OLEDs – State of the art report

Up-to-date and characterization

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DTU Fotonik
Department of Photonics Engineering

ELFORSK

DCL
Dansk Center for Lys

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Summary

This report is prepared within the project "OLED Academy - prospects for energy saving and design" (ELFORSK: 349-032; DTU PROJECT NO. 71012.). The project is carried out by the department of photonics engineering at the technical university of Denmark (DTU Fotonik) in collaboration with Danish Lighting Centre (DCL), an association of lighting professionals in Denmark, and a group of Danish lighting designers. This report summarize the state of the art of the technology of organic light emitting diodes (OLEDs). The first part of the report introduces the current technology of OLEDs, different types of panels and their performance. The second part presents a characterization of light quality and efficacy of panels available on the market 2015-2018. Since the number of producers are limited and has decreased lately, the characterization covering seven panels from three producers is considered adequate for describing the market. The report is targeted against people within the lighting industry, whether as designers, production, marketing or research, but aims to be available for anyone with an interest in the subject. Within the project, a final report has also been produced, describing the design competition and its results.

OLEDs – up to date

Organic light emitting diodes (OLEDs) is a technique of transforming electricity directly into light. The biggest market for OLEDs are displays, for example for smart phones and TVs. However, ever since the birth of OLEDs, the strife has always been to also use the OLED for general lighting. This report only considers the lighting applications. In contrast to LEDs, OLEDs are not based on crystalline materials, but rather on organic molecules. A further major difference from LEDs, which are to be considered as small-point light sources, is that OLEDs are made in sheets, resulting in diffuse area light sources. Being thin, flat and lightweight is the biggest advantages of OLEDs. OLED lighting is still an emerging solid-state lighting technology, with active research and development started in 1987 and the first commercial product available in 2011 by Lumiotec [Koden, 2016].

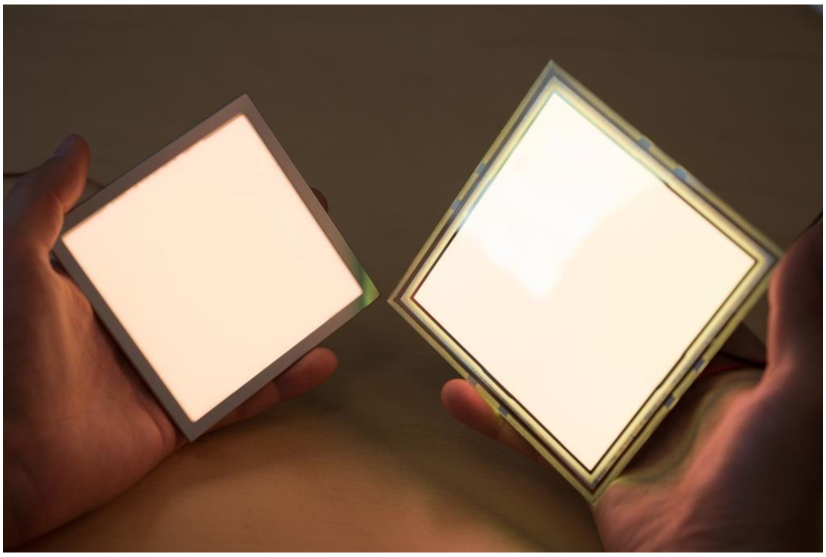


Figure 1 OLED lighting panels. Photo: DTU Fotonik

Introduction to OLED technology

The principle structure of an OLED device is illustrated in Figure 2. It consists of different kinds of organic layers sandwiched between an anode and a cathode. When a voltage is applied over the cathode and the anode, light is generated.

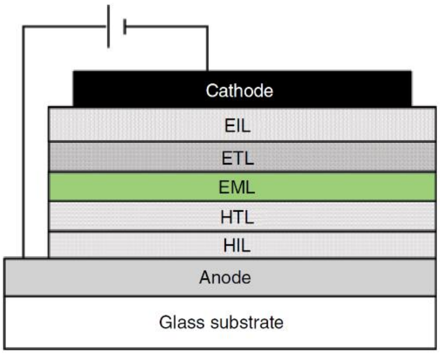


Figure 2 Illustration of a typical OLED device structure [Koden, 2016 p.14]

The layers consists of organic molecules, each layer with different functions. The light itself is generated in the emission layer (EML), when electrons and holes (an absence of an electron) are recombined, transferring energy into the organic molecules, which then are excited. Emission of photons occurs when the excited state of the molecule relaxes to the ground state. Holes are injected from the anode and electrons are injected from the cathode. In Figure 2, the different layers are named by its function: electron injection layer (EIL), electron transport layer (ETL), emission layer (EML), hole transport layer (HTL) and hole injection layer (HIL). The individual layers of the OLED are in the µm-scale, i.e. extremely thin, and the resulting panels are often less than 1 mm thick. The limitation of the thickness are due to the encapsulation.

Different types

In order for the OLED device to emit the light, the anode or cathode needs to be transparent. With the anode transparent, the device is classified as a *bottom emission type*, and with the cathode transparent, the device is classified as a *top emission type*. Both the anode and the cathode could be transparent, in which case the device then is classified as a *transparent type*. The entire device is then transparent when turned off, and emits light in both directions when turned on. In most cases, a transparent anode is deposited on a glass substrate, hence resulting in a bottom emission type. Using a reflective rather than an opaque cathode, the device acts like a mirror when turned off.

White OLEDs

The color of the light emitted from an OLED depends on the type of molecule consisting in the emission layer. A large range of different colors are available, and for lighting applications an appropriate mix of different colors are needed in order to generate white light. There are several methods for obtaining white light, the most common one being stacking a number of emission layers with different emission spectra. For example, a blue emission layer and a yellow emission layer could be combined (see Figure 3). However, stacking three emission layers of red, green and blue are needed for achieving a higher color rendering index. With three emission layers a color rendering index of 90 or higher is possible.

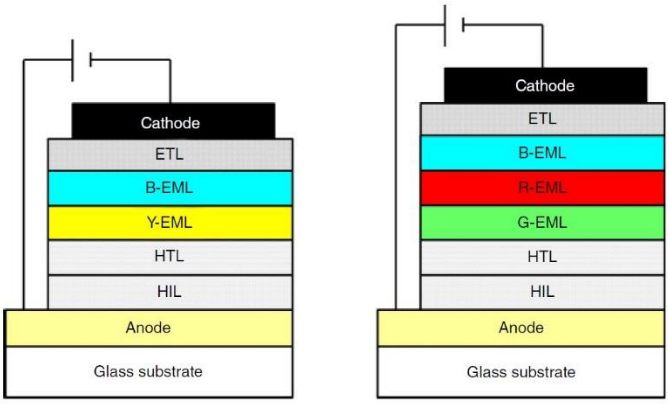


Figure 3 Examples of white OLED lighting devices with stacked emission layers with different spectra [Koden, 2016 p.152]

Performance of OLED lighting

While the performance of OLED lighting has increased steadily, the efficacy numbers are still surpassed by those of LEDs, which is reported 205 lm/W for a lamp system from Osram [Osram, 2014] and 303 lm/W for laboratory result from Cree [Cree, 2014]. Even though the efficacy record for OLEDs in laboratory have been reported to be as high as 139 lm/W [Koden, 2016], this is not yet what to be expected by products available on the market. Among the most active OLED manufacturers, the declared efficacies of the available products ranges from 40 lm/W (Kaneka) to 90 lm/W (LG). In a report from US Department of Energy [Miller, 2017] 2015, the declared efficacies of some investigated panels were in the range from 23 lm/W to 45 lm/W. Then again, these numbers should not be confused with those reported by independent laboratories. In Table 9 on page 19, the results of some investigated OLED panels recently purchased are shown.

As mentioned above, OLED panels needs to be encapsulated. This needs to be done in order to prevent degradation of the organic molecules by water and oxygen in the ambient air. This degradation is the main factor determining the lifetime of the panels. The better encapsulation, the longer the lifetime. This is one of the facing challenges regarding breakthroughs of OLEDs. The rated lifetime (L70) of available panels on the market spans from 10.000 to 40.000 hours, and as for the case of LEDs, the lifetime increases with lower forward current. However, it lacks official publications considering lifetime investigations of OLEDs, partly due to the lack of measurement standardization. However, the international commission on illumination, CIE, recently published a supplement to CIE S 025:2015 [CIE, 2019] which specifies the requirements for measurements of OLED luminaires and OLED light sources.

Market review

Several companies offers OLED products, most of them as displays, as mentioned above. Manufacturers for OLED panels for lighting include LG Display, Kaneka Corporation, and OLEDWorks. Still the production lines are small, and most of the panels should be considered as "samples", as production levels are low. In 2015 there were 17 companies on the market offering OLED panels [ELFORSK, 2016].

Because OLEDs have been in somewhat a catch 22, where the market needs to grow in order for the technology to develop, and the technology needs to develop for the market to grow, initiatives have continuously been taken in order to boost breakthroughs. One of these initiatives has been the three-year EU-funded Flexolighting programme, coordinated by Brunel University London [Flexolighting, 2018]. In September 2018, they announced that a potential production cost of 14 USD/1000lm was achieved. This compared with the current position of around 180 USD/1000lm, hence corresponds to a cut in costs by 92%. Again, this could be compared to the cost of LEDs, which since the 1970s have had a reduction with a factor of 10 per decade, and today has a purchase price of 1 USD/1000lm [Cho, 2017].

Products

Most panels available comes in square shapes and different sizes, but mostly about 100x100 mm. Rectangular shape is also common, in size up to about 50x200 mm. OLEDWorks also offers a circular shape, diameter about 100 mm.

As mentioned above, panels can be made transparent or reflecting like a mirror, depending on type and substrate.

The encapsulation, which is needed in order to prevent degradation, can be realized in the form of plastic or glass. Plastic is very suitable for flexible panels, but not by far as encapsulating as glass, making long lifetime hard to achieve for flexible plastic OLEDs. Up until recently, several flexible OLED where available. The possibility of adding a desiccant (moister absorber) inside the encapsulation is also utilized. OLEDWorks recently developed a bendable panel made of "bendable" glass (see Figure 4). This BendOLED [OLEDWorks, 2018] is encapsulated with such a thin layer of glass, that the panel becomes flexible, with a bending radius of about 10 cm and a rated lifetime of 10 000 hours at highest light level output.

Figure 4 Flexible OLED from OLEDWorks. Photo: Carsten Dam-Hansen

Luminaires

Both OLEDWorks, Kaneka and LG Display offers OLED luminaires, and at the Light+Building exhibition in Frankfurt 2018 companies like Escale, Lighting Technologies, Sumitomo Chemical and Haechan Co. Ltd were found among the luminaire producers. See Figure 5 to Figure 8.

Figure 5 OLEDWorks. Photo: DCL

Figure 6 Lighting Technologies. Photo: DCL

Figure 7 Round OLED panel with moon pattern from Sumitomo Chemical. Photo: DCL

Figure 8 LG. Photo: DCL

Challenges

There are some key barriers inhibiting the commercial viability of OLED lighting, including several areas of cost reduction and core research activities. Below five major challenges are briefly described [DOE, 2018].

Cost

For OLED lighting to gain the market entry point, cost reduction needs to be achieved in the areas of substrate, stack, encapsulation, production equipment and materials.

Materials

The materials used in OLEDs needs to be soluble in the productions phase, and to find feasible solvent is still a challenge.

Drivers

At the moment there are not standardized way to power OLEDs with respect to voltage and current. Still many product solutions needs customized driver solutions.

Lifetime

The materials used for light generation in OLEDs are subject to degradation, much more than in the case of LEDs. The degradation, and thus the lifetime, needs to be controlled by effective encapsulation, in order to reduce contact with water and oxygen in the ambient air.

Light Extraction

Photons emitted by the luminous materials in the OLED are emitted in all directions. The challenge is to have this photons not trapped in the glass or the different organic materials but to get as much light as possible into the viewing angle of the OLED. This would highly increase the efficacy of the OLED.

Standards

Partly because of the small market volume standards for performance and characterization of OLED, have been delayed compared to the standardization of general LED lighting. However, as mentioned above, CIE recently published an intentional standard for measurement of OLED luminaires and OLED light sources [CIE, 2019].

Characterization

This part of the report presents the results of the characterization measurements done on a number of OLED panels recently produced. From a total number of three OLED manufacturers (Kaneka, LG Display and OLEDWorks), seven panels has been characterized with respect to photometric and colorimetric properties.

The panels tested differs in dimensions, light characteristics and efficacy. See Table 1 for detailed, rated, information of the measured light sources.

Manufacturer	Product name	Size (mm)	U (V)	I (mA)	P (W)	CCT (K)	Flux (lm)
Kaneka*	KN-P-HC-BK-30-U	80x80	6.9	250	1.73	3000	60
Kaneka	KN-P-HC-EF-30	15.1x137.5	6.8	86	0.58	3000	19
LG*	N6SB30	53x55	8.5	40	0.34	3000	20
OLEDWorks	Brite 2 FL300 WW Level 1	102x102	20	260	5.2	3000	300
OLEDWorks	Brite 2 FL300 NW Level 1	102x102	20	260	5.2	4000	250
OLEDWorks	BendOLED WW Level 1	46x221	19.5	295	5.8	3000	300
OLEDWorks*	Brite 3 FL200R WW Level 1	102x102	18.7	145	2.7	3000	200

Table 1 The OLED panels that where measured and characterized within the project. The asterix (*) marks the three panels which have been investigated as a function of current.

Method

The panels were investigated using both a near field goniophotometer (TechnoTeam RiGO 801) and a 2m integrating spherespectroradiometer (ISP 2000 CAS 140CT, Instrument Systems). Besides a photometer, which enables Light Intensity Distribution (LID) diagrams, the goniophotometer is also equipped with a luminance camera, enabling 2D luminance images of the panels from different angels. With the integrating sphere, which is used for measuring total luminous flux and spectral power distribution, the panels were measured through a 300mm port in the sphere, a so-called 2π measurement. During measurements in both the goniophotometer and the integrating sphere, both the current and voltage, and hence the power consumption of the panels, are measured, enabling measurement of the efficacies of the panels. With this equipment, the following parameters where measured for all the panels:

- Total luminous flux [lm]
- Correlated color temperature (CCT) [K]
- Luminous efficacy of source [lm/W]
- Luminance (2D from 0, 45 and 60 degrees) [cd/m^2]
- Colour Rendering Index (CIE CRI R_a, R_9, TM-30 R_f, R_g and color vector graphics)
- Light intensity distribution (LID)
- Spectral Power Distribution (SPD)
- Chromaticity coordinates (x,y)

Additionally, for three of the above panels (marked with an asterix (*) in the table) the following parameters where measured as a function of forward current:

- Voltage [V]
- Luminance [cd/m^2]
- Total luminous flux [lm]
- Luminous efficacy of source [lm/W]
- Chromaticity coordinates (x,y)

Results

The following pages completes the results of the characterization and measurements, first for all the seven panels operating at rated forward current and then for three selected panels which were characterized as a function of forward current.

Characterization of seven panels at rated current

The results of the panels at rated forward currents are in the following pages presented in identical manner for each of the seven panels, in order for easier comparison.

Photograph, spectrum and light intensity distribution are shown at the first row.

Second row shows the 2-dimensional luminance images from three different angles with respect to the normal of the panel surface: 0, 45 and 60 degrees. Then follows a table presenting the measured and rated values of total luminous flux, correlated color temperature, consumed electrical power, luminous efficacy of source, luminance, color rendering index R_a, special rendering index R_9 and chromaticity coordinates.

Last the IES color vector graphics (TM-30-15) are shown, together with IES R_f, R_g and “Delta u,v”-distance, D_{uv}.

After the presentation of the individual panels, a summary and analysis of the results follows.

Kaneka 60 lm

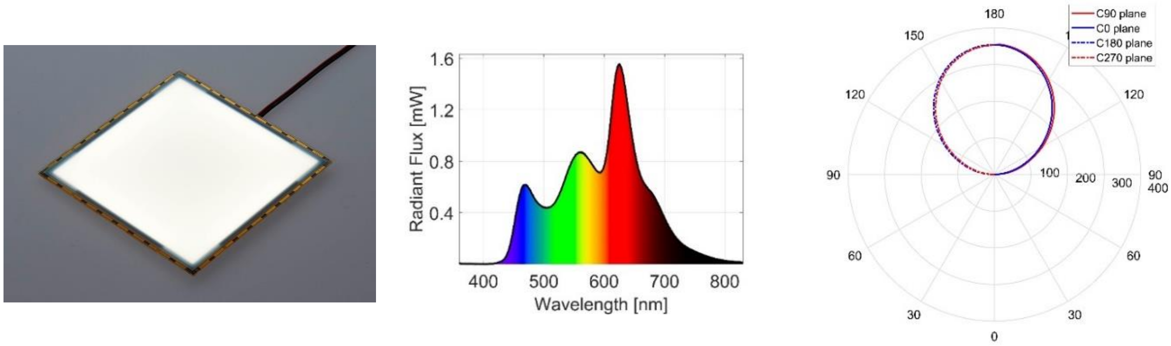


Figure 9 Kaneka 60 lm panel. From left to right: Photo of the panel; Emission spectra; Light intensity distribution

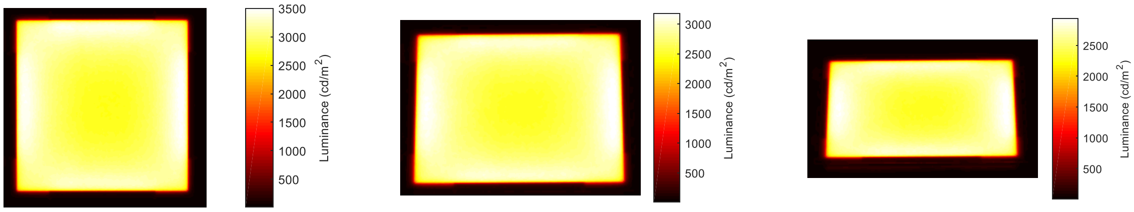


Figure 10 Kaneka 60 lm. 2D luminance images at three different angels. From left to right: 0 degrees; 45 degrees; 60 degrees.

	Flux (lm)	CCT (K)	Power (W)	η (lm/W)	L (cd/m2)	Ra	R9	(x,y)
Measured	56.5	3038	1.83	30.9	3025	94.5	88.0	(0.4341, 0.4029)
Rated	60	3000	1.73	34.8	3000	93	-	(0.434, 0.403)

Table 2 Measured and rated values for Kaneka 60 lm.

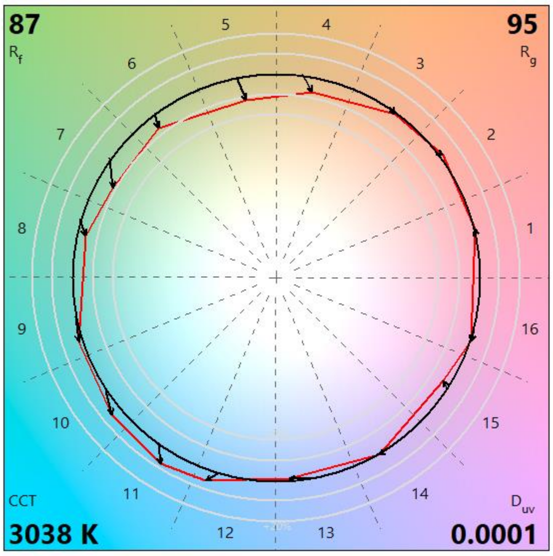


Figure 11 IES Color Vector Graphics (TM-30-15) together with IES R_f, R_g, CCT and D_{uv} for Kaneka 60 lm.

Kaneka 19 lm

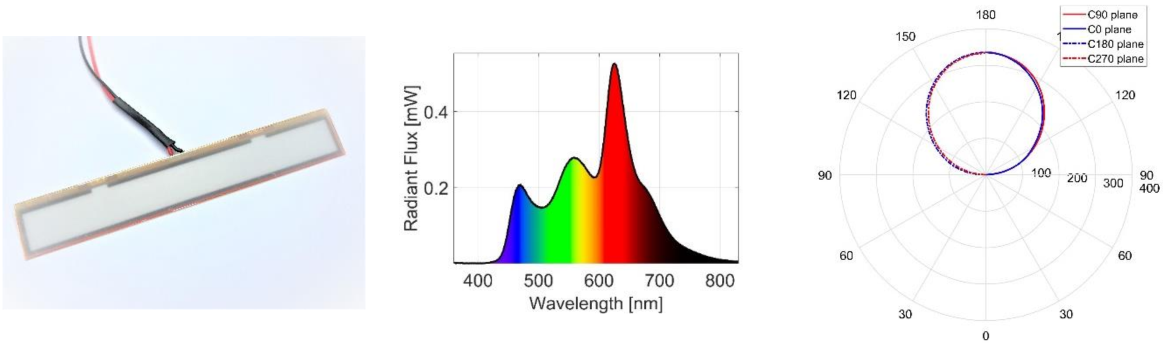


Figure 12 Kaneka 19 lm panel. From left to right: Photo of the panel; Emission spectra; Light intensity distribution

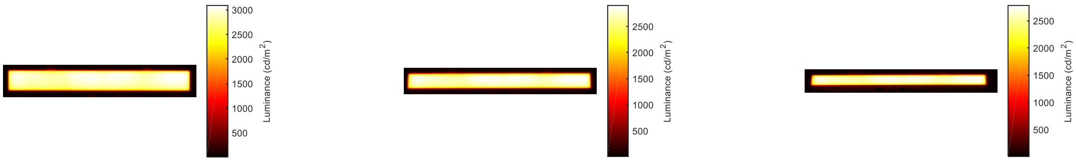


Figure 13 Kaneka 19 lm. 2D luminance images at three different angels. From left to right: 0 degrees; 45 degrees; 60 degrees.

	Flux (lm)	CCT (K)	Power (W)	η (lm/W)	L (cd/m2)	Ra	R9	(x,y)
Measured	18.5	3008	0.61	30.2	2757	92.8	79.5	(0.4394, 0.4008)
Rated	19	3000	0.58	32.5	3000	92	-	(0.434, 0.403)

Table 3 Measured and rated values for Kaneka 19 lm.

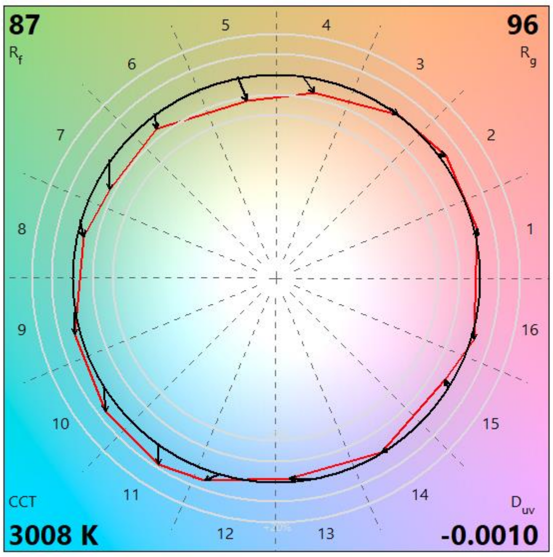


Figure 14 IES Color Vector Graphics (TM-30-15) together with IES R_f, R_g, CCT and D_{uv} for Kaneka 19 lm.

LG 20 lm

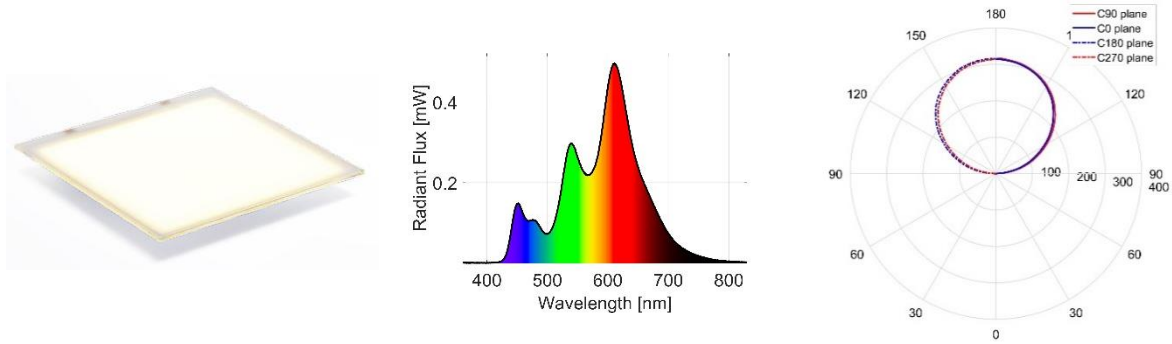


Figure 15 LG 20 lm panel. From left to right: Photo of the panel; Emission spectra; Light intensity distribution

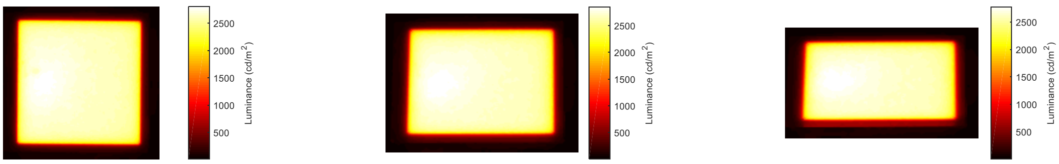


Figure 16 LG 20 lm. 2D luminance images at three different angels. From left to right: 0 degrees; 45 degrees; 60 degrees.

	Flux (lm)	CCT (K)	Power (W)	η (lm/W)	L (cd/m2)	Ra	R9	(x,y)
Measured	19.1	2754	0.39	49.0	2536	90.9	31.9	(0.4540, 0.4068)
Rated	20	3000	0.34	58.8	-	90	-	-

Table 4 Measured and rated values for LG 20 lm.

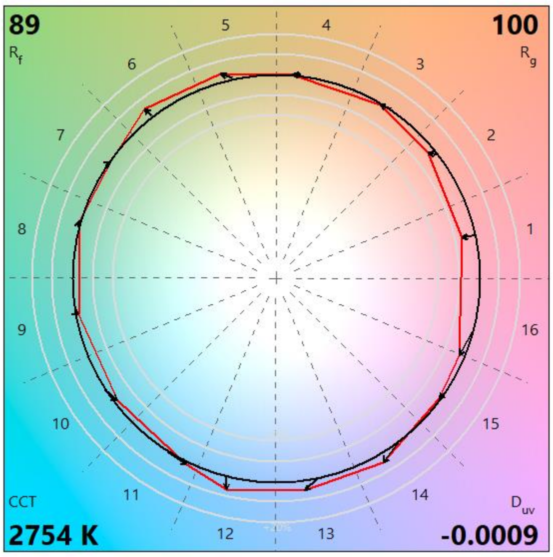


Figure 17 IES Color Vector Graphics (TM-30-15) together with IES R_f, R_g, CCT and D_{uv} for LG 20 lm.

OLEDWorks WW 300 lm

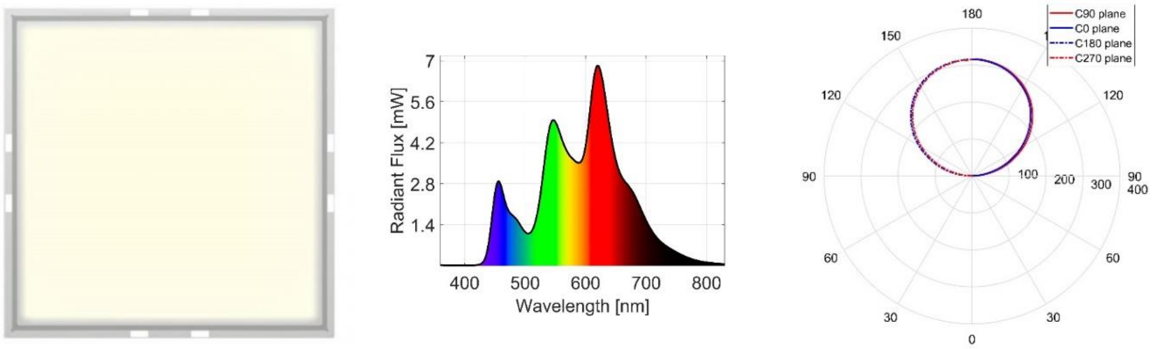


Figure 18 OLEDWorks WW 300 lm panel. From left to right: Photo of the panel; Emission spectra; Light intensity distribution

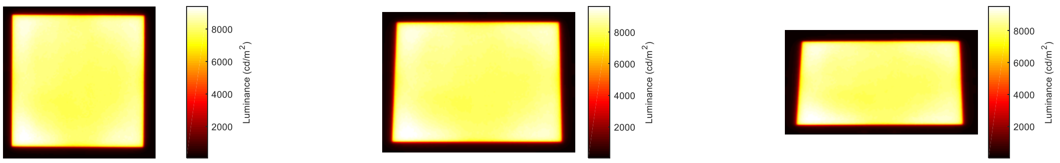


Figure 19 OLEDWorks WW 300 lm. 2D luminance images at three different angels. From left to right: 0 degrees; 45 degrees; 60 degrees.

	Flux (lm)	CCT (K)	Power (W)	η (lm/W)	L (cd/m2)	Ra	R9	(x,y)
Measured	276.4	3085	5.61	49.3	8126	90.7	75.5	(0.4327, 0.4055)
Rated	300	3000	5.33	57	8300	>90	>70	(0.4345, 0.3992)

Table 5 Measured and rated values for OLEDWorks WW 300 lm.

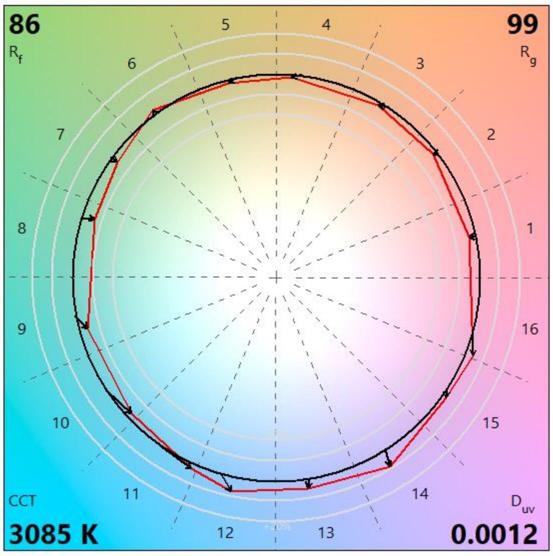


Figure 20 IES Color Vector Graphics (TM-30-15) together with IES R_f, R_g, CCT and D_{uv} for OLEDWorks WW 300 lm.

OLEDWorks NW 250 lm

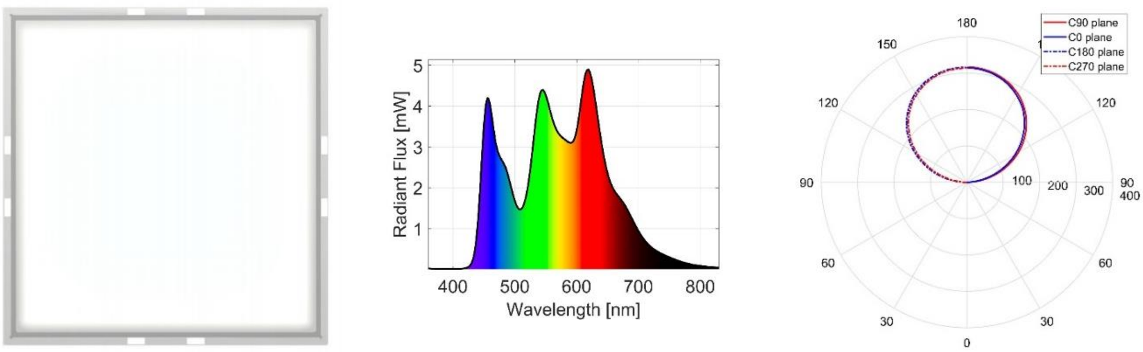


Figure 21 OLEDWorks NW 250 lm panel. From left to right: Photo of the panel; Emission spectra; Light intensity distribution

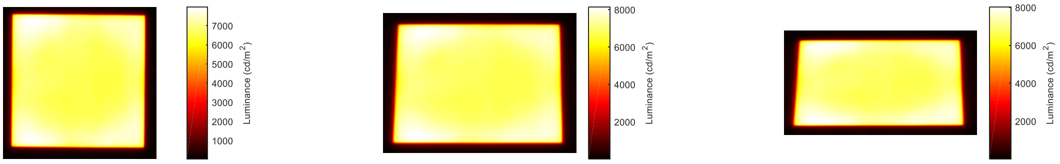


Figure 22 OLEDWorks NW 250 lm. 2D luminance images at three different angels. From left to right: 0 degrees; 45 degrees; 60 degrees.

	Flux (lm)	CCT (K)	Power (W)	η (lm/W)	L (cd/m2)	Ra	R9	(x,y)
Measured	242.4	4039	5.9	41.1	6861	91.3	70.5	(0.3785, 0.3749)
Rated	250	4000	5.4	46	7100	>90	>70	(0.3738, 0.3684)

Table 6 Measured and rated values for OLEDWorks NW 250 lm.

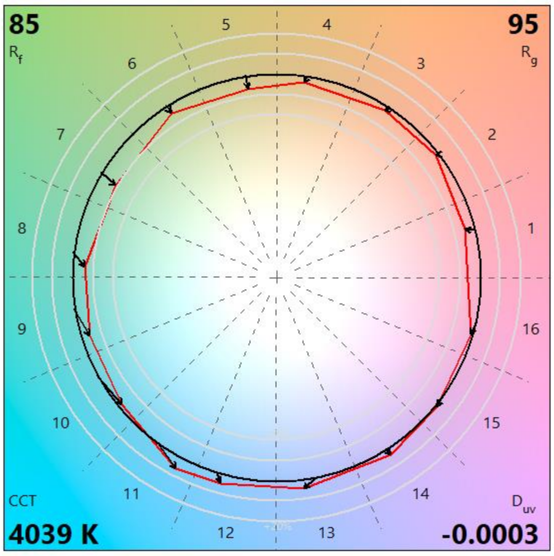


Figure 23 IES Color Vector Graphics (TM-30-15) together with IES R_f, R_g, CCT and D_{uv} for OLEDWorks NW 250 lm.

OLEDWorks BendOLED 300 lm

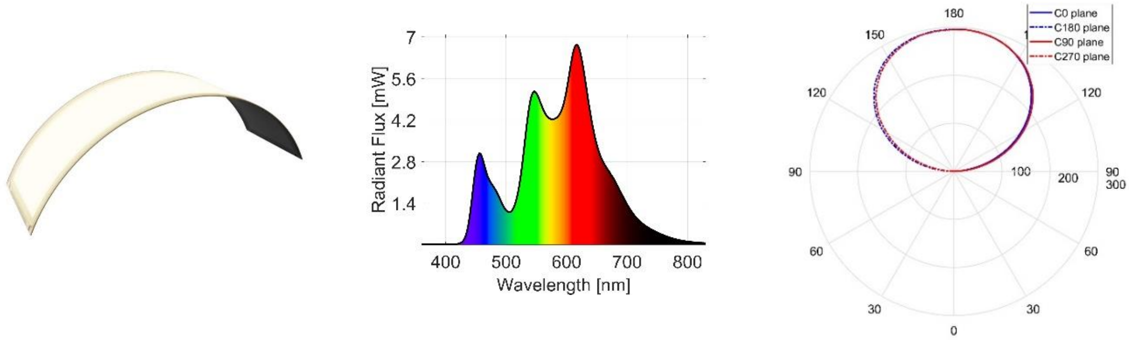


Figure 24 OLEDWorks BendOLED 300 lm panel. From left to right: Photo of the panel; Emission spectra; Light intensity distribution

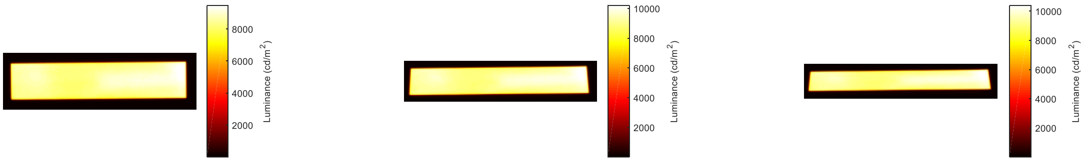


Figure 25 OLEDWorks BendOLED 300 lm. 2D luminance images at three different angels. From left to right: 0 degrees; 45 degrees; 60 degrees.

	Flux (lm)	CCT (K)	Power (W)	η (lm/W)	L (cd/m2)	Ra	R9	(x,y)
Measured	297.6	3093	5.7	52.2	8419	85.2	39.6	(0.4313, 0.4035)
Rated	300	3000	5.6	55	8500	90	50	(0.4345, 0.3992)

Table 7 Measured and rated values for OLEDWorks BendOLED 300 lm.

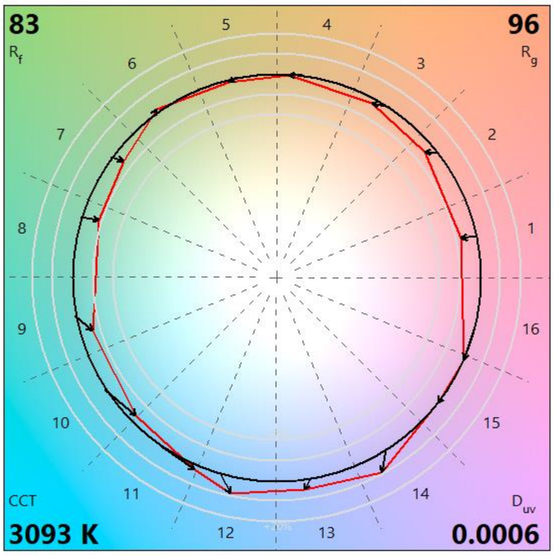


Figure 26 IES Color Vector Graphics (TM-30-15) together with IES R_f, R_g, CCT and D_{uv} for OLEDWorks BendOLED 300 lm.

OLEDWorks FL200R Circular 200 lm

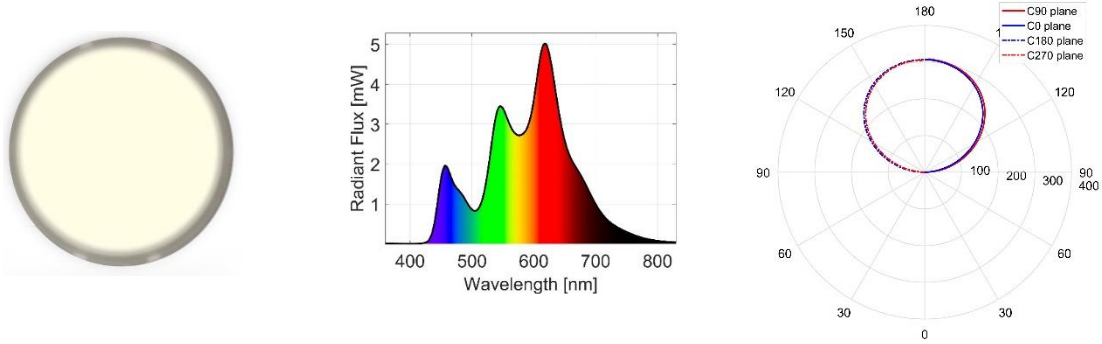


Figure 27 OLEDWorks Circular 200 lm panel. From left to right: Photo of the panel; Emission spectra; Light intensity distribution

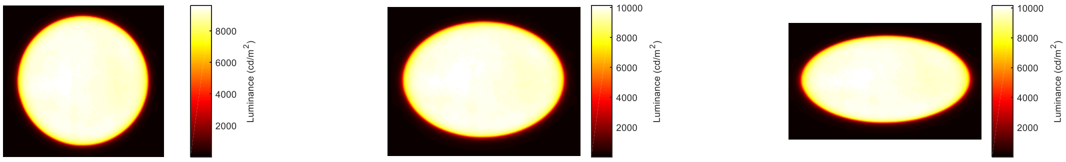


Figure 28 OLEDWorks Circular 200 lm. 2D luminance images at three different angels. From left to right: 0 degrees; 45 degrees; 60 degrees.

	Flux (lm)	CCT (K)	Power (W)	η (lm/W)	L (cd/m2)	Ra	R9	(x,y)
Measured	204.2	2951	2.85	71.6	8976	90.1	56.6	(0.4399, 0.4041)
Rated	200	3000	2.7	75	8500	>90	>50	(0.4345, 0.3992)

Table 8 Measured and rated values for OLEDWorks Circular 200 lm.

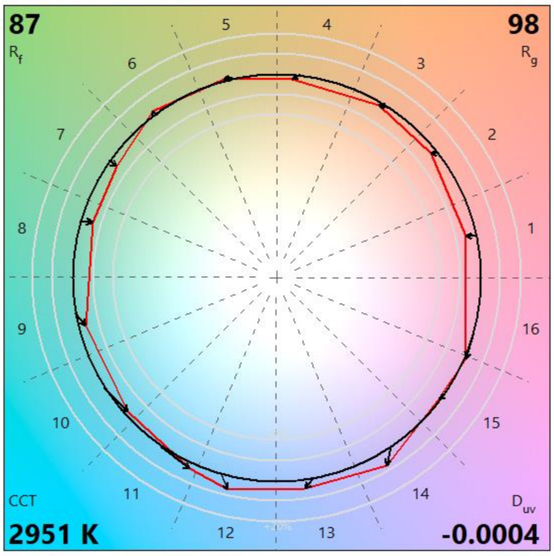


Figure 29 IES Color Vector Graphics (TM-30-15) together with IES R_f, R_g, CCT and D_{uv} for OLEDWorks Circular 200 lm.

Analysis of photometric results

Below, in Table 9, some summarized results of the characterization of the seven investigated panels are shown.

Panel	Flux (lm)	CCT (K)	Power (W)	η (lm/W)	L (cd/m2)	Ra	R9	Rf^{TM30}	Rg^{TM30}
Kaneka 80x80	56.5	3038	1.83	30.9	3025	94.5	88.0	87	95
LG 53x53	19.1	2754	0.39	49.0	2536	90.9	31.9	89	100
OLEDWorks Circular	204.2	2951	2.85	71.6	8976	90.1	56.6	87	98
Kaneka 15x137	18.5	3008	0.61	30.2	2757	92.8	79.5	87	96
OLEDWorks 102x102	276.4	3085	5.61	49.3	8126	90.7	75.5	86	99
OLEDWorks 102x102	242.4	4039	5.9	41.1	6861	91.3	70.5	85	95
OLEDWorks 46x221	297.6	3093	5.7	52.2	8419	85.2	39.6	83	96

Table 9 Measurement results from the seven investigated OLED panels.

The luminous efficacy of source is varying, the lowest being 30.2 lm/W and the highest value reaching 72 lm/W at rated forward current. As the results from the measurements as function of forward current will show, the lower the forward current even higher luminous efficacies are reached.

In general, the light quality is impressive, with R_a well exceeding 90 and R_9 reaching 88. Typical R_f and R_g values (according to TM-30-15) are 87 and 98, respectively.

The light emitting surface are very diffuse, resulting in an almost perfect Lambertian. In addition, the luminance across each panel is very even, and ranges from 2500 to 8500 cd/m^2 between the different panels. Higher luminance values tends to be experienced as uncomfortable.

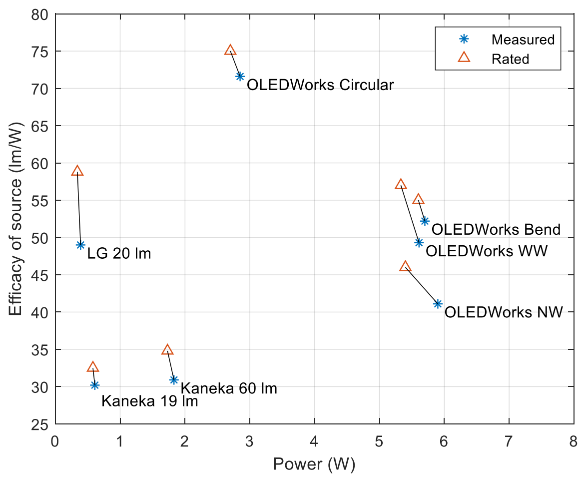


Figure 30 Relation between measured and rated power consumption and efficacy of source

Figure 30 shows the relation between measured and rated values of power consumption and luminous efficacy of source. The blue stars indicates the measured values and the red triangles the rated. For all panels, the blue stars (measured) are located below and to the right compared the corresponding red triangle (rated). That is, the power consumption is rated lower than what is measured, and the efficacy is rated higher than what is measure. Consequently, the conclusion is that the performance of all panels are overestimated in the rated specifications, especially the efficacy.

In Figure 31 and Figure 32, the chromaticity coordinates of all seven panels are marked in the CIE 1931 chromaticity diagram.

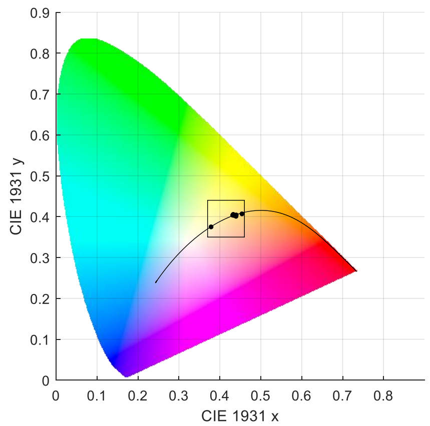


Figure 31 The chromaticity of the seven panels marked out in a CIE 1931 Chromaticity diagram. The square marks the zoomed in area in Figure 32.

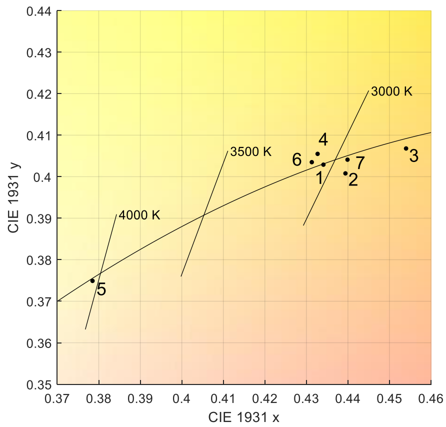


Figure 32 A zoom-in of the chromaticity positions of the seven panels in the CIE 1931 Chromaticity diagram. The numbers are referring to the panels according to Table 10. In addition, the isotherms for 3000 K, 3500 K and 4000 K are shown.

Panel	Legend	(x,y)	CCT (K)	Duv	Duv < 0.05
Kaneka 80x80	1	(0.4341, 0.4029)	3038	-7.32E-05	True
Kaneka 15x137	2	(0.4394, 0.4008)	3008	-0.00163	True
LG 53x53	3	(0.4540, 0.4068)	2754	-0.00090	True
OLEDWorks WW	4	(0.4327, 0.4055)	3085	0.00118	True
OLEDWorks NW	5	(0.3785, 0.3749)	4039	-0.00030	True
OLEDWorks BendOLED	6	(0.4313, 0.4035)	3093	0.00058	True
OLEDWorks Circular	7	(0.4399, 0.4041)	2951	-0.00038	True

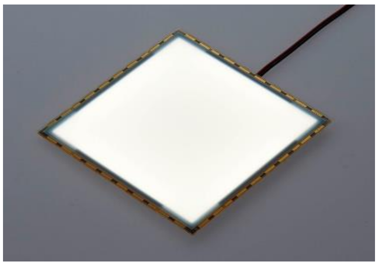
Table 10 The chromaticity properties of the seven panels and the numbers referred to in Figure 32.

As can be seen in Figure 32 the chromaticity of all panels ends up very close to the Planckian locus, all panels showing a chromatic distance (Duv) less than 0.05.

Characterization of three panels as a function of current

Below follows the result of the investigation of the three selected panels, which were characterized as a function of forward current. The panels are Kaneka 60 lm, LG 19 lm and OLEDWorks FL200R Circular 200 lm.

Kaneka 60 lm



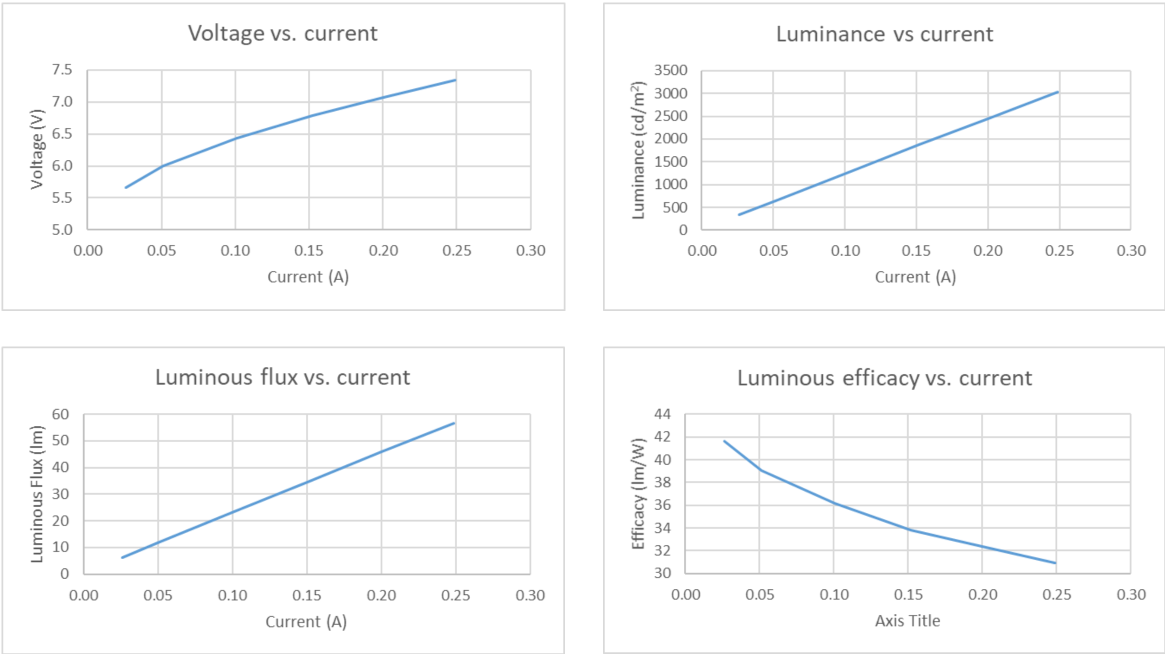
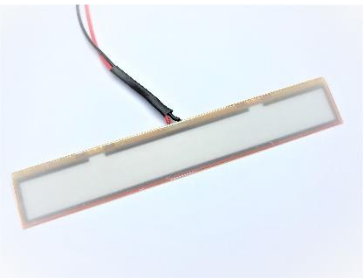


Figure 33 Results as a function of forward current for Kaneka 60 lm.

LG 19 lm



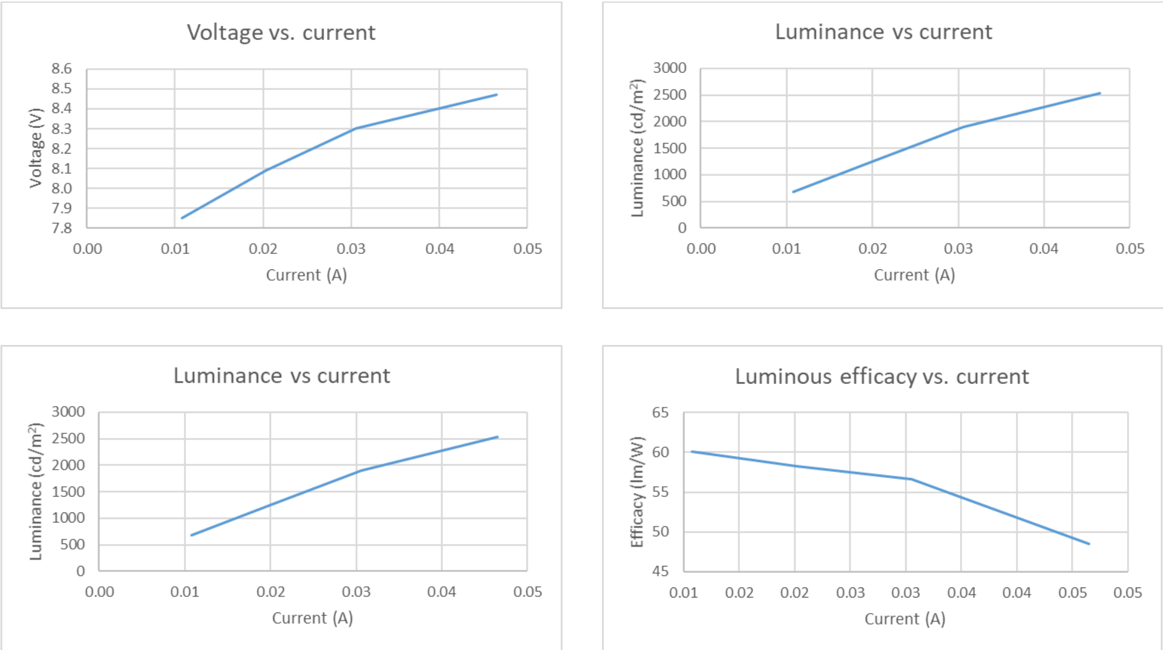
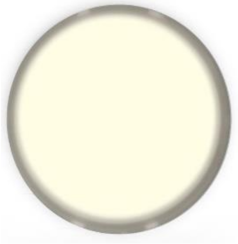


Figure 34 Results as a function of forward current for LG 19 lm.

OLEDWorks FL200R Circular 200 lm



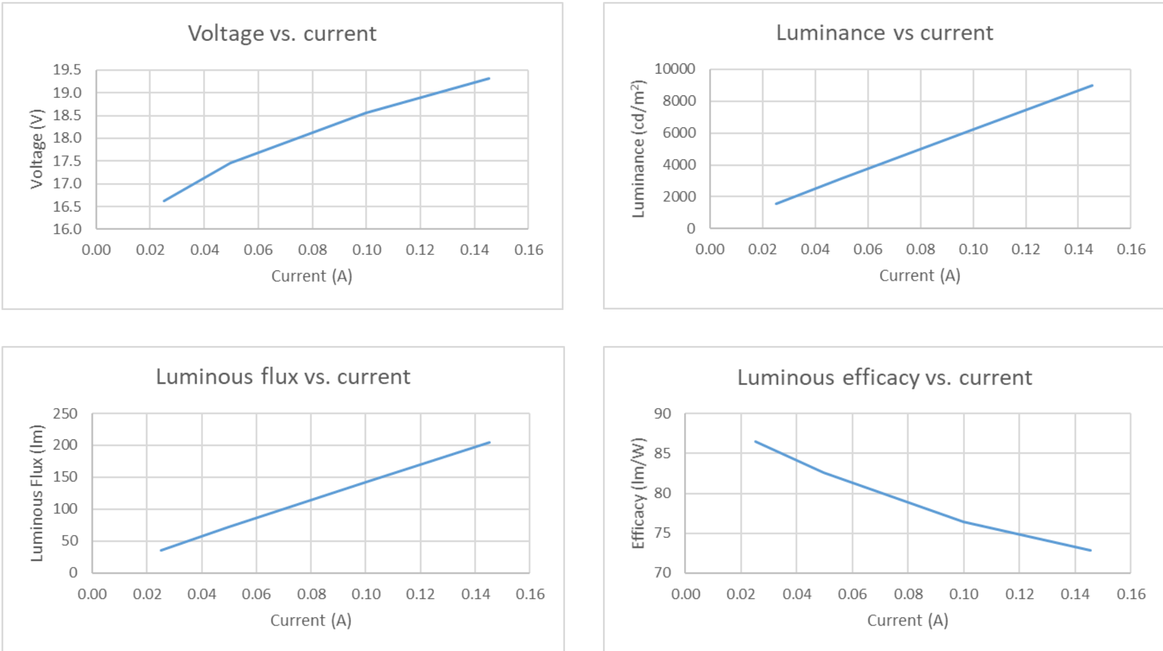


Figure 35 Results as a function of forward current for OLEDWorks FL200R Circular 200 lm

Analysis of results as a function of current

As the forward current is varied, the color characteristics of the panels may change. Therefore, the chromaticity of the light was measured for all three panels, as the forward current were changed. Figure 37 shows how the chromaticity changes with current, illustrated in a zoom-in of the CIE 1931 chromaticity diagram.

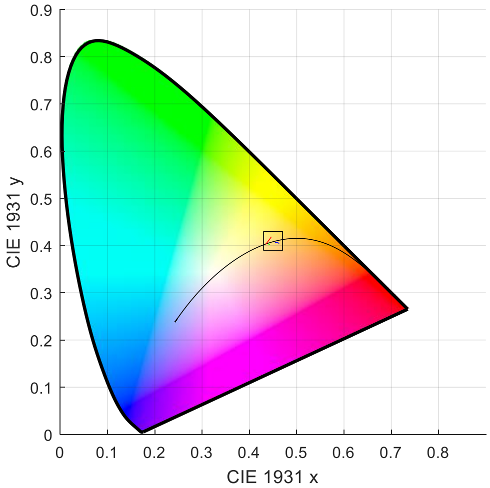


Figure 36 The CIE 1931 Chromaticity diagram. The square marks the zoomed in area in Figure 37

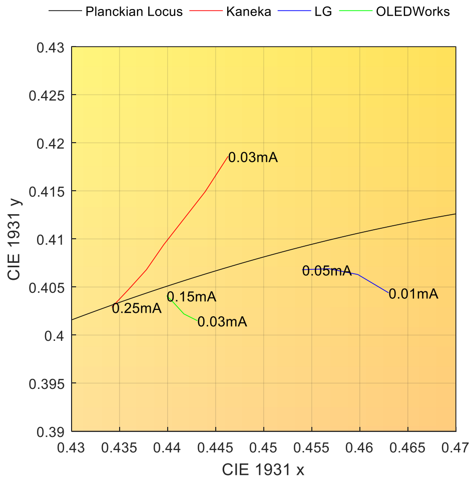


Figure 37 A zoom-in of the chromaticity positions of the three panels in the CIE 1931 Chromaticity diagram, as the forward current is changed.

It is seen from Figure 37 that as the forward current changes, a significant drift in chromaticity of especially one of the panels (Kaneka 60 lm) could be observed. The other two panels do not drift that much.

Conclusion

This report describes the current technology of OLEDs and presents a characterization of light quality and efficacy of panels available on the market 2015-2018.

The performance of OLEDs are steadily increased, reaching a luminous efficacy of source of 70 lm/W, excellent color rendering index as high as 94. Recently, in September 2018, a breakthrough regarding production costs were made in an EU-funded programme, Flexolighting, announcing a potential production cost of 14 USD/1000lm was reached.

The market of OLEDs suffers though from somewhat a catch 22, where the market needs to grow in order for the technology to develop, and the technology needs to develop for the market to grow. In 2015 there were 17 companies producing OLED panels. In 2018, only three of these still did. OLED Academy is one of many initiatives trying to encourage the development of OLED luminaires, by designing new products to exploit OLED technology.

Among the challenges for OLED production are cost reduction associated with production and materials, need of technology improvements regarding light extraction, lifetime and driver standardization. A big achievement is the publication from CIE, which specifies the requirements for measurements of OLED luminaires and OLED light sources. This will enable better comparison and hence smoother improvements of OLED characteristics.

The report contains a thorough characterization of seven OLED panels recently produced, from three different companies. The results shows an impressive light quality, with CRI R_a-values in the range of 85 to 94 and typical R_f and R_g values (according to TM-30-15) of 87 and 98, respectively. The chromatic distance (Duv) are far below the value of 0.05, which is high quality of a white light source. All the panels are almost perfect Lambertian, i.e. producing diffuse light.

Three panels were investigated as a function of forward current, which indicated the expected behavior with respect to photometric and electric characteristics: luminous flux increases with current and luminous efficacy decreases with current. However, one of the panels showed a significant chromatic drift as the current dropped.

Comparing the relation between measured and rated values of power consumption and luminous efficacy of source, the conclusion is that the performance of all panels are overestimated in the rated specifications, especially the efficacy. This was the case for all the measured panels.

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