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Organic LED Lighting in European Dimensions

OLED Glossary
WP5

Project Coordinator	Dr. Stefan Grabowski Philips Technologie GmbH		
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AUTHORS DATA

Authors	Benificiary	e-mail
Karsten Diekmann	OSRAM OS	karsten.diekmann@osram-os.com
Wilfried Pohl	Bartenbach Lichtlabor	Wilfried.Pohl@bartenbach.com
Thorsten Gerloff	PTB	Thorsten.Gerloff@ptb.de
Michael Hoffmann	Fraunhofer IPMS	Michael.Hoffmann@ipms.fraunhofer.de
Tom Munters	Philips	tom.munters@philips.com
Armin Sperling	PTB	Armin.Sperling@ptb.de

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1 Purpose of Document

Although Organic Light Emitting Diode (OLED) technology in general is considered a mature one – largely due to the progress of using the technology for displays – with regards to the lighting industry it is new and consequently there is uncertainty and risk associated with adopting the technology.

Uncertainty raises questions about OLED lighting in terms of product performance, product safety, measurement of physical attributes such as luminous efficacy, luminance, lifetime and colour. Without adequate answers potential adopters consider the technology to be higher risk than it really is. The presence of uncertainty and perceived risk stifles innovation and holds back market adoption, and ultimately delays the benefits that society would enjoy as a consequence of the transition from inefficient lighting solutions to efficient solid-state lighting solutions.

To increase innovation and market adoption uncertainty and risk need to be reduced. One way to reduce uncertainty and risk is to introduce standards. It is widely acknowledged that the introduction of standards greatly accelerates market adoption, increases innovation and increases trade. OLED lighting does not yet have any standards in place. It is therefore considered both important that OLED lighting initiates agreed procedures for measurement and standards, and that early discussions and frameworks are initiated and promoted.

Before introducing standards a common use of terms and definitions is an important boundary condition. The need to come up with a standardised language and a common understanding in terms of measuring OLEDs and the interpretation of measurement results is evident, since OLED technology made the first move into applications via displays. Now the technology has emerged, the performance has reached a level that the threshold is reached to move into lighting applications. Display and lighting requirements are different and OLED technology has to adopt to lighting terms, but it also has to emphasise its special features such as large area, thinness and degrees of freedom in design such as flexibility and transparency. In this sense, OLEDs are a special type of light sources, which are not compatible with existing lamps.

This document aims for a common use of terms and definitions referring to all aspects of OLED technology and products. Currently, many terms are not well defined or are used with double meaning. Additionally, when scientific results are reported, very often background information is not published which is necessary to reach a suitable judgement of measurement values.

The document is created and updated continuously. The owner is the WP5 leader of OLED100.eu project. It will be regularly disseminated within the OLED100.eu consortium. Furthermore, the document will be distributed to selected OLED players world wide and their feedback will be used for improvement of this document.

The ultimate goal is to convert this document into a worldwide accepted OLED lighting dictionary and to feed it into appropriate OLED norms and standards.

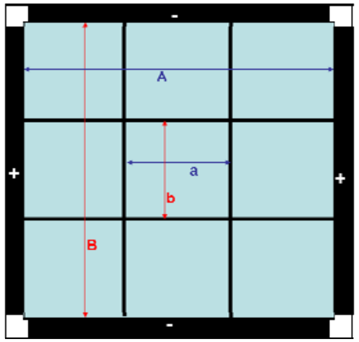
2 Glossary

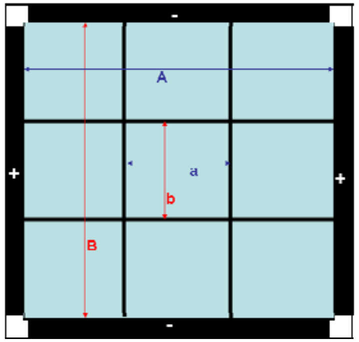
Term or Quantity / Abbreviation / Acronym / Symbol	Classification	Description & Definition	Unit	Remark
OLED: Organic Light Emitting Diode	General	Semiconductor device for the generation of light containing organic semiconductor materials. Most common building blocks of an OLED device are the OLED stack which is embedded between the substrate and the encapsulation, and optionally optical outcoupling structures.	n.a.	
PLED: Polymeric organic light emitting diode	General	An OLED where the organic semiconductor materials are polymers.	n.a.	
SMOLED: Small molecule organic light emitting diode	General	An OLED where the organic semiconductor materials are small molecules.		
Substrate	Vertical structure	Material to carry the OLED stack. Most common is the use of glass, metal foils or polymer foils.	n.a.	
OLED stack	Vertical structure	Core element of an OLED to generate light. It is a multi-layer structure with significant lateral dimensions where each layer has a special functionality. The two sandwiching layers at top and bottom are electrodes which need to be connected to an electrical power supply. At least one of the electrodes has to be transparent to enable light extraction to air.	n.a.	
Anode	Vertical structure	Electrode which is part of the OLED stack and from where holes are injected into the organic layers.	n.a.	
HIL: Hole Injection Layer	Vertical structure	Adjacent layer to the anode which shall improve the hole injection. Part of the OLED stack.	n.a.	
Cathode	Vertical structure	Electrode which is part of the OLED stack and from where electrons are injected into the organic layers.	n.a.	
EIL: Electron Injection Layer	Vertical structure	Adjacent layer to the cathode which shall improve the electron injection. Part of the OLED stack.	n.a.	

HTL: Hole Transport Layer	Vertical structure	Layer inside the OLED stack with a relatively high conductivity for holes. It is used to adjust the charge carrier balance in the stack. The special case of an electrically doped HTL for further conductivity increase is called p-HTL.	n.a.	Same or similar as EBL.
HBL: Hole Blocking Layer	Vertical structure	Layer inside the OLED stack with a relatively low conductivity for holes. It is used to adjust the charge carrier balance in the stack.	n.a.	Same or similar as ETL.
ETL: Electron Transport Layer	Vertical structure	Layer inside the OLED stack with a relatively high conductivity for electrons. It is used to adjust the charge carrier balance in the stack. The special case of an electrically doped ETL for further conductivity increase is called n-ETL.	n.a.	Same or similar as HBL.
EBL: Electron Blocking Layer	Vertical structure	Layer inside the OLED stack with a relatively low conductivity for electrons. It is used to adjust the charge carrier balance in the stack.	n.a.	Same or similar as HTL.
EML: Emissive Layer	Vertical structure	Layer in the emissive zone of an OLED stack where exciton formation and photon generation take place. It can consist of several materials.	n.a.	
Matrix	Vertical structure	Material in the EML which acts as host for emitter materials.	n.a.	
Emitter	Vertical structure	Material in the EML which acts as phosphor, typically used in very low concentrations as dopant in a matrix.	n.a.	
PIN OLED	Vertical structure	An OLED incorporating conductivity doping (see p-HTL and n-ETL).	n.a.	
Fluorescent Emitter	General	A type of emitter material. According to spin statistics in quantum chemistry, excitons formed by an electron and a hole can have two different spin multiplicities, i.e. 1 (singlet state) or 3 (triplet state). Simply spoken, 25% of the states are singlets and 75% are triplets. In a fluorescent emitter only the singlet state excitons can show radiative decay and photon emission. The theoretical maximum of the internal quantum efficiency is 25%.	n.a.	

Phosphorescent Emitter	General	A type of emitter material. According to spin statistics in quantum chemistry, excitons formed by an electron and an electron hole can have two different spin multiplicities, i.e. 1 (singlet state) or 3 (triplet state). Simply spoken, 25% of the states are singlets and 75% are triplets. In a phosphorescent emitter singlet and triplet state excitons can show radiative decay and photon emission. The theoretical maximum of the internal quantum efficiency is 100%.	n.a.	
Hybrid OLED stack	General	a) An OLED stack which contains fluorescent and phosphorescent emitters. b) An OLED stack which contains polymer and small molecule layers.	n.a.	
ITL: Interlayer	Vertical structure	Typically, a layer in a hybrid OLED (type (a)) which serves to separate fluorescent from phosphorescent emission zone.	n.a.	
CGL: Charge Generation Layer	Vertical structure	Layer in a stacked OLED which is sandwiched by two single OLED structures. It generates electrons for one adjacent OLED unit (acting as a cathode) and electron holes for a second adjacent OLED unit (acting as anode). The CGL is not directly connected to an electrical power supply. It enables the serial connection of two or more OLED structures which are placed on top of each other.	n.a.	
Stacked OLED	Vertical structure	At least two single OLED stacks – stripped by the electrodes – stacked on top of each other. The interface between the single OLED stacks is not formed by an anode and a cathode pair, but by a CGL. The structure is completed by an embedding anode and cathode pair.	n.a.	
Encapsulation	Vertical structure	A barrier structure on the OLED stack to protect the OLED device from moisture and oxygen.	n.a.	
TFE: Thin Film Encapsulation	Vertical structure	A special type of encapsulation which is significantly thinner than the conventional method of using a cavity glass with getters which is glued onto the substrate with the OLED stack.	n.a.	
Optical Outcoupling Structures	Vertical structure	Special means to enhance the light extraction from the OLED to the air.	n.a.	
External Outcoupling Structures	Vertical structure	Optical outcoupling structures which are located on the outer substrate surface to extract more light from the substrate into the air.	n.a.	

Internal Outcoupling Structures	Vertical structure	Optical outcoupling structures which are located between the OLED stack and the substrate to bring more light into the substrate which finally leads to a higher amount of photons extracted into the air.	n.a.	
Bottom Emitter	Vertical structure	An OLED which emits light through the substrate side.	n.a.	
Top Emitter	Vertical structure	An OLED which emits light through the encapsulation side.	n.a.	
Transparent OLED	Vertical structure	An OLED which emits light through both encapsulation and substrate sides.	n.a.	
Inverted OLED	Vertical structure	An OLED where the substrate carries the cathode.	n.a.	
OLED Segment	Horizontal structure	Viewed from the emissive side, an OLED segment is a simply connected area defined by the full overlap area of an anode and a cathode. This area may contain non-active areas due to passivation or metallization structures (busbars).	n.a.	
Busbars	Horizontal structure	By design non-lighting, grid-like or other patterned structures within the area of OLED segments used for the improvement of the current density distribution on transparent electrodes.	n.a.	
OLED Tile	Horizontal structure	Functional OLED light source which cannot be separated into smaller OLED lighting elements. An OLED tile exhibits at least one OLED segment and at least one contact ledge with at least one positive (anode) and one negative (cathode) pole for connection to an electrical power supply. In the case that the OLED tile contains more than one OLED segment, these segments can be either independently addressed (the contact ledges exhibit poles for each segment) or the wiring is done on the substrate (parallel or serial) and the segments can only be addressed together.	n.a.	
OLED Cell	Horizontal structure	Small partial area of an OLED segment whose boundaries are defined by – usually periodic – busbar structures. An OLED cell cannot be independently addressed.	n.a.	
Contact Ledge	Horizontal structure	Metallised area, typically at the edge of an OLED tile, exhibiting one or more poles for electrical connection of the OLED tile.	n.a.	
OLED Module	Higher integration levels	An OLED module is an assembly of one or more OLED tiles and at least one additional component such as connectors, flex-PCBs (printed circuit boards), passive or active electronic components, caps or lampholders, etc.	n.a.	

OLED Cluster	Higher integration levels	An OLED cluster is an OLED module containing more than one OLED tile in an irregular arrangement.	n.a.	
OLED Array	Higher integration levels	An OLED array is an OLED module containing more than one OLED tile in a regular arrangement.	n.a.	
Cap	Higher integration levels	A housing, casing or fixture which holds an OLED tile or an OLED module. It contains – usually standardised – interfaces for electrical and mechanical connections.	n.a.	
OLED Lamp	Higher integration levels	An OLED tile or OLED module with a cap providing - usually standardised – mechanical and electrical interfacing.	n.a.	
Lampholder	Higher integration levels	A fixture with – usually standardised – electrical and mechanical interfaces capable of holding an OLED lamp.	n.a.	
Light Output Area A_{LO}	Area Dimensional Quantity	Area of a flat light source (in case of OLED technology an OLED tile or an OLED segment) – defined by design layout – which emits light; including inner non-lighting areas like defects, busbars or other mechanical structures.	m²	 Example, where A_{LO} is given by A*B.

Active Lighting Area A_{act}	Area Dimensional Quantity	Area of a flat light source (in case of OLED technology an OLED tile or an OLED segment) – defined by design layout – which emits light; including inner non-lighting areas due to defects, but excluding layout defined busbars and other mechanical structures.	m²	 Example, where A_{act} is given as a sum of nine OLED cell areas defined by busbar structures. (A_{act} = 9*a*b)
Aperture ratio F	Area Dimensional Quantity	Quotient of Active Lighting Area and Light Output Area $F = \frac{A_{act}}{A_{LO}}$	1	Can be used for a single OLED tile, but also for OLED arrays; also known as fill factor,
Radiant Flux Φ_e ; (Φ, P)	Electro-optical Quantity (General Lighting)	Power emitted, transmitted or received in form of radiation.	W	Taken from IEC60050 Chapter 845
Luminous Efficacy of a source η_v; η	Electro-optical Quantity (General Lighting)	Quotient of the luminous flux emitted by a source and the power P consumed by the source. $\eta = \frac{\Phi_v}{P}$	lm/W	Taken from IEC60050 Chapter 845; a guideline for measuring the luminous efficacy of an OLED light source is given in the OLLA white paper "**OLLA White Paper on the Necessity of Luminous Efficacy Measurement Standardisation of OLED Light Sources**" (www.olla-project.org)

Luminous Efficacy of Radiation	Electro-optical Quantity (General Lighting)	Quotient of the luminous flux Φ_v by the corresponding radiant flux Φ_e $K = \frac{\Phi_v}{\Phi_e}$	lm/W	Taken from IEC60050 Chapter 845
Luminous Flux Φ_v ; Φ	Electro-optical Quantity (General Lighting)	Quantity derived from radiant flux Φ_e by evaluating the radiation according to its action upon the CIE standard photometric observer. For photopic vision $\Phi_v = K_m \int_0^\infty \frac{d\Phi_e(\lambda)}{d\lambda} \cdot V(\lambda) d\lambda$ where **$d\Phi_e(\lambda)/d(\lambda)$** is the spectral distribution of the radiant flux and **$V(\lambda)$** is the spectral luminous efficiency	lm	Taken from IEC60050 Chapter 845; Value for K_m is also reported there.
Power (consumption) *P*	Electrical quantity	Electrical power consumed by a) a light source b) a light source with electronic control gear c) a luminaire with one or more light sources and/or one or more electronic control gears	W	
Forward direction	General	Direction of electrical current that results when the HIL / HTL side of the OLED stack (p-type region) connected to an electrode is on **positive** potential relative to the EIL / ETL side (n-type region) connected to the other electrode. It is marked by the subscript *F*.	n.a.	
Reverse direction	General	Direction of electrical current when the HIL / HTL side of the OLED stack is connected to an electrical contact which is on **negative** potential with regard to the connection of the EIL / ETL side. It is marked by the subscript *R*.	n.a.	
Forward current I_F	Electrical quantity	Electrical current in forward direction.	A	
Forward voltage V_F	Electrical quantity	Potential difference pertaining to the forward direction dependent on the forward current.	V	
Reverse current I_R	Electrical quantity	Electrical current in reverse direction.	A	

Reverse voltage V_R	Electrical quantity	Potential difference pertaining to the reverse direction dependent on the reverse current.	V	
Current Performance r	Electro-optical Quantity	Quotient of the averaged luminance $\overline{L}$ of an OLED light source and the averaged current density $\overline{J}$ caused by the electrical supply at a given device temperature. $r = \frac{\overline{L}}{\overline{J}}$	cd/A	Widely used term in the literature is “current efficiency”. However, this is not correct since an “efficiency” has to be dimensionless. **OLED100.eu welcomes counterproposals.**
Luminance (in a given direction, at a given point of a real or imaginary surface) L	Electro-optical Quantity	Quantity defined by the formula $L = \frac{d\Phi_v}{dA \cdot \cos\theta \cdot d\Omega}$ where $d\Phi_v$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam	cd/m²	Taken from IEC60050 Chapter 845
Averaged Luminance $\overline{L}$	Electro-optical Quantity	Quotient of the luminous intensity I_v of an OLED tile and the Light Output Area A_{LO}	cd/m²	
Emission ratio	Electro-optical Quantity	Ratio of the two averaged luminance values on both sides of a transparent OLED. The ratio is given in a normalised form, stating the bottom side value first. The smaller value is normalised to unity.	x : 1 or 1 : x	

Internal Quantum Efficiency η_{IQE}	Electro-optical quantity	A quantity describing the yield of generated photons with regard to injected charge carriers (electrons). It can be expressed as $\eta_{IQE} = \gamma * \eta_{s/t} * \eta_{rad,eff} * 100\%$ where γ is the charge recombination factor, i.e. the quotient of excitons and injected electrons in the same period of time; $\eta_{s/t}$ is the fraction of excitons which are allowed to decay radiatively according to spin statistics (0.25 for fluorescent emitters, 1.0 for phosphorescent emitters); $\eta_{rad,eff}$ is the effective radiative quantum efficiency, in other words the quotient of the number of excitons which effectively decay under radiation of light and the number of excitons which are allowed to decay radiatively according to spin statistics. It is given by $\eta_{rad,eff} = \frac{k_r^*}{k_r^* + \sum k_{nr}} = \frac{\eta_{rad}}{\eta_{rad} + \frac{k_r^*}{k_r}(1-\eta_{rad})}$ with the radiative quantum efficiency η_{rad} $\eta_{rad} = \frac{k_r}{k_r + \sum k_{nr}}$ and where k_r^* is the radiative decay rate determined by the boundary conditions of the electromagnetic field in the optical cavity, k_r is the radiative decay rate in an – electro-magnetically – unbounded emitter material and Σk_{nr} is the sum of the decay rates of all competing (non-radiative) processes.	%	Deduced from **B.C. Krummacher et al. / Organic Electronics 10 (2009) 478–485.**

External Quantum Efficiency η_{EQE}	Electro-optical Quantity	Quotient of the number of photons extracted from an OLED in a fixed period of time $\dot{n}_{phot}$ and the number of electrons injected into the OLED in the same period of time $\dot{n}_{electr}$. The value is usually expressed in %. $\eta_{EQE} = \frac{\dot{n}_{phot}}{\dot{n}_{electr}} * 100\%$ It can be measured by the determination of radiant flux and current consumption. Alternatively, it can be expressed as $\eta_{EQE} = \eta_{IQE} * \eta_{out}$ where η_{out} is the extraction efficiency. η_{out} contains optical loss modes such as surface plasmon polaritons or waveguided modes. As well as η_{IQE} it is not directly measurable or it is at least very difficult.	%	Deduced from **B.C. Krummacher et al. / Organic Electronics 10 (2009) 478–485.**
Outcoupling Efficiency η_{out}	Electro-optical quantity	Quotient of the external quantum efficiency and the internal quantum efficiency. $\eta_{out} = \frac{\eta_{EQE}}{\eta_{IQE}}$		
Contrast (in a given direction of a real or imaginary surface) *C*	Electro-optical Quantity	Quotient of the maximum luminance L_{max} and the minimum luminance L_{min} on a given surface of a light emitting area (excluding non-lighting areas like defects and bus-bars) $C = \frac{L_{\max}}{L_{\min}} = U_{ISO}$	1	Also called "Uniformity" (for displays) at **International Organization for Standardization, *ISO 13406-2:2001 and EN ISO 13406-2:2003*, www.iso.org, 2001**

Threshold Contrast C_{th}	Horizontal Optics and Perception	Contrast of a light emitting surface which is just noticeable by a human viewer.	1	Subjective rating which can differ from viewer to viewer and will also depend on the viewing angle and the luminance level and layout.
Tolerance Contrast C_{tol}	Horizontal Optics and Perception	Contrast of a light emitting surface which is tolerated or accepted by a human viewer as non-disturbing.	1	Subjective rating which can differ from viewer to viewer and will also depend on the viewing angle and the luminance level and layout.
Uniformity and Non-uniformity	Horizontal Optics and Perception	Describes changes of luminance or chromaticity without any consideration of parameters affecting the visual perception, aside from the definition of the CIE standard observer.		
Homogeneity and Inhomogeneity	Horizontal Optics and Perception	Describes changes of luminance or chromaticity including the consideration of parameters affecting the visual perception like luminance and chromaticity gradients and others.		
Illuminance (at a point of a surface) E		Quotient of the luminous flux $d\Phi_v$ incident on an element of the surface containing the point, by the area dA of that element. *Equivalent definition.* Integral, taken over the hemisphere visible from the given point, of the expression $L_v \cdot \cos\theta \,.\, d\Omega$, where L_v is the luminance at the given point in the various directions of the incident elementary beams of solid angle $d\Omega$, and θ is the angle between any of these beams and the normal to the surface at the given point. $E = \frac{d\Phi_v}{dA} = \int_{2\pi sr} L_v * \cos\theta * d\Omega$	lm/m² = lx	Taken from IEC60050 Chapter 845

Luminance Uniformity of a light emitting surface *U*	Horizontal Optics and Perception	Quantity derived by the maximum luminance L_{max} and the minimum luminance L_{min} on a given surface of a light emitting area, several definitions in use: 1) $U = (1 - \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}}) \cdot 100\% = \frac{L_{\min}}{(L_{\max} + L_{\min})/2} \cdot 100\%$ 2) $U = (1 - \frac{L_{\max} - L_{\min}}{L_{ave}}) \cdot 100\%$ 3) $U_{VESA} = \frac{L_{\min}}{L_{\max}} \cdot 100\%$ 4) $U_{SPWG} = (1 - \frac{L_{\min}}{L_{\max}}) \cdot 100\%$	%	1. so far widely used for OLEDs 2. sometimes used **3. Video Electronics Standards Association (VESA), Flat Panel Display Interface Committee, Flat Panel Display Measurements Standard Working Group, Flat Panel Display, Measurements Standard FPDM Version 2, www.vesa.org, 2005** **4. Standard Panels Working Group, *SPWG 3.8,* www.spwg.org, 2007**
Chromaticity difference *ΔE*	Optical Quantity	The difference between two colour stimuli defined as the Euclidean distance between the points representing them in the various colour spaces and calculated as below: a) CIELUV (1976) colour difference $\Delta E_{u'v'} = ((u'_1-u'_2)^2 + (v'_1-v'_2)^2)^{1/2}$ b) CIE-x,y (1931) colour difference $\Delta E_{xy} = ((x_1-x_2)^2 + (y_1-y_2)^2)^{1/2}$ c) UCS colour space 1964 based on u,v colour space $\Delta E = ((U_1-U_2)^2 + (V_1-V_2)^2 + (W_1-W_2)^2)^{1/2}$	1	a) IEC60050 includes *L* b) Basically, not valid, but still very common c) Taken from CIE 13.3-1995 and CIE15:2004

Lifetime	Reliability	Period of time which an OLED tile or OLED module can be operated under specified conditions until it fails. The failure criteria are subject of standardised definitions.	h	Currently, there is no standard available. The most common definitions currently in use are L50 and L70 criteria, meaning the OLED tile reaches 50% or 70% of its initial luminance.