MSc in Photonics

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Master in Photonics

MASTER THESIS WORK

OLED FEASIBILITY STUDY IN THE AUTOMOTIVE SECTOR

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OLED feasibility study in the automotive sector

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Abstract: The aim of this study is to know the limits, advantages and disadvantages of the organic light emitting diodes (OLED) to be used as a lighting source in the gear shifter manufacturing. To do this we developed a prototype that was illuminated with a flexible deep blue OLED and analysed their emission in terms of luminance and colour across its surface as well as over time. We also conducted a durability test at room temperature with periodical photometric and colorimetric measurements. The results were analysed taking into account the recommendations of the engineering specification based on a German standard used for this purpose.

1. Introduction

The organic light emitting diodes (OLEDs) [1] conform a new solid-state lighting technology that is already being used for lighting purposes, and also as digital displays in different electronic devices. This technology has already been commercialized by several manufacturers: Osram, Philips, and Blackbody commercialize OLED panels, LG sells a TV with a curved panel based on OLEDs, Samsung uses active matrix OLEDs for mobile phones and tablets, and Apple produces a wearable device that use a flexible OLED panel manufactured by LG.

Two different configurations are used in these devices. On one hand, conventional OLED panels involve several steps: taking a substrate, cleaning it, making the switching and driving circuitry, deposition and patterning the organic layers and finally their encapsulation to prevent dust, oxygen and moisture damage [2]. On the other hand, active matrix OLED (AMOLED) technology consist of an active matrix of OLED pixels generating light (luminescence) upon electrical activation that have been deposited or integrated onto a thin- film-transistor (TFT), which functions as a series of switches to control the current flowing to each individual pixel [3].

This master thesis is based on the study of the first configuration, i. e., the OLED panel technology, to be used in the automotive sector, specifically as a lighting source of a gear shifter. In this context, a feasibility study of this kind of OLEDs is carried out taking into account an analysis of their luminance and colour across their surface, studying their emission over time and also their durability.

1.1 Principles of OLED technology

The basic OLED structure consists of a stack of fluorescent organic layers sandwiched between a transparent conducting anode and metallic cathode. When an appropriate bias is applied to the device, holes are injected from the anode and electrons from the cathode: some of the recombination events between the holes and electrons result in electroluminescence (EL) [4]. Structure of different OLEDs is shown in Figure 1. A single-layer OLED is made of a single organic layer sandwiched between the cathode and the anode. In a two-layer OLED, one organic layer is specifically chosen to transport holes and the other layer is chosen to transport electrons. Recombination of the hole-electron pair (exciton generation) takes place in the interface between the two layers, which generates electroluminescence. In a three-layer OLED an additional layer is placed between the hole transporting layer and electron-transporting layer. The emitting layer is primarily the site of hole-electron recombination and thus for electroluminescence. Multi-layer OLEDs consist of different layers namely Indium Tin Oxide (ITO) glass plate, hole injection layer (HIL), hole transport layer (HTL), emitting layer (EML), electron transporting layer (ETL) and anode. The introduction of multi-layer OLED device structure removes the charge carrier leakage as well as exciton quenching, as excited states are generally quenched at the interface of the organic layer and the metal.

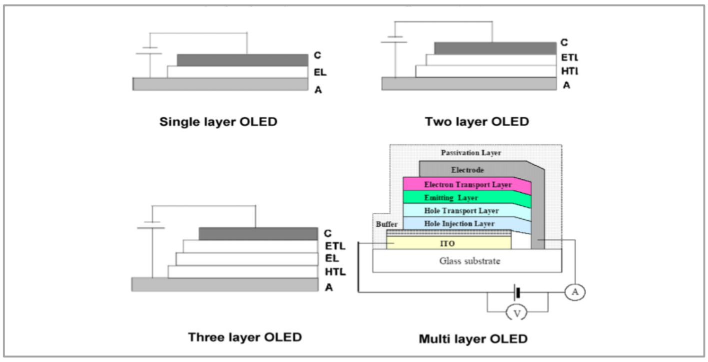


Figure 1. Structure of different OLEDs. (C=Cathode; EL=emitting layer; ETL=electron transporting layer ;HTL=hole transporting layer; HIL=hole injection layer; A= anode small molecules).

The roles of each of the former layers are the following [5] [6]:

Substrate: This is usually made of plastic, glass or metal foil, which is transparent and conductive. It is generally pre-coated with ITO with a high work function ($\varphi_w \approx$ 4.7-4.9ev), which promotes injection of holes into highest occupied molecular orbital (HOMO) level of the organic layer.

Anode: This is a transparent electrode to inject holes into organic layers. The requirement of this layer is that it must have low roughness and with high work function.

Hole injection layer (HIL): It is made of materials with high mobility, and electron blocking capacity.

Hole transport layer (HTL): It plays an important role in transporting holes and blocking electrons, thus preventing electrons from reaching the opposite electrode without recombining with holes.

Emissive layer (EML): The layer in between HTL and ETL is an emitter of visible photons, generally made of organic molecules.

Electron transport layer (ETL): This layer should have good electron transporting and hole blocking properties.

Cathode: It is a typically a low work function metal ($\varphi_{w\approx}$2.9-4.0ev) and injects electrons into emitting layers.

An important feature of OLEDs refers to its quantum efficiency: the internal quantum efficiency (IQE) and external quantum efficiency (EQE) are parameters used to quantify how effectively an OLED device is emitting light. The IQE indicates how much light is generated, and is proportional to the electron-hole balance, the exciton generation efficiency and to the fluorescence quantum efficiency. This process is shown in Figure 2. It is also to be considered that a significant portion of generated light is reflected, transferred and absorbed, which is known as outcoupling efficiency. Thus the EQE is proportional to the IQE and the outcoupling efficiency [7].

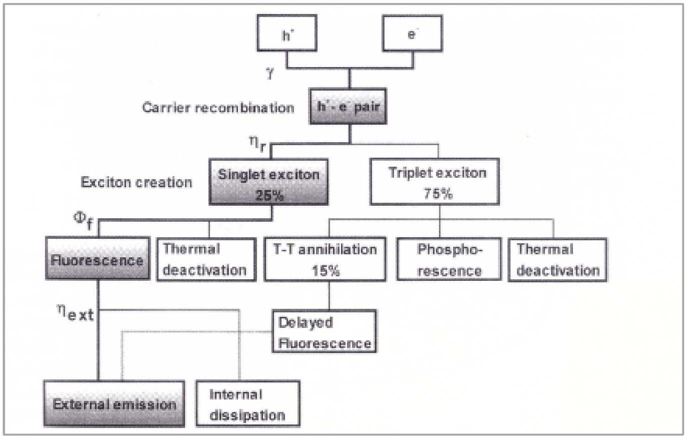


Figure 2. A schematic representation of the elementary process for hole-electron recombination and production of molecular excitons, emission, and external emission.

A recent report by ID TechEx [8] determines that OLEDs technology is of great potencial, but it will be difficult to overthrow conventional LED lighting technology. Figure 3 shows the comparison between both. It can be seen, that regarding the wavelength of emission, OLEDs offer an extensive range of colours, mainly within the visible spectral range [9]. However OLED lifetime is still critical. The degradation in OLEDs occurs through the formation of non-emissive "dark spots" as well as through a long-term "intrinsic" decrease in the electroluminescence (EL) efficiency of the devices during operation.

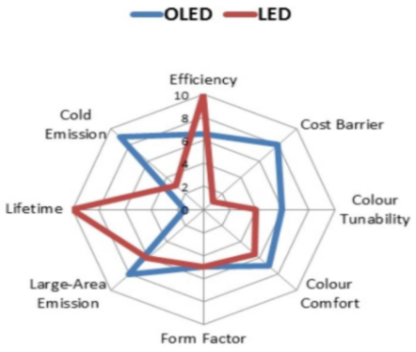


Figure 3. OLED vs LED.

The intrinsic degradation is due to a series of slow phenomena triggered by the mechanisms of species diffusion and morphological changes of the material. The crystallization effect in HTL produces a detachment of the HTL from the electrode, and locally interrupts the electrical conduction, reducing the effective contact area and the electroluminescent efficiency [10]. On the other hand, the organic materials are highly sensitive to atmospheric moisture and oxygen, and this leads to degradation of the OLEDs, causing non-emissive "dark spot" areas. When the device in under electrical stress, the dark spot begins to grow up to a point where the luminance of the emissive area is extinguished [11].

1.2. OLEDs in the automotive sector

The automotive sector involves hard specific requirements, especially in terms of durability and ageing, and this is the reason why nowadays OLED technology has not yet been used for car lighting applications.

The engineering specification used for the manufacturing of gear shifters (Figure 4) is the one made by General Motors (GM) [12][13]. These German standards include specifications regarding the luminance (cd/m^2) of the PRND selected gear for day and night operation, their colour in terms of chromaticity coordinates of the CIE-1931 colour space (x, y) and the corresponding tolerance and stability of emission over time. It also includes durability requirements at different operation temperatures to ensure that the emission of light through the PRND symbols will be corrected in any case.

v

Figure 4. Automatic gear shifter with the illuminated PRND symbols.

Nowadays, traditional light-emitting diodes (LEDs) together with waveguides are used to fulfil all the former requirements when automatic gear shifters are to be built. The use of the OLED technology in the car manufacturing sector, especially for the gear shifters, could notably improve the spatial uniformity requirements provided by common LEDs. Accordingly, several practical aspects in terms of the OLED emission (luminance and colour) as well as physical and durability properties are deeply analysed in this master thesis, as a preliminary feasibility study. Figure 5 shows a mechanical design of a gear shifter which has been specifically developed to carry out this analysis. In this figure the space to place the OLED panel can be easily seen.

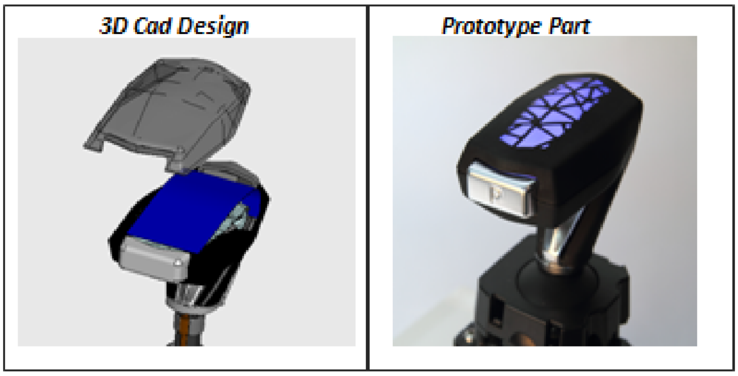


Figure 5. 3D Cad design and prototype part of a gear shifter designed with the OLED panel.

2. Material and methods

To perform the tests of the OLED panels to be used as the lighting component of automatic gear shifters, the following model was chosen: Astron Fiamm Deep blue AFS stack. It consists of 8 layers on transparent and flexible substrate and also two additional layers of encapsulation. The five samples purchased to carry out this master thesis can be seen in Figure 6. Their technical characteristics provided by the manufacturer are shown in Table 1 and Figure 7.

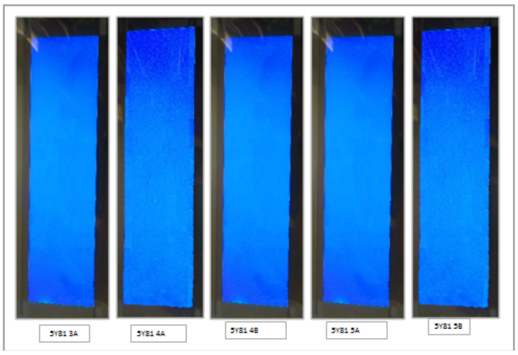
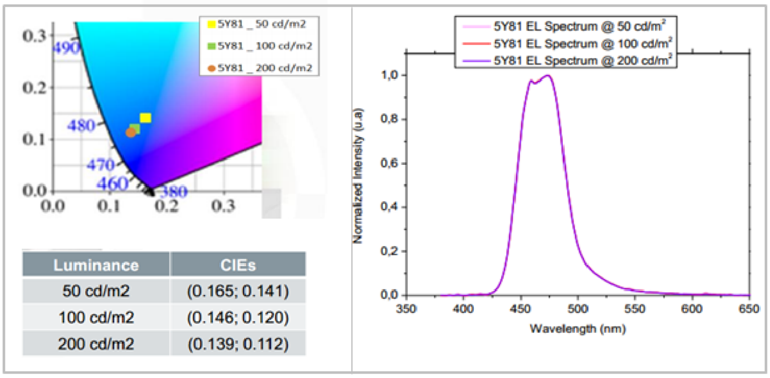


Figure 6. The five OLED panel samples: 5Y813A/5Y814A/5Y814B/5Y815A/5Y815B.



Luminance	CIEs
50 cd/m2	(0.165; 0.141)
100 cd/m2	(0.146; 0.120)
200 cd/m2	(0.139; 0.112)

Figure 7: Spectral and colorimetric characteristics of the OLED panel Astron_Fiamm Deep blue AFS stack (CIEs: CIE-1931 xy chromaticity coordinates). The spectral emission is also shown.

Table 1: Photometric characteristics of the OLED panel Astron_Fiamm Deep blue AFS stack.

Current (A)	Voltage (V)	Luminance (cd/m2)	Consumption (W)
0.05	2.78	50	0.15
0.10	2.92	100	0.29
0.18	3.11	200	0.56

For the sample chosen, which has a peak wavelength of 475 nm, the engineering specifications that must be fulfilled for gear shifter manufacturing detailed in the standard by General Motors are those shown in Tables 2 and 3 [12][13].

In this study, the photometric and colorimetric features of the OLED samples under analysis have been characterized. Specifically, their spatial emission (uniformity) has been tested by means of measurements of luminance (cd/m^2) and chromaticity coordinates (x, y) carried out with the spectroradiometer PhotoResearch PR655. The spectral emission of the OLEDs under analysis has also been measured. For each of the five samples, 3 different regions of 3 cm in diameter approximately have been taken into account when a current of 100mA was applied (Figure 8). This corresponds to the night max. condition of Table 2.

On the other hand, the stability of the OLEDs emission over time has also been analysed as follows: the 3 former regions of the OLEDs have been periodically measured 3 times: the first two times one week apart from each other and the last one after two weeks of the second.

Both the uniformity of the samples (spatial emission) and stability over time were carried out with samples: 5Y813A, 5Y814B, 5Y815A, 5Y815B. The four OLEDs films were turned on only during the measuring process.

Furthermore, sample 5Y814A was used in a durability test. In this case, the sample 5Y814A was turned on and remained lighted at room temperature during 1008 hrs to analyse possible variations in its structure. Cycles with changes of temperature (as detailed in Table 3) were out of the scope of this study.

Table 2: Photometric and colorimetric requirements of the GM standards.

GM General Specification	**Luminance**			**Color (Chromaticity)**		
Requirements	Day Cd/m2	Night max. Cd/m2	Night min. Cd/m2	Color	CIEs	CIEs (tolerance)
	1500	100	6	Blue	(0.1357, 0.07)	(0.139, 0.035), (0.150, 0.052), (0.128, 0.114), (0.117, 0.095)

Table 3: Durability requirements of the GM standards.

GM General Specification	**Durability (14600 hr.)**			
Requirements	23ºC	85ºC	-40ºC	Transition thermal Chamber from(ºC) -40 to 23->23 to 85->85 to 23->23to -40
	10220 hr.	2774hr.	584hr.	1022hrs

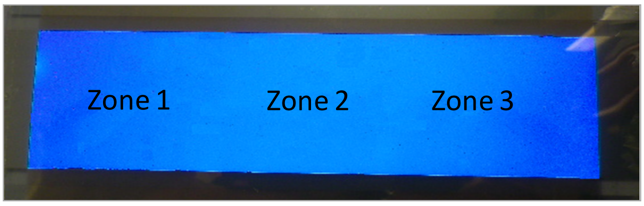


Figure 8. Zones defined to characterize the spatial emission in terms of luminance and colour.

3. Results

3.1. Spatial analysis of luminance and colour

Figure 9 shows the emission of an OLED panel (5Y814A, zone 3) as a function of the wavelength. As it can be seen the peak wavelength is of 472 nm, similar to that specified by the manufacturer.

In order to carry out an analysis of the uniformity of the OLED panels emission, Table 4 shows the luminance of zones 1, 2 and 3 as well as the averaged value (L_{mean}) and corresponding standard deviation (σ) of the 4 samples considered for this analysis. The percentage of uniformity (%) defined as the ratio between σ and L_{mean} is also detailed. The same analysis is carried out for the chromaticity coordinates (CIEs).

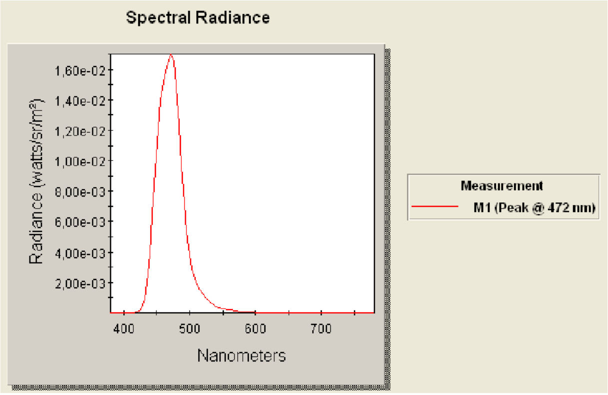


Figure 9. Spectral emission of one of the OLED panels (5Y814A, zone 3).

Table 4: Luminance (cd/m^2) and chromaticity coordinates (CIEs). Mean value (L_{mean}) and standard deviation (σ) of zones 1, 2 and 3 of the four samples. The percentage of uniformity is also shown.

OLEDs samples	**Zone**	**Luminance (cd/m2)**	**CIEs**	
5Y81 3A	Zone 3	101,80	0,1296	0,1039
	Zone 2	90,20	0,1285	0,1068
	Zone 1	88,50	0,1280	0,1088
	L_{mean}	**95,15**		
	σ	**9,40**	**0,0011**	**0,0035**
	Uniformity (%) = (σ/L_{mean})x100	**9,88**		
5Y81 4A	Zone 3	109,60	0,1305	0,0999
	Zone 2	100,00	0,1292	0,1064
	Zone 1	96,26	0,1288	0,1064
	L_{mean}	**102,93**		
	σ	**9,43**	**0,0012**	**0,0046**
	Uniformity (%) = (σ/L_{mean})x100	**9,16**		
5Y81 5A	Zone 3	105,00	0,1303	0,1017
	Zone 2	97,85	0,1294	0,1043
	Zone 1	95,50	0,1295	0,1066
	L_{mean}	**100,25**		
	σ	**6,72**	**0,0006**	**0,0035**
	Uniformity (%) = (σ/L_{mean})x100	**6,70**		
5Y81 5B	Zone 3	102,10	0,1300	0,1024
	Zone 2	95,50	0,1292	0,1057
	Zone 1	93,07	0,1284	0,1282
	L_{mean}	**97,59**		
	σ	**6,39**	**0,0011**	**0,0182**
	Uniformity (%) = (σ/L_{mean})x100	**6,54**		

It can be concluded that the variation in terms of luminance is smaller than 10% in any of the samples. Therefore, they are within the specified range of the standard which is of 20% (Table 2). Furthermore, the changes in terms of chromaticity coordinates (CIEs) are also within the tolerances of the GM standard (Table 2).

3.2. Stability of emission over time

Table 5 shows the emission values of the sample 5Y815B over time. Specifically, the luminance of zones 1, 2 and 3 measured on the three dates are shown as well as the averaged value (L_{mean}) and corresponding standard deviation (σ). The percentage of stability (%) is defined in this case as the ratio between σ and L_{mean} of each zone measured at different times. A similar analysis is carried out for the chromaticity coordinates (CIEs).

Table 5: Luminance (cd/m^2) and chromaticity coordinates (CIEs). Mean value (L_{mean}) and standard deviation (σ) on different dates of sample 5Y815B. The percentage of stability is also shown.

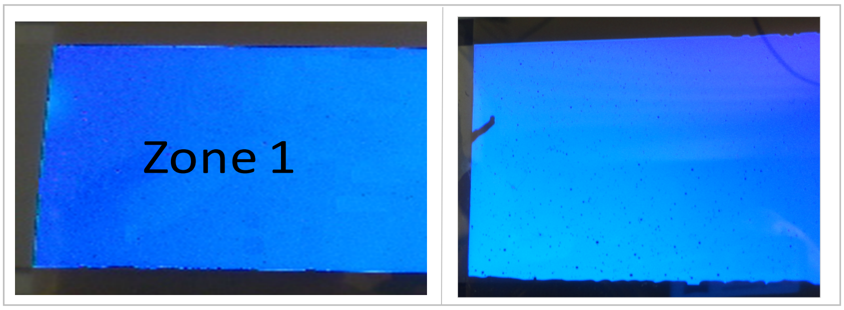
OLED sample	**Date**	**Zone**	**Luminance (cd/m2)**	**CIEs**	
5Y81 5B	05/06/2015	Zone 3	102,10	0,1300	0,1024
	12/06/2015		105,80	0,1303	0,1015
	26/06/2015		109,90	0,1305	0,1011
		L_{mean}	106,00		
		σ	**5,52**	**0,0004**	**0,0009**
		Stability (%) = (σ/L_{mean})x100	**5,20**		
5Y81 5B	05/06/2015	Zone2	95,50	0,1292	0,1057
	12/06/2015		96,85	0,1295	0,1062
	26/06/2015		95,55	0,1292	0,1066
		L_{mean}	95,53		
		σ	**0,04**	**0,0000**	**0,0006**
		Stability (%) = (σ/L_{mean})x100	**0,04**		
5Y81 5B	05/06/2015	Zone 1	93,07	0,1284	0,1282
	12/06/2015		92,16	0,1285	0,1087
	26/06/2015		93,98	0,1288	0,1082
		L_{mean}	93,53		
		σ	**0,64**	**0,0003**	**0,0141**
		Stability (%) = (σ/L_{mean})x100	**0,69**		

From the table it can be concluded that the variation in terms of luminance over time is of 5% in zone 3 and smaller than 1% in the other two cases. Therefore, variability over time appears to be smaller than spatial uniformity of OLEDs, and also the values remain inside the general specified tolerance.

The changes in terms of chromaticity coordinates (CIEs) are smaller than the spatial changes except in zone 1, in which similar variations are assessed. This is within (the tolerance established in the standard.

3.3. Durability

In this case, the sample under analysis remained lighted at room temperature until 1008 hrs. of operation. Small dark spots appeared during the first 24 hrs and increased even more later (see the Figure 10).



a) b)

Figure 10. Dark spots evolution at room temperature: a) at the beginning of the test and b) after 1008 hrs.

In spite of this problem the test continued until 1008 hrs, in order to know the OLED behaviour as far as photometric and colorimetric characteristics is concerned (Table 6). It can be seen that there is a tendency of decreasing the luminance as time goes on probably linked to the evolution of dark spots (non-emissive area). In this case, variations of luminance are even higher than 20% and therefore they do not fulfil the CM standard.

Table 6: Luminance (cd/m^2) and chromaticity coordinates (CIEs) in the durability test at room temperature (until 1008 hrs.).

OLEDs sample	Date	Zone	Luminance (cd/m2)	CIEs	
5Y81 5B	05/06/2015	Zone 3	106,30	0,1307	0,1002
	12/06/2015		95,22	0,1291	0,1078
	26/06/2015		88,29	0,1308	0,0996
	16/07/2015		79,59	0,1306	0,1011
		L_{mean}	92,95		
		σ	**11,29**	**0,0001**	**0,0006**
		Stability (%) = (σ/L_{mean})x100	**12,14**		
	05/06/2015	Zone 2	118,20	0,1415	0,0915
	12/06/2015		94,60	0,1294	0,1036
	26/06/2015		86,30	0,1290	0,1066
	16/07/2015		86,30	0,1294	0,1065
		L_{mean}	102,25		
		σ	**22,56**	**0,0086**	**0,0106**
		Stability (%) = (σ/L_{mean})x100	**22,06**		
	05/06/2015	Zone 1	100,00	0,1293	0,1062
	12/06/2015		95,22	0,1291	0,1078
	26/06/2015		87,22	0,1288	0,1079
	16/07/2015		79,62	0,1294	0,1065
		L_{mean}	89,81		
		σ	**14,41**	**0,0001**	**0,0002**
		Stability (%) = (σ/L_{mean})x100	**16,05**		

4. Conclusion

In this study we have carried out a feasibility analysis for the use of OLED panels in the automotive sector. The results in terms of spatial uniformity in terms of luminance and colour indicate that the OLED technology could be a good option to consider as it simplifies the current designs, reducing components like lenses, light guides, etc. Furthermore, new possibilities open up in the curve surface designs due to their flexibility.

The analysis of emission of photometric and colorimetric features across the surface and over time show a good uniformity and stability in the period analysed.

Nevertheless, the results on the durability test carried out at room temperature during 1008 hrs. excluded the OLED option to be considered in this moment since dark spots appeared and lifetime produced a failure mode in luminance emission inadmissible for this sector.

For all the former reasons, it can be concluded that OLED technology has to overcome the actual limitations in terms of durability before being used in the car manufacturing process as part of gear shifters.

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