space. In this case, the coordinate axis or axes concerned shall be clearly stated.

6.4.3.5 Report of the results

The report shall include the following items:

a) measuring instrument and light source;

b) measurement method (reflected light or transmitted light);

c) chromaticity (numerical values of each of the $L^*a^*b^*$ coordinate axes, plotted in the $L^*a^*b^*$ colour space, or the numerical value of a specific coordinate axis or numerical values of two specific coordinate axes of the $L^*a^*b^*$ colour space).

6.4.4 Uniformity of colour

6.4.4.1 Principle

Colour differences are obtained at 10 points on the specimen and their average is evaluated by the difference from the standard chromaticity and standard deviation.

6.4.4.2 Measuring equipment

According to 6.4.3.3.

6.4.4.3 Illuminant (light source)

According to 6.4.3.3.

6.4.4.4 Measurement method

According to 6.4.3, chromaticity shall be measured at 10 points on a single specimen using the same instrument and under the same conditions. Five or more pairs of points are selected so that all 10 points are chosen, as shown in Annex B. From the colour difference between each pair of points, the mean colour difference, the difference between the reference chromaticity and the mean, and the standard deviation are calculated.

6.4.4.5 Calculation of colour difference

Colour difference is calculated by using the colour difference formula based on the numerical values of each of the $L^*a^*b^*$ coordinate axes, or using the colour difference formula based on lightness, chroma, and hue.

The colour difference based on the $L^*a^*b^*$ colour system is calculated by using the following formula:

$$\Delta E^* ab = \left[\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2 \right]^{\frac{1}{2}}$$

where:

ΔE^*ab is the colour difference based on the $L^*a^*b^*$ colour system;

ΔL^*, Δa^*, Δb^* is the difference in L^* and difference in colour coordinates a^* and b^* of the chromaticity between the pair of points obtained in 6.4.3.

The colour difference based on the luminosity, chroma, and hue is calculated by using the following formula:

$$\Delta E^{*}ab = \left[\left(\Delta L^{*}\right)^{2} + \left(\Delta aC^{*}ab\right)^{2} + \left(\Delta Hb^{*}ab\right)^{2}\right]^{\frac{1}{2}}$$

where:

$\Delta E^{*}ab$ is the colour difference based on the $L^{*}a^{*}b^{*}$ colour system;

ΔL^{*} is the difference in luminosity L^{*} of the chromaticity between the pair of points obtained in 6.4.3;

$\Delta C^{*}ab$ is the difference in ab chroma of the chromaticity between the pair of points obtained in 6.4.3;

$\Delta H^{*}ab$ is the difference in ab hue of the chromaticity between the pair of points obtained in 6.4.3.

The colour difference formula in CIE DE 2000 (see CIE Publication No.142 in the Bibliography) may also be used for calculating colour difference.

6.4.4.6 Report of the results

The report shall include the following items:

a) measuring instruments;
b) measurement method (reflected light or transmitted light);
c) standard chromaticity;
d) difference between the standard chromaticity and the mean, and standard deviation.

6.4.5 Haze

6.4.5.1 Measurement method

Haze shall be measured using the method specified in ISO 14782. A similar method may be used as agreed between the trading partners (supplier and purchaser).

6.4.5.2 Report of the results

The report shall include the following items:

a) thickness of the specimen;
b) type of light source;
c) haze.

6.4.6 Refractive index

6.4.6.1 Measurement method

The refractive index shall be measured using method A (for measuring the refractive index of films using a refractometer) specified in ISO 489 or a similar method.

6.4.6.2 Contacting liquid

A contacting liquid with a refractive index higher than that of the measured object and with a substrate which does not swell or dissolve as listed in ISO 489:2022, Table 1, shall be used. When using a plastic film for the substrate, choose the contact liquid in consideration of the refractive index, swelling and melting of the substrate.

6.4.6.3 Conditioning

Conditioning shall be performed at a temperature of (23 ± 2) °C and a relative humidity of (50 ± 10) % for 88 h or longer. Other conditioning shall be determined by the trading partners (supplier and purchaser), if necessary.

6.4.6.4 Report of the results

The report shall include the following items:

a) refractometer used, and the type of light source and wavelength;
b) refractive index;
c) dispersion (if applicable).

7 Storage

7.1 General

Semiconductor inks can deteriorate by a number of different mechanisms, such as oxidation of molecules by air and humidity, decomposition of molecules by UV light, ozone, nitrogen oxides. They can experience an increase in viscosity due to polymerization, hydrolysis of metal alkoxides, evaporation of solvent, sedimentation, falling out of solution, and cohesion of particles or other mechanisms not mentioned here.

7.2 Storage conditions

One of the methods for measuring deterioration caused by ageing is evaluating the field effect mobility of TFT. In this case, the following method is recommended. TFT devices can be fabricated from the inks which are reserved at certain intervals such as one month. Semiconductor ink storage conditions can be described for the optimum environment for storage of that ink. This can be for example to prevent chemical reactions with the atmosphere. Storage of the ink may be in an inert environment, obtained through use of a glovebox enclosure or through use of an airtight container, or in the dark.

7.3 Method for measuring deterioration caused by ageing

Semiconductor ink ageing can be evaluated by fabricating TFT devices from the ink at regularly spaced intervals such as one month. The TFT devices can be measured in accordance with IEC 62860 and the average mobility for at least ten devices will be used to compare performance of the ink over time. A semiconductor ink can be determined to be degraded if, in two consecutive tests, the mean mobility measurement is more than two standard deviations away from the average of the first six tests. The lifetime of the ink is then determined to be the date before which the performance was outside two standard deviations from the mean. An example of such measurements is included in Annex A.