OLED100.eu NEWSLETTER – FEBRUARY 2010

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OLED100.eu and Fast2Light to organise an International Summer School

From 22-28 June 2010 OLED100.eu and Fast2Light, in association with the Polish Supramolecular Chemistry Network, and the Institute of Physical Chemistry of the Polish Academy of Sciences are organizing an International Summer School on OLEDs, "**Organic Optoelectronics on the move",** which will take place at the Conference Centre, Krutyn, Masurian Lake District, Poland.
More information: http://ikss.ichf.edu.pl/OLED2010/

Mark your calendars!

The School is a high-level and highly intensive scientific event focusing on cutting edge know-how in organic optoelectronics aiming at state-of-the-art training in the form of lectures and consulting sessions addressed to Ph.D. students and young researchers seeking to build knowledge and skills in this field. Top experts will deliver lectures and consulting sessions. The school is intended both for people already active in this R&D field as well as for those new to the field.

OLED100.eu is an FP-7 integrated research project which brings together a consortium of experts from leading industry and academic organizations to accelerate the development of OLED technologies in Europe. It receives €12.5 million funding from the EC's 7th Framework Programme to form the technological basis for efficient OLED applications for the general lighting industry in Europe. OLED100.eu is an important initiative to advance the development of energy efficient lighting solutions.

Partners in the OLED100.eu consortium are: Bartenbach LichtLabor GmbH (AT), European Photonics Industry Consortium (EPIC) (FR), Evonik Degussa GmbH (DE), Fraunhofer Institute for Photonic Microsystems (IPMS) (DE), Microsharp Corporation Limited (UK), Novaled AG (DE), Océ Technologies B.V. (NL), OSRAM Opto Semiconductors GmbH (DE), Philips Technologie GmbH, Business Center OLED Lighting (DE), Philips Technologie GmbH Forschungslaboratorien (DE), Physikalisch-Technische Bundesanstalt (PTB) (DE), Saint-Gobain Recherche S.A. (FR), Siemens AG (DE), Technische Universität Dresden, Institut für Angewandte Photophysik (DE), Universiteit Gent (BE).

The overall objective of Fast2Light is to develop novel, cost-effective, high-throughput, roll-to-roll, large area deposition processes for fabricating light-emitting polymer-OLED foils for intelligent lighting applications. The Fast2Light consortium consists of 14 partners from 8 countries: Swansea University (UK), Budapest University (HU), TNO-Holst Centre (NL), IMEC (Interuniversitair micro-electronica) (BE), Gaiker (ES), OTB DISPLAY (NL), Hanita Coatings (IL), Oxford Lasers (UK), PHILIPS Research (NL), PHILIPS Lighting (DE), BEKAERT (BE), AGFA-GEVAERT (BE), Huntsman (CH), Orbotech (IL).

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Luminance Homogeneity of OLEDs

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Introduction

OLEDs are flat light sources and one of their outstanding properties is that they are large area emitters. This is a very important characteristic which distinguishes them from all other well-known light sources which are more or less point or linear light sources. Other light sources are characterised according to standard procedures, and it is widely known how quantities like luminous efficacy, colour temperature and luminous flux are defined and have to be measured.

For large area light sources the above-mentioned quantities are also important, but since OLEDs already exhibit luminaire or building component properties, other parameters need special attention as well.

One important requirement for highly-efficient white OLED devices is the achievement of a homogeneous light output. One can imagine some direct view applications in general illumination where homogeneity plays a very important role – also in an aesthetical sense. Some definitions on uniformity have already been made for displays or display backlights, but the requirement in this segment is less severe because of moving pictures. The perception of a static light tile is the most critical issue.

All known definitions of uniformity or homogeneity just take minimum and maximum luminance into account and neglect spatial effects like distribution patterns and gradients as indicated in the figure below. Two different luminance distribution patterns (for example in figure 1) might deliver the same uniformity value – for this case only minimum and maximum luminance are considered in the formula – but the perceived homogeneity, due to different brightness gradients, might be completely different.

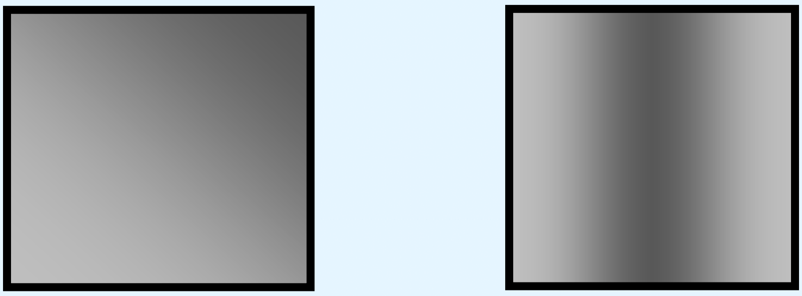

Figure 1: Two different luminance distribution patterns with the same minimum and maximum luminance; the left pattern is perceived as much more homogenous than the pattern on the right since the luminance gradient is roughly just a third of the one in the right pattern.

A special OLED topic in defining luminance homogeneity is the treatment of the so-called busbar structures which are used in some OLED designs. The inhomogeneities shown in the above figure are mainly caused by the limited conductivity of the indium tin oxide (ITO) electrode. One possibility to improve the conductivity is to use metal support lines (busbars), which can reduce the effective ITO resistance significantly as one can see in figure 2.

The busbars are not transparent and, thus, a busbar grid is visible as black lines with customisable pitch and thickness on the OLED. In addition the active lighting area is reduced.

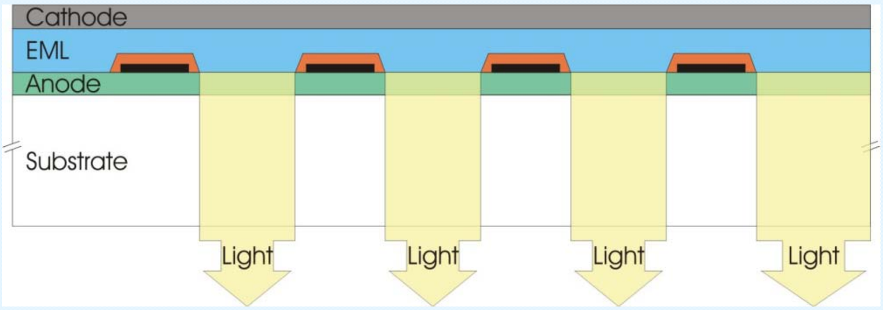

Figure 2: OLED with busbars (black) and corresponding insulators (orange) to improve homogeneity of the active lighting area (yellow). Please note that all kinds of light-guiding, stray light etc. are disregarded in this schematic view.

As one can see, a lot of different OLED designs and shapes are available and many more can be thought of. However, almost each OLED for lighting applications is required to have a homogenous light output area. Therefore, it is necessary to create homogeneity measurement standards with regard to different designs and shapes.

The OLED100.eu project addresses this topic (amongst others) in one of its five technical workpackages (WPs). The WP “Application Research” is led by one of the authors (Karsten Diekmann) and in this framework the expertise of the “Physikalisch-Technische Bundesanstalt” (PTB) is used. PTB’s main objective in this context is to develop measuring setups for measurements of photometric quantities which are traceable to the SI units. It is important to mention that PTB is a leading member of the international metrological organisations and offers traceability to the national realisations of the units, which are equivalent to the international reference values. That means that PTB´s calibration certificates are accepted world-wide.

The goal of OLED100.eu is to come up with a proposal for the definition of homogeneity which reflects the needs of lighting applications and perceivers. A reportership under the leadership of PTB has already been initiated within the “Commission Internationale d’Eclairage” (CIE) and this activity will ultimately lead to a widely accepted standard definition [1].

Luminance Homogeneity - Definition and Measurement

In the OLED community most photometric measurements are based on the determination of OLED luminance.
Luminance L is defined as luminous intensity $\mathrm{d}I$ (SI unit of this quantity is cd) of an area $\mathrm{d}A$, or, more precisely, as partial luminous flux emitted by an area and propagating in the solid angle $\mathrm{d}\Omega$ containing the given direction.

$$L = \frac{\mathrm{d}I}{\mathrm{d}A} = \frac{\mathrm{d}\Phi}{\mathrm{d}A \cdot \mathrm{d}\Omega}$$

A detailed description of various systems to determine luminance is not undertaken here. It has to be mentioned that a preferred option is the use of Imaging Luminance Measurement Devices (ILMDs). The use of CCD cameras allows the comparison of various locations within a larger lighting area.

Homogeneity and Uniformity

Homogeneity refers to a quantity that characterises the changes of luminance or colour over the surface of an OLED. However, just the differences are not enough to describe the appearance of the OLED. The gradient of the luminance changes over the light output area is one criterion which has to be regarded.
The success of many photometric measuring procedures is based on the definition of standard observers. Hence, the determined values of photometric quantities like luminance do not correspond to the perception of an individual but to the CIE standard observer.
Many existing measuring procedures for displays determine the uniformity or non-uniformity of the device. These definitions do not consider copious perception aspects like the gradient. Later we will show some examples.
Therefore, it is suggested to use the following definitions for the terms uniformity and homogeneity:
Uniformity and non-uniformity describe changes of luminance without any consideration of parameters affecting the visual perception, aside from the definition of the CIE standard observer.
Homogeneity and inhomogeneity describe changes of luminance including the consideration of parameters affecting the visual perception like the luminance gradient.

Sampling Scheme

A practical system for measuring homogeneity must be quick and easy. Too much complexity guarantees that it will not be used.
In other words: It is not useful to define a formula with too many variables such as

$$\textit{Homogeneity} = \mathrm{f}\,(\textit{mean luminance}, \textit{maximum luminance}, \textit{minimum luminance}, \textit{gradient of luminance}, \textit{surrounding luminance}, \textit{location}, \textit{age of perceiver}\ldots)$$

Such a formula might ultimately be correct, but a good model should just describe reality in a sufficient way. Therefore, one should identify just the dominant parameters which affect the visual perception of homogeneity.
There is a consensus in the OLED100.eu project that the gradient of luminance is the most dominant parameter in the perception of homogeneity.
In the following, models are developed which describe homogeneity by including the luminance and the luminance gradient. More parameters might be added as the procedures become fully developed.
A symmetrical sampling scheme is recommended for determining the homogeneity of OLEDs. For a rectangular flat light output area it is advisable to put one measuring spot in the centre and 4, 8, or 12 additional measuring spots evenly distributed around the centre spot.
More than 13 measuring spots will unnecessarily increase the complexity without appreciable advantages. As a reference, for the determination of the homogeneity of luminance cameras, a similar setup is chosen. To increase the number would mean to increase the handling effort and to decrease/reduce the speed of the measurement.
For the location of the measurement points, the following recommendations can be derived:

1. The active lighting area is divided into 13 segments with approximately the same area.
2. Each measuring spot L_i is positioned in or as close as possible to the centre of a segment and must be representative of the segment.
3. The area of one measuring spot should be in the range of 10 percent of the segment area.

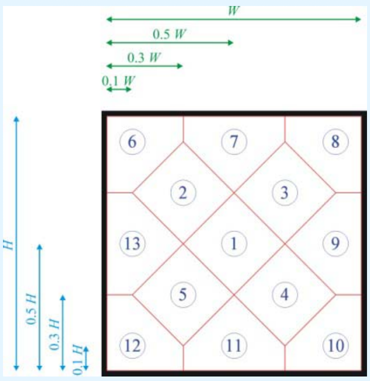

Figure 3: Sampling scheme – W is the width and H is the height of the active lighting area.

The positions of the measuring spots in figure 3 are rounded values of optimised distances for approximately identical areas of each segment. This useful sampling scheme can be simply applied to all kinds of square and rectangular shaped OLEDs. For other shapes of the light output area, slight adjustments have to be made, but the three recommendations mentioned above remain valid. Due to the size of the measurement spots, it is assured that a measurement on a single spot is not dominated or heavily influenced by busbars. All busbar patterns in common OLED designs with fill-factors > 75% (meaning that more than 75% of the light output area is a real emissive area and less than 25% is covered by busbars) just act as a slight grey filter on the single measurement, not affecting the macroscopic determination of homogeneity.

This proposal is not able to consider defects and very short range modulations. Defects are a non-reproducible effect on OLED lighting tiles. In production, they have to be sorted out by specific failure recognition modes. On shipped products they should not occur, thus, they are negligible for homogeneity definition and measurement. For short range modulations it is at least questionable whether they are application relevant. It may highly depend on parameters like viewing distance and some customers may regard darker areas as defects.

Homogeneity and Uniformity Models

For the purpose of comparison, we have calculated here for all OLEDs not only homogeneity values, but also uniformity values based on definitions from standards for measuring flat panel displays (see table 1).

Established Uniformity Standards

The VIDEO ELECTRONICS STANDARD ASSOCIATION (VESA) standard for FLAT PANEL DISPLAY MEASUREMENTS (FPDM) [2] seems to be a main standard in industry. The sampling scheme for the determination of the Uniformity U_{VESA} requires that the luminance meter is positioned at five or optionally nine locations perpendicular to the display surface.

A second definition is defined by the INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO 13406-2) [3]. The measuring setup is complex and depends on the display size, direction, the recommended position of the eye and some other parameters. In the simplest scenario the calculation of the uniformity ratio U_{ISO} requires three measuring spots. The uniformity ratio U_{ISO} is assessed against a maximum allowed compliance threshold, which depends on measuring point locations and varies from 1.3 to 1.7. The definition is application oriented and specifies flat panel displays for office environments.

The STANDARD PANELS WORKING GROUP (SPWG) recommendation for measuring the uniformity of displays uses 13 measuring spots [4]. The arrangement is similar to the recommendation of OLED100.eu, but the size of the area segments follows a different rule. They are not of similar size. In contrast to all other definitions, a value of 0% for U_{SPWG} indicates a perfectly uniform luminance distribution.

$$U_{\mathrm{VESA}} = 100\% \frac{L_{\min}}{L_{\max}} \qquad U_{\mathrm{ISO}} = \frac{L_{\max}}{L_{\min}} \qquad U_{\mathrm{SPWG}} = 100\% \frac{L_{\max} - L_{\min}}{L_{\max}}$$

Homogeneity Models

In the models presented in the following, luminance homogeneity is a quantification of the luminance distribution on the surface of the active light output area of an OLED with respect to the luminance gradient. As stated earlier, this quantity is considered to be the most important one for the definition of homogeneity. It will be shown that alternative approaches are possible. The first approach is taking the maximum luminance gradient into account while the second is focusing on a mean gradient. Consequently, we define the first quantity simply as homogeneity while the second one is defined as mean homogeneity.

The distance between two measuring points follows from Pythagoras' theorem $d_{ij} = \sqrt{(\vec{i} - \vec{j})^2}$ where i and j are the positions of two measuring spots.

The mean luminance of the OLED is $L_{\mathrm{mean}} = \frac{1}{13}\left(\sum_{i=1}^{13} L_i\right)$

Following this, the homogeneity H can be defined as

$$H = 1 - \mathrm{Max}\left[\frac{|L_i - L_j|}{(d_{ij})^{\varepsilon}}\right] \Big/ \frac{L_{\mathrm{mean}}}{(\mathrm{Max}[d_{ij}])^{\varepsilon}}$$

where L_i and L_j are the luminance values of the measuring spots i and j, respectively. ε is a weighting factor to achieve the best match with visual perception.
In case of $\varepsilon = 1$ the numerator of the fraction is the maximum gradient and the denominator is just a normalising term. Basically, the weighting factor does not make a certain luminance distribution pattern worse or better compared to another pattern. It may serve two purposes. On the one hand the weighting factor can spread or compress the different values for different patterns. A good choice of the weighting factor delivers results of homogeneity determination which are highly plausible to a non-expert. An evaluation or judgement scheme of such results could be (as an example):

1.0 to 0.8	very homogeneous
0.8 to 0.6	homogeneous (i.e. still acceptable from an application point of view)
0.6 to 0.4	inhomogeneous (i.e. irritating, not acceptable for direct view applications)
< 0.4	very inhomogeneous.

The second purpose of this weighting factor is perception related. It is anticipated that in a certain luminance gradient regime (especially at short distances) linear changes of gradient are perceived as more disturbing by a human observer than in another gradient regime. This might lead to the necessity to set the value of ε to a value different from 1. This is not yet confirmed, but experiences from displays indicate this and future perception studies may deliver additional input.
The alternative proposal for the homogeneity definition is the introduction of the mean homogeneity H_{mean} of the luminance. It can be calculated according to:

$$H_{\mathrm{mean}} = 1 - \sum \frac{|L_i - L_j|}{(d_{ij})^{\varepsilon}} \Big/ \sum \frac{L_{\mathrm{mean}}}{(d_{ij})^{\varepsilon}}$$

Also in this formula a weighting factor can be included.

Simulation Results

Table 1 gives a comparison of values derived from formulas proposed by the OLED100.eu project and from the various display standards for the luminance distribution patterns shown in Fig. 4. The values of L_{min} and L_{max} are equal for all presented luminance distribution patterns. They are kept at 950 cd/m² and 1050 cd/m². It is obvious that the display standards do not distinguish between the various patterns which again emphasises the need for a new standard for lighting applications.

All OLED100.eu formulas derived in the previous section achieve a ranking between the luminance patterns. The ranking is more or less always the same which means the quality of these formulas is good.

In terms of quantification one can see differences. The homogeneity formula focuses on the maximum luminance gradient, thus delivering a larger spread of values. The mean homogeneity formula mainly looks into an average luminance gradient, thus delivering a smaller spread. In general, the mean homogeneity formula also delivers higher values. The weighting factor variation does not lead to big changes in the mean homogeneity values, but for the homogeneity, there is a significant impact.

Table 1: Simulation results for homogeneity and uniformity on three luminance distribution patterns; The values marked in green are derived using the OLED100.eu proposed formulas, the values marked in orange are derived from various display standards. For comparison, the homogeneity values are also given as percentage values. In all cases L_{min} and L_{max} are kept constant (950 cd/m² and 1050 cd/m²).

Distribution Pattern	Bathtub	Corner to Corner	Side to Side
H $\varepsilon = 1$	72.0 %	90.0 %	85.9 %
H $\varepsilon = 0.5$	83.3 %	90.0 %	88.1 %
H_{mean} $\varepsilon = 1$	95.3 %	97.4 %	96.2 %
H_{mean} $\varepsilon = 0.5$	95.5 %	97.2 %	95.9 %
U_{VESA}	90.5 %	90.5 %	90.5 %
U_{ISO}	110.5 %	110.5 %	110.5 %
U_{SPWG}	9.5 %	9.5 %	9.5 %

A first conclusion might be that the homogeneity formula with weighting factor 0.5 delivers a reasonable spread and reasonable values for the newly defined quantity homogeneity. However, it is too early to stop the discussion at this point. As stated above, a reportership in the CIE has been initiated. In this reportership, further input from the lighting community will be collected and considered in the future evolution of this formula.

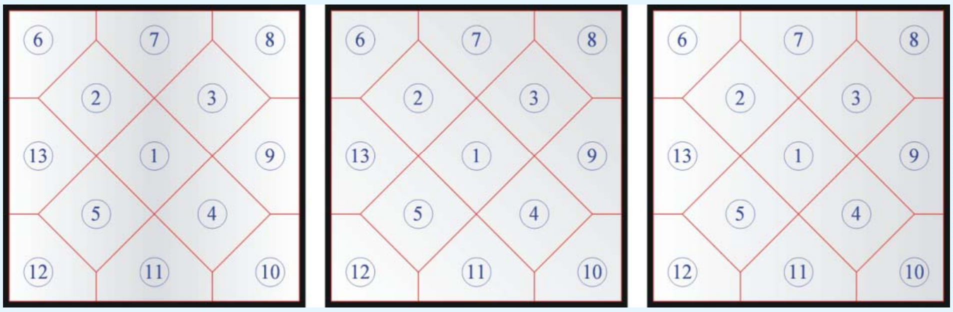

Figure 4: "Bathtub" luminance distribution pattern (left), "Corner to corner" luminance distribution pattern (middle) and "Side to side" luminance distribution pattern (right).

Conclusion

The need for a new standard which defines homogeneity for area emitters in lighting applications is evident. Existing standards from the display industry are not sufficient.

In the framework of the OLED100.eu project the problem of the lack of a suitable homogeneity definition was already addressed at the CIE Division 2 meeting in Budapest in June 2009 [1]. As a consequence, a reportership under the leadership of PTB was initiated. This reportership will bundle the future discussions.

The OLED100.eu proposals are the starting point in the process of deriving a final standard. We have proposed two formulas which have the potential to meet the requirements of such a standard. The formulas contain a special weighting factor making the resulting homogeneity values compatible with human perception. Some perception studies are required to obtain reasonable values for the weighting factor.

Additionally, for the measurement setup, a recommendation to use an imaging luminance measurement device was given.

Colour homogeneity was not addressed in this paper, but some relevant aspects can be transferred. Other aspects are, however, not applicable. OLED100.eu is considering colour homogeneity issues as well.

References

[1] Summary of 2009 CIE Division 2 Meeting, Budapest, Hungary, June 3, 2009: *Photometric characterisation of large area flat sources used for lighting*, Reporter: Armin Sperling (PTB, Germany); TR: To investigate and identify criteria for the characterisation of source spatial uniformity / homogeneity, including measurement procedures and classification. www.cie.co.at

[2] 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

[3] International Organization for Standardization, *ISO 13406-2:2001 and EN ISO 13406-2:2003*, www.iso.org, 2001

[4] Standard Panels Working Group, *SPWG 3.8,* www.spwg.org, 2007