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APPLICATION OF DISPLAY TECHNOLOGY FOR LIGHTING

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ABSTRACT

The article is devoted to contemporary overview of development of a number of display technologies, which have been applied or may be applied for creation of new prospective light engineering solutions. The emphasis is on OLED-based technologies and liquid crystals-based technologies. Examples of their application in automotive industry and architecture are given with consideration of various economic indicators and hygienic and usability limitations.

Keywords: light engineering, optoelectronics, lighting specifications, solid and organic LED, display technology, nanotechnology

Nowadays, development of light engineering has been being significantly promoted by new inventions in different areas, primarily in electro-optics and optics. This leads to appearance of new market niches for devices with increased light engineering specifications or improved functionality. A classic example is light emitting diodes (LED) and LED luminaires. Their application is safer, more environmentally-friendly and more ergonomic from different points of view than application of other lighting devices [1].

Such area of science and technology as information displaying systems or displays has a good outlook for lighting engineering. Some technological solutions for displays, including organic light emitting diodes (OLED), had been originally designed for formation of flat images without application of backlighting but turned out to be prospective for creation of flat and very thin light sources (LS) [2]. Another important technology for flat screens is liquid crystals technology (LC). Because back lighting is necessary for LC displays (LCD), development of this technology required development of many types of accessories for formation and control of a light beam: FL, LED, light-guiding plates and other elements.

Development of nanotechnology led to appearance of materials influencing on luminous efficacy and chromaticity of existing LSs or optical elements. Among the most well-known are quantum dots materials which have already been manufactured.

Development of display technology requires different usability studies: careful study of human vision system and impact of different LSs with different chromaticity and capability of light adjustment on it. Among the rapidly developing areas there are car displays, displays for industrial and military applications, etc., where light control is an important element.

This review briefly examines the contemporary level of development of different display technologies which have been applied or may be applied for creation of new prospective light engineering solutions.

The world leading companies, such as *Konica Minolta*, *LG Chem*, *AcuityBrands*, *OLEDWorks*, *BMW*, *Audi*, etc., are developing and manufacturing different types of OLED-based lighting devices (LD) with new functional capabilities as compared with conventional ones [2]. The OLED-based LDs may be flat and flexible and very thin at the same time, as well as be capable to be placed on sur-

Table 1. Prospective Specifications of White LED Light Sources

Characteristics	Target and practiceable limit
Luminous efficacy of radiation	350 lm/W
Internal quantum efficiency	95 %
Luminous efficacy of a pixel	180 lm/W with luminance of 3,000 cd/m^2

faces of almost any shape and flexion. Their big advantage is capability to vary their radiation spectra in space and time. Modern OLED technologies allow LDs creation with rather high luminance and luminous efficacy adopted for application in extreme environment, for instance, in motor cars some part of which are under high mechanical and temperature loads.

In the field of semiconductor lighting technology, the LED LSs, which have been becoming cheaper and cheaper are dominating, but illumination based on OLED LSs with characteristics and capabilities supplementing the previous has been rapidly developing and becoming more commercialised. With OLED, it's possible to construct large-area LSs with diffuse radiation and excellent colour rendering. And application of plastic substrate allows manufacturing of very thin and lightweight LD with any shape and flexion. Unlike the most of conventional LDs, OLED-based LD do not cause dazzling and exclusion of such components as diffusers significantly reduce their prices, which, by the way, positively affects the luminous efficacy of LD.

Nowadays, many companies manufacture OLED-based illumination panels for a number of applications including one of the major ones – lighting of motor cars. Such companies as *Audi*, *BMW* and others have shown that special OLED-based LDs provide more design freedom than others mostly thanks to OLED panels with different shape and extremely uniform illuminance distribution [3]. Also not without interest are applications of plastic OLED-based LDs in airplane interiors.

The target and prospective indicators of LD's based on white OLED are shown in Table 1 [3].

As for profitability of these LDs, according to the Department of Energy of the USA [4], as compared with conventional ceiling luminaires, the OLED-based flat luminaires used in corridors reduce power consumption by 73 %, which at the level of 2020 will allow saving up to USD $1.7 billion per year. The ownership forecasts for 2020 for 4 types of ceiling luminaires presented in Fig. 1 show that at equal level of illumination of a 6 m^2 office space for 10 years (more precisely, taking office non-operational hours into account, 20,800 hours of operation), the luminaire based on a combination of LED and OLED is more economically efficient than the OLED-based luminaire. The latter here is inferior not only to the LED-based luminaire but even to the fluorescent luminaire. It is anticipated that the cost of 1,000 lm will be equal to $30 for fluorescent luminaires, $24 for LED-based luminaires, and $100 for OLED-based luminaires in 2020.

The US Department of Energy has compiled 2025 roadmaps for luminous efficacy and the cost of manufacturing of OLED panels (Tables 2 and 3). It is anticipated that the general colour rendering index R_a will exceed 80 and the correlated colour temperature T_{cc} will be equal to 3,000K. Within a decade, the luminous efficacy should increase by 2.5 times due to improvement of materials and control devices (CD) efficiency. This should be achieved by multiple increase of investments in facilities for manufacturing of OLED panels with their technical and economical specifications comparable with LCD panels. Moreover, the cost of all materials and production operations should be significantly reduced. As a result, the cost of manufacturing of 1 m^2 of an OLED panel should reduce by 33 times within 10 years.

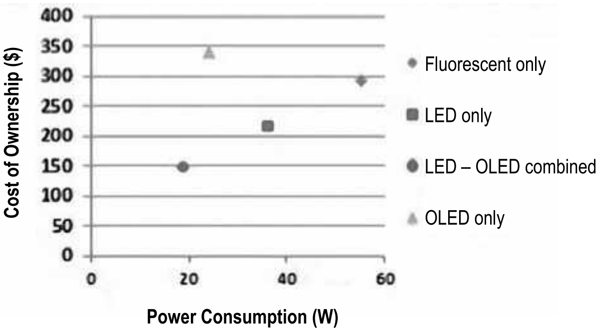

Fig. 1. Ownership cost estimation of ceiling illuminaires with FL, LED, OLED and combination of LED and OLED for office spaces (as of 2020)

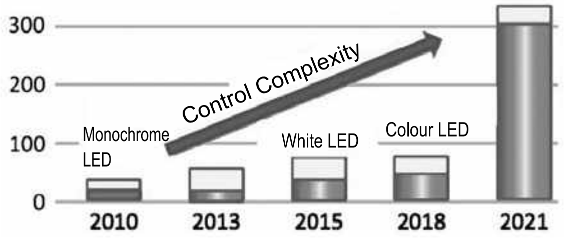

Fig. 2. Number of LED's for interior lighting of one premium class motor car (according to data of *BMW*)

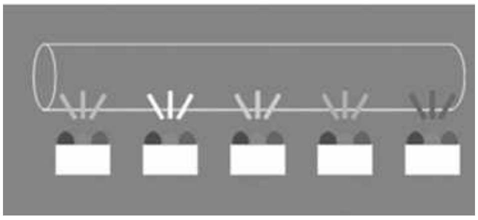

Fig. 3. Colour lighting of motor car interior with monochrome or polychrome LED's with application of a light guide and a colour adjusting device

In study [5], capabilities of comfortable illumination options formation adjustable for different environments are overviewed. The strategy of energy efficient lighting is aimed to achievement a required level of illuminance and spectrum of the light in the right place at the right time. Herewith, such adjustable luminaire should contain a bright source of white light and a non-bright source of amber light integrated with the illuminance and an occupancy sensors. Signals from the illuminance sensor are used for turning off of both LS's at daytime and for turning on at night. Signals from the other sensor are used for turning on of bright white light in presence of a person and it turning off during absence of a person.

Today automobile manufacturers keep demanding increase of functionality of LED for support of innovative features of their cars and ease of information reading from the relevant LED devices during daytime. While in 2010 there were 50 LEDs in a typical car for sale, their number should exceed 300 by 2021 (Fig. 2) [6]. Such increase occurs primarily by application of LEDs with three major colours (red, green and blue) connected in the united LS. In this case, it is necessary to develop relevant CD's with pulse-duration modulation to obtain required colours, which adds non-required complexity as compared with systems applying platforms with white and monochrome LEDs dominated in the market several years ago.

Fig. 3 shows that interesting capabilities of motor car illumination with different chromaticity and intensity are obtained by application of light guides with end or side location of monochrome or polychrome LEDs.

OLED-based LSs are flexible, light-weight and thin, but despite such unique features, there are serious problems in development of this market. For market expansion, *Konica Minolta* has proposed the *True Value* concept for flexible OLEDs [4]. This concept considers "uniform light radiated by a surface with an extremely thin installation space" as

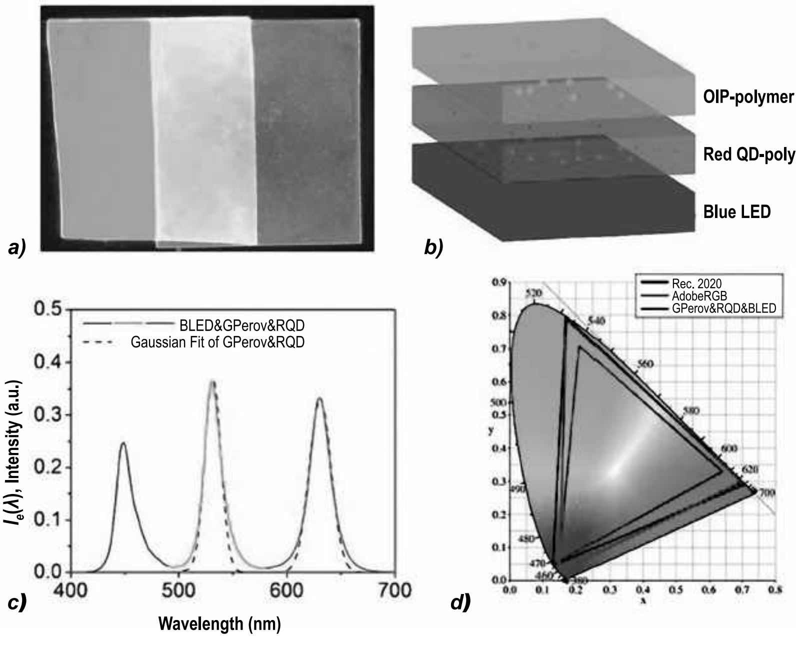

Fig. 4. Application of special composite film as a dimmer for backlighting of a wide colour spectrum display: *a* – composite film with red quantum dots and polystyrol as well as green $MAPbBr_3$ and polystyrol under impact of UV radiation; *b* – the diagram of white light generation by means of above mentioned films integration with a blue LED; *c* – white radiation spectrum of a system with above mentioned films (green and red) used as a radiation converter of blue LED. The dashed lines are Gaussian approximations of the green and red components of the spectrum; *d* – the chromaticity diagrams of the white LED system (blue line), of the system with *Adobe RGB* spectrum (grey line) and of the system complying with the CIE recommendation for 2020 (black line) as compared with the CIE chromaticity diagram for 1931

Table 2. 2025 Roadmap for OLED-based LD's

Characteristics	2015	2017	2020	2025	Target
Luminous efficacy (of a panel), lm/W	60	100	125	160	190
Optical efficiency,%	100			90	
CD efficiency,%	85			90	95
LD efficency,%				81	86
Luminous efficacy of LD, lm/W	51	85	106	130	162

Table 3. 2025 Roadmap for Manufacturing Cost of OLED Panels

Parameter	2015	2016	2018	2020	2025
Base area, m^2	0.17	0.17	1.38	2.7	5.5
Capital investments, million $USD	75	75	200	300	400
Production cycle duration, min	3	2	1.5	1	1
Performance, thousand m^2 per annum	14	25	300	1,000	2,400
Life cycle cost, $/$m^2$	1050	600	125	60	35
Cost of organic materials, $/$m^2$	200	150	100	35	15
Cost of non-organic materials, $/$m^2$	200	200	120	50	30
Cost of work, $/$m^2$	150	100	20	10	5
Other costs, $/$m^2$	75	50	15	10	5
Full cost without product yield taken into account, $/$m^2$	1,675	1,100	355	160	90
Product yield,%	50	60	70	80	90
Full cost, $/$m^2$	3350	1850	550	200	100

the main value. This value is increased by three main drivers: "weight reduction", "*Twilight* light control" and "opportunity to touch LD without burning oneself"; in case of transparent LD's, there can be another driver: "invisible magic".

As a result, different flexible OLED-based LD's can be built-in in ordinary objects, such as umbrellas, hand fans, clothes, overhead moving structures, and so on.

Apart from classical quantum dots, perovskite mineral nanoparticles are widely applied in fluorescent materials. In particular, there is a report [7] about a recent invention of organic and non-organic hybrid perovskites (ONHP) added to compound polymer films with exceeded efficiency of photoluminescence, higher monochromaticity (spectral line half-width is <20 nm), unprecedented water and heat resistance, applicability for backlighting in LCD screens as well as for sensors and light therapy. LEDs based on quantum dots and ONHP (*QLED*) already created and being manufactured, and their colour gamut, energy efficiency and cost can be better than those of OLED (Fig. 4). It is anticipated that for *QLED*-based LS luminous efficacy will exceed 359 lm/W and R_a will be equal to at least 91.

But the service life of such devices is still less than 30,000 h which is required for application in LDs. Currently it is equal to 2000 h with luminance of 500 cd/m^2 and 7000 h with luminance equal to100 cd/m^2 [8].

Table 4. Impact of Adjustment of T_{cc} on Maximum Acceptable Duration of Retina Irradiation t with illuminance of 500 lx

T_{cc}, K	Planckian radiator	LED	OLED
	t, s		
2,000	407	370	369
3,000	146	155	153
5,000	63	74	70
8,000	40	50	47

OLEDWorks LLC has developed the second generation of high-performance amber-colour OLED panels for medical institutions [9]. As compared with the first generation panels, their luminance efficacy is increased to 60 lm/W by using phosphorescent materials. Moreover, their laminar design increases service life and uniformity of glow.

Pixelligent Technologies LLC has developed the technology of manufacturing of *PixClear*® material on the basis of dispersions and nanocomposites with nanocrystals of ZrO_2, which allows the light extraction ratio to exceed 100 % for OLED-based LSs [10]. These materials have significantly increased refractive index of monomers and polymers with content of nanoparticles of ZrO_2 up to 90 %. Wherein, visible transparency of the material is high.

Usually LCD devices are used for formation or processing of images. But resent years, LCD devices for application in headlights of motor cars or architectural lighting has been intensively developed. LCD materials for such applications should be more resistant against extreme environment as well as against very bright light. To obtain required optical specifications when using in architectural lighting, LCD should have very high double refraction with high light-resistance. The German company *Merck* has developed such LCD mixtures, whereas *Hella KGaA Hueck & Co* [11, 12] has designed a luminaire with application of such LCD for operation in extreme environment (Fig. 5). The new monochrome structure is distinguished by availability of double light polarization (vertical and horizontal), and its polarization efficiency is 76 %. The LS is a LCD-matrix panel with relatively low resolution.

The structures allowing consumers to adjust them on the basis of their personal needs have been becoming more popular in the market. One of the ways to resolve this problem is to build in a dimmer. A good example is the *Hue* series of smart lighting devices by *Philips Lighting*. Not long ago, *LensVector* developed methods of changing the shape of light spot from local lighting. LCD elements can be used for adjustment of light direction or it's focusing (Fig. 6) [12].

The study being fulfilled in the National Tsing Hua University (Hsinchu, Taiwan) shows that it is not necessary to consider only the luminous efficacy and energy efficiency to obtain "proper" lighting for a user [13]. The scientists had studied the process of suppression of melatonin secretion under influence of three types of LSs (a Planck radiator, LED

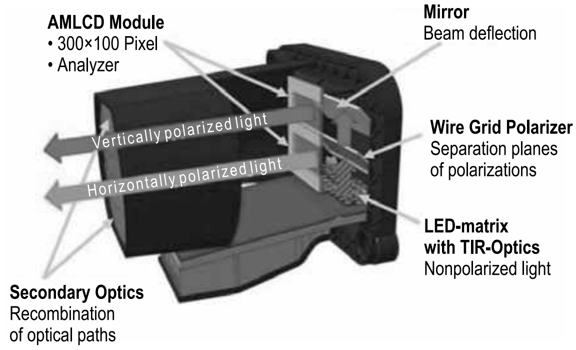

Fig. 5. Diagram of the structure of a directional luminaire with a LC light source

Fig. 6. Two concepts of light guides for architectural application: focusing or shape changing and direction adjustment

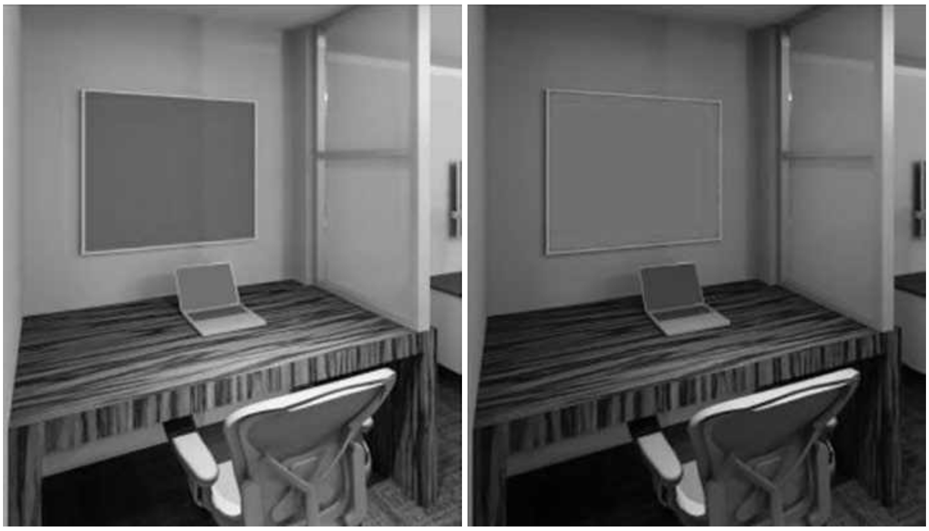

Fig. 7. Example of application of a self-glowing display panel for creation of efficient (blue) and inefficient (red) light (in terms of circadian rhythms) depending on the time period

and OLED) with T_{cc} varying between 2,000 and 8,000 K. Table 4 shows maximum acceptable values of retina irradiation for these three LSs in terms of photobiological safety [14].

Usually it is believed that the white light with T_{cc} of about 6000 K is more suitable for displays of TV's, monitor units and mobile phones than the light with T_{cc} equal to 7,000 K (with relatively higher content of blue colour).

The combination of the "proper" light and energy-saving technologies allows to avoid sleep disruption and risk of retina damage or diseases.

The Lighting Research Centre of the Rensselaer Polytechnic Institute (USA) conducted a study of synchronisation of circadian rhythms of different groups of people including those suffering various neurological disorders with local time [15]. The study also included research of potentially useful impact of lighting display panels on sleep and feeling. In the pilot experiments, a 70-inch display panel by Japanese company *Sharp* was used, the publication does not specify whether it was a plasma panel or a LCD panel. In the course of the one-week experiment, the people suffering Alzheimer disease sat at the table made of a lighting display panel during the light day from 7 in the morning till 6 in the evening. At the specified time, they had meal at this table. The table could be used also as a sensor screen for games and entertainment. As a result, sufficient improvement of sleep and reduction of depression and irritation were witnessed. The glow of the panel was either blue or red depending on the time period (Fig. 7), which allowed the circadian rhythms adjustment. Moreover, there were vertical display panels in the room so that their light could reach retina. This cannot be always reached if LS is located on the ceiling.

CONCLUSION

The article contains a brief overview of contemporary safe, environmentally friendly and ergonomics technologies based on LED and OLED and application of some new composite materials. New fields of application of such devices are overviewed with consideration of economical prospects; possibility to apply such technologies in medicine is noted.

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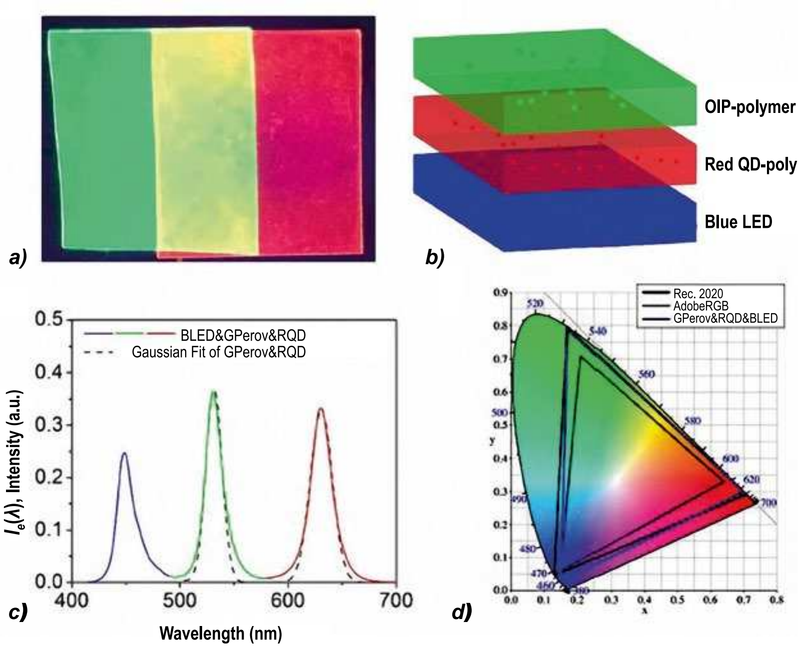

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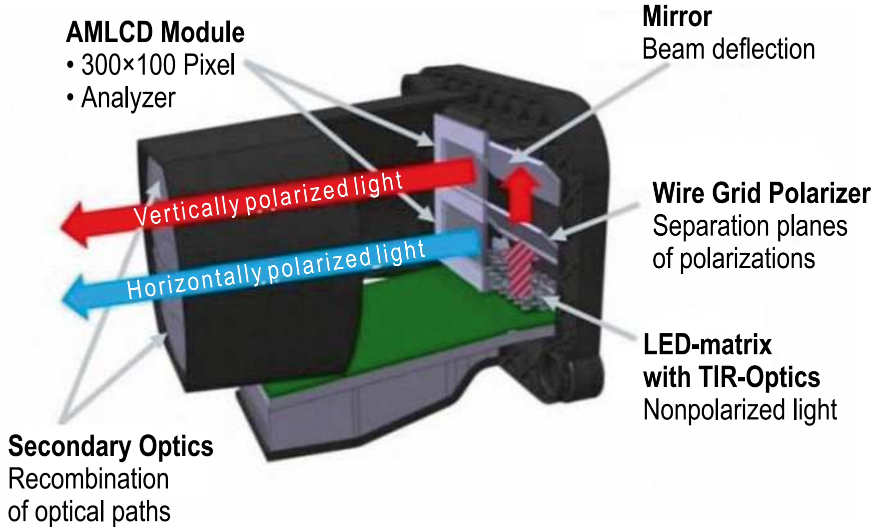

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