MECHANIKA
CZASOPISMO TECHNICZNE
TECHNICAL TRANSACTIONS
MECHANICS
WYDAWNICTWO
POLITECHNIKI KRAKOWSKIEJ
9-M/2012
ZESZYT 26
ROK 109
ISSUE 26
YEAR 109

MARCIN MAJKA*, TOMASZ M. MAJKA**

THE FUTURE OF THE LIGHT SOURCES

PRZYSZŁOŚĆ ŹRÓDEŁ ŚWIATŁA

A b s t r a c t

In this paper will discuss the main source of light, their impact on work and human health. Sources of natural and artificial light can be classified in terms of spectral and photometric. For artificial lighting are also important determining the performance characteristics of the conversion of electricity into light. In addition to these classifications, the light sources differ from each photon generation process, as well as the influence of light on the human eye. Will discuss the effects on the human eye light from organic LEDs and to what result this technology aims.

Keywords: light source, natural and artificial light, influence of light, influence light on the human eye

S t r e s z c z e n i e

W powyższym artykule omówiono podstawowe źródła światła i ich wpływ na pracę i zdrowie człowieka. Naturalne i sztuczne źródła światła można sklasyfikować pod względem spektralnym i fotometrycznym. Dla sztucznego oświetlenia ważne są również charakterystyki wydajności świetlnej określające wartości konwekcji energii elektrycznej na świetlną. Dodatkowo wymienione klasyfikacje różnią się sposobem generacji fotonów oraz wpływem wytworzonego światła na ludzkie oko. Omówione zostaną efekty działania światła pochodzącego z diod organicznych na ludzkie oko oraz do jakiego wyniku dąży ta technologia.

Słowa kluczowe: źródło światła, naturalne i sztuczne światło, wpływ światła, wpływ światła na ludzkie oko

* Eng. Marcin Majka, Faculty of Physics, Mathematics and Computer Science, Cracow University of Technology.

** MSc. Eng. Tomasz M. Majka, Faculty of Chemical Engineering and Technology, Department of Chemistry and Technology of Polymers, Cracow University of Technology

1. Introduction

The most important spectral parameter of the source is color temperature. This corresponds to the temperature of the blackbody, in which it emits radiation corresponding to the color-impression, it produces investigated the source. It is an objective measure of color experience the light source. Light source because of the color divide according to the standards set by the agency adopted standards in the countries of the European Union and American into:

- Illuminants type A – color temperature of 2500 to 3500 K gives a warm light WW (Warm White), it corresponds to, for example, tungsten radiation.
- Daylight illuminants – the spectral distribution corresponds to the decomposition of averaged radiation power, with varying degrees of cloudiness and at different latitude. The most important of these is the D65 illuminant – 6500 K color temperature, which, according to European and American standards, corresponds to the average color of light between the hours of 10 and 12 local time.
- Fluorescent illuminants – 12 illuminants marked with symbols from F1 to F12 which include most of commercial lamps.

For common light sources are designated color temperatures. And so the color temperature of 2000 K is the color of light the candles, 2800 K – a very warm color (light bulb), 3000 K – Sunrise and Sunset, 3200 K – color of incandescent studio lighting, 4000 K – color white, 5000 K – Cool color, 6500 K – color of the day, 10000–15000 K – color pure blue sky, 28000–30000 K – lightning [1].

Another important parameter is the color rendering index (CRI). Is expressed as the number from 0 (for monochromatic light) to 100 (for white light). Determines how accurately perceive color lighted object. If the CAR is higher, then colors are better given away. Low coefficient of CRI have, for example, low-pressure sodium lamps, and high coefficient of CRI have sunlight. Figure 1 shows a graphical model useful in determining CRI factor.

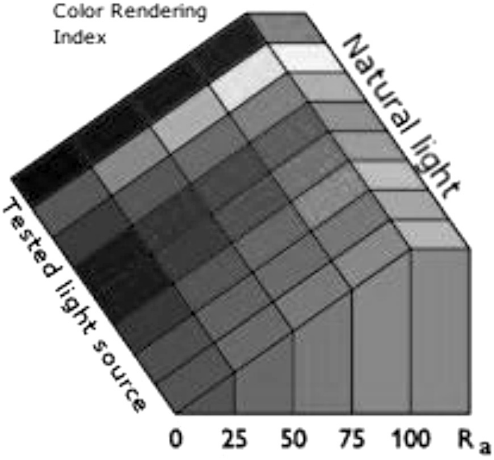

Fig. 1. Graphic design for the determination of the coefficient of CRI expressed in Ra (general colour-rendering index) [1, 3]

Rys. 1. Schemat graficzny do wyznaczania współczynnika CRI wyrażony w Ra (ogólny współczynnik oddawania barw) [1, 3]

In Table 1 are given the coefficients of CRI for the selected source radiation.

Table 1

Color temperatures and CRI factors for some light sources [1, 3]

The light source	The color temperature [K]	CRI [R_a]
Low-pressure sodium	1800	5
Mercury	6410	17
High-pressure sodium	2100	24
Mercury from the phosphor	3600	49
Fluorescence	4230	73
Fluorescent daily	6430	76
Quartz with pairs of metal halides	4200	85
Ceramic metal halide	5400	96
Thermal/halogen bulb	3200	100

According to the accepted norms of the source were evaluated in view of the color rendering index CRI. Table 2 presents the sources in the numerical classification of coefficient of CRI.

Table 2

Division sources due to the group by CRI factors

<table>
<tr><th colspan="2">Group</th><th>Color rendering quality</th><th>CRI</th></tr>
<tr><td rowspan="2">1</td><td>1A</td><td>ideal</td><td>90–100</td></tr>
<tr><td>1B</td><td>very good</td><td>80–89</td></tr>
<tr><td rowspan="2">2</td><td>2A</td><td>good</td><td>70–79</td></tr>
<tr><td>2B</td><td>satisfactory</td><td>60–69</td></tr>
<tr><td colspan="2">3</td><td>sufficient</td><td>40–59</td></tr>
<tr><td colspan="2">4</td><td>insufficient</td><td>20–39</td></tr>
</table>

The most typical sources of natural light is thermal radiation resulting from the emission of photons from a blackbody. The value of radiation energy emitted by a black body which is in thermodynamic equilibrium with the environment is equal to the radiation energy absorbed from the outside by the body. If the body temperature is higher, the radiation that is emitted by the heat of the body is called thermal radiation. If the ambient temperature is higher than body temperature, the emission processes will dominate the absorption. Conversely, when the body temperature is higher. Planck's theory describes the emission of a black body was a turning point in the development of physics. The formula for the capacity issue is the following function of the frequency distribution of light.

$$R_T(v) = \left(8\pi \frac{v^2}{c^3}\right)\left(\frac{hv}{\exp\left(\frac{hv}{kT}\right) - 1}\right) \tag{1}$$

where:

hv – frequency $v = \frac{c}{\lambda}$ of the photon energy,

h – Planck's constant.

Total emission of thermal radiation energy is the sum of values for all wavelengths:

$$\int_o^\infty R_\lambda d\lambda \tag{2}$$

After converting variable frequency wavelengths and by integrating over all lengths receive the Stefan's law formulated empirically before Planck, which states that the total capacity of the blackbody emission $R(T)$ at T is equal to the total energy emitted in unit time per unit area of a black body at a temperature T.

$$R(T) = \sigma T^4 \tag{3}$$

where $\sigma = 5.67 \cdot 10^{-8} \frac{W}{\mathrm{m}^2 K^4}$ is the Stefan-Boltzmann constant.

Finding the distribution of Planck's radiation peaks at different temperatures, we can conclude that the spectrum of the radiation is shifted towards higher frequencies (shorter wavelengths). This is called Wien's displacement law also empirically found before reaching the Planck model: $v_{\max} \sim T \Rightarrow \lambda_{\max} T = \text{const}$. – where $v_{\max}$ is frequency and $\lambda_{\max}$ is wavelength for which $R_T(v)$ has a maximum value of temperature T.

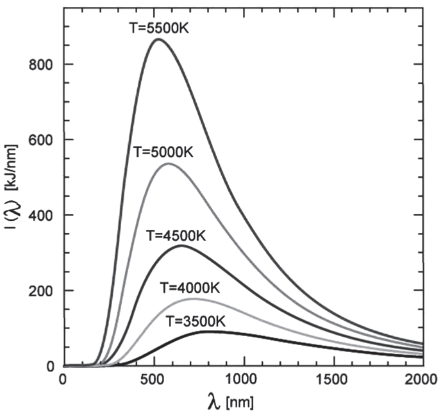

Fig. 2. Ability distributions of the emission of a black body radiation [1, 2, 4]

Rys. 2. Rozkłady zdolności emisyjnych promieniowania ciała doskonale czarnego [1, 2, 4]

The distribution of sunlight emissivity differs from the distribution of a blackbody at the same temperature as the Sun $T = 5800$ K. Figure 3 shows the spectral distribution of sunlight on Earth observed. The greatest value of the thermal radiation from the Sun is observed for the length of 550 nm.

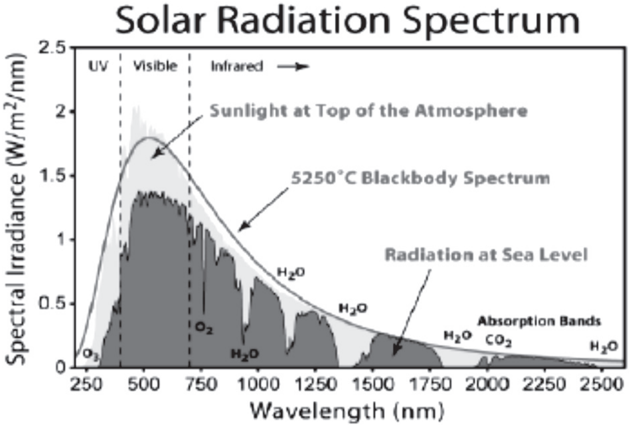

Fig. 3. Spectral distribution of solar radiation observed at the earth's surface [4]

Rys. 3. Widmowy rozkład promieniowania słonecznego obserwowany na powierzchni ziemi [4]

Solar radiation is attenuated by the earth's atmosphere, for example, ozone molecule absorbs the ultraviolet radiation and the molecule H_2O and CO_2 certain infrared bands.

Bulbs are typical representatives of the sources of continuous emission spectrum. So the temperature of their spectral distribution is equal to the color temperature. Timbre parameters bulbs practically does not depend on the material from which the filament is made, and only the value of temperature to which they are heated. Distribution close to the decay of a black body is a classic tungsten. However, the standard bulb light output is low (about 20 lm/W), which leads the governments of many countries to withdraw them from the market. Thermal lamp halogen lamps are equipped with a tungsten filament is the same as an ordinary light bulb, filled with inert gas with a small amount of halogen, which regenerates the filament, preventing the spraying.

Another of thermal radiation is the light coming from sources of luminescence. Luminescence comes from the pass energy in atoms, molecules, chemical or solids. The spectra of light emitted by the atoms and molecules are characteristic of them, which is why the study of these spectra allows the identification of emitting atoms and molecules. Based on this fact, the method of testing the chemical composition of the substance is called spectral analysis. Luminescence can occur under the influence of an electric field (electroluminescence), ambient light (photoluminescence), can also be thermally stimulated (thermoluminescence – cold glow). Photoluminescence is caused by the absorption of radiation in the visible light region, ultraviolet or infrared. Absorbed energy is the emitted in the form of light energy, less than the energy of excitation light. Electroluminescence of gas is the result of the electrical discharge. There is also some solids as results from a variable or a constant electric field. The most commonly used artificial light sources are luminescent lamps which include:

– fluorescent lamps – these lamps phosphor coated on the inside filled with mercury vapor and argon. Inorganic phosphors are materials doped small amount of rare earth ions or transition metal. By appropriate selection of the phosphor can change the color temperatures from 4000 K (white) to 6500 K (color daily);
– high-pressure mercury lamps – the radiation source is a mercury vapor discharge at high pressure (for example, around 1 MPa);
– mercury halogen lamp – with the introduction of metal halides (silver) is smoothed out their characteristics;
– sodium lamp – center of the discharge are sodium vapor and auxiliary gas (mixture of neon and argon). Due to the vapor pressure of sodium in the lamps are divided into low and high pressure. Low-pressure emit a distinctive gold – orange light. High pressure sodium lamps have lower efficiency but higher rates of CRI;
– xenon lamp – xenon pressure in the range from 8 to 30 atmospheres. Light is produced by electric arc formed between electrodes placed in the environment of xenon.

Table 3 presents the efficiency of different sources of light for illumination.

Table 3

The luminous efficacy of some light sources [4]

Light source	Luminous flux [lm/W]
ordinary bulb	8…20
halogen bulb	20…30
fluorescent lamp	40…90
ordinary mercury	30…65
mercury-filament lamp	17…25
halogen mercury	75…100
low-pressure sodium	80…180
High-pressure sodium	90…120

LEDs (Light-emitting diodes) are p-n connectors, selected semiconductor materials. Operation of the LEDs based on the phenomenon of recombination radiant. Emission is caused by current flow in pn junction, polarized in the direction of conduction. LEDs are at the moment the most durable light source. Some LEDs are lit continuously up to 100 000 hours. LEDs are great competitors for light bulbs and fluorescent lighting in the area of white light. High quality LEDs are up to ten times more light output than incandescent bulbs. Currently, traditional lighting and halogen lamps are replaced with high-performance LEDs. LED lights do not emit harmful ultraviolet light for the people, the light is not flashing, no stroboscopic effect, you can design the desired color temperature. Today's LEDs have an efficiency of the order of 20 ... 40%, which makes them very efficient sources of colored light. They produce light with a luminance of one thousand candelas per square meter. But the resolution of the screens where are installed LED matrix is small so they are used mainly in the billboards. The new technologies are already used organic LED (OLED). You can get big their density per area unit and the high flexibility and small thickness of the screens.

The eye allows us to gain a very large amount of information about their surroundings. It allows us to safely navigate in space. Image captured by the retina of the eye is its pre-processed and sent through the optic nerve to the brain. There, by the centers is recorded, processed and interpreted. Retina is the beginning of the nervous system leading to the brain. It consists of more than a hundred million light-sensitive nerve endings of two kinds. Because of their shape, they are called rods and cones. Rods is about 120 million, and about 6 million cones.

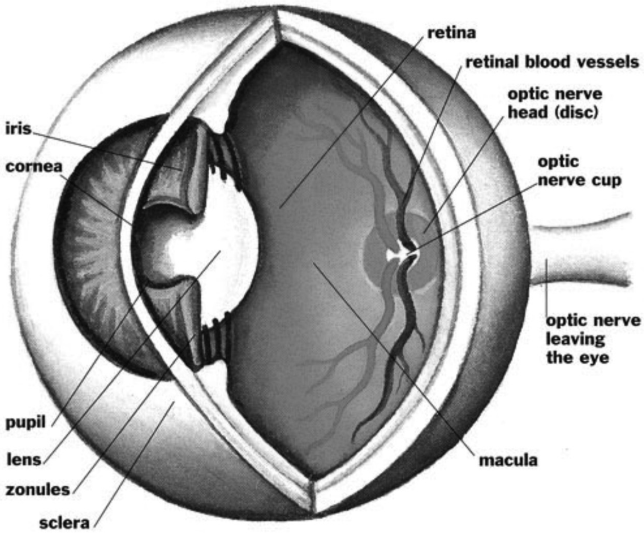

Fig. 4. The composition of the human eye [5]

Rys. 4. Budowa ludzkiego oka [5]

Rods are distributed throughout the retina, in addition to a yellow spot in the center of the visual axis. Cones are concentrated precisely in the yellow dot and are quite rare in the rest of the retina. Cones enable color vision, while the rods are responsible for the perception of shape and movement. Throughout the period of the evolution of visual receptors have adapted to white light coming from the Sun. Eyestrain and diseases associated with it are usually caused by working with artificial light is not coming from the Sun. Blinking lights, strobe lights as well as unnatural spectrum has a huge impact on the human eye, which in turn moves the time and its effectiveness.

2. Methods

Analysis of the light from the various tubes may be made due to the many factors of their properties. Hardly anyone wonders what impact has produced a light on the human eye. Many lamps illuminate our jobs or homes, they produce light in an unnatural way to the light sources on Earth. How easily can infer from this, the human eye is not accustomed to the light of artificial origin. Only the origin of the solar light to the human eye is most relevant, because the human eye is adapted to the spectrum of sunlight. Therefore, spectroscopic measurements made for artificial light sources can give meaningful information about the positive or negative impact on the health of the eyes.

Using a digital spectrometer for the analysis of the emission spectrum, it is possible to capture and compare lamp spectrum with the spectrum of sunlight. The test lamp should be placed so that the light produced by the courts come into the spectrometer. The entire spectrum measurement must be performed in the dark, so that light from other laboratory equipment did not affect the results. Figure 5 shows a schematic diagram of the light spectrum measuring apparatus.

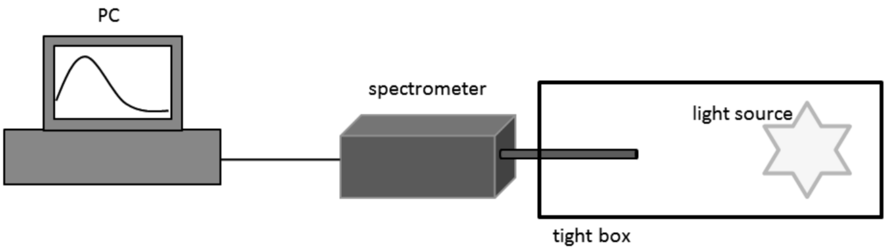

Fig. 5. Diagram of the system for measuring spectrum for different light sources

Rys. 5. Schemat układu pomiarowego widma świetlnego dla różnych źródeł światła

To improve the quality of measurement, you can use the integrating sphere. Integrating sphere connected on pin of spectrometer captures the spectrum of the total light flux. Since the spectrometer is not required that the wavelength range was wider than the wavelength of visible light.

3. Results and Discussion

Measurement of the spectrum of light sources is performed in order to compare it with the spectrum of day light. The spectrum is more similar to the solar spectrum, the human eye is working on the light slowly gets tired, and thus is less exposed to disease. Contrary to general belief, it has just bulbs from the beginning have a spectrum as close to natural daylight. Contrary to the general belief, the light bulb is characterized by a spectrum closest to natural daylight. Figure 6 shows the spectrum of the light bulb compared to the solar spectrum.

The above figure shows that the light bulb has spectral characteristics similar to sunlight. Despite this, the bulbs are slowly withdrawn from the domestic markets and are replaced by energy saving light bulbs.

In the case of luminescent lamps, there is a spectrum unnatural. Although these lamps have a high power efficiency, the light produced is not similar to the solar spectrum. Figure 7 shows a spectrum for P-VIP halogen discharge lamp (Special version for original equipment manufacturers named P-generation Video Projectors). Solar spectrum can be approximated by a black body spectrum with a temperature of 6000 Kelvin. The spectrum of P-VIP lamp halogen discharge does not even have a course similar to the said a black body spectrum.

The next light sources are LEDs. Interestingly, the white LED light is most similar to the solar spectrum only when the light is produced by a combination of three colors: red, green, and blue. With this type of physics, it is possible to adjust the individual LED spectra to the total spectrum was most similar to the solar spectrum. Figure 8 is a sample of the LED spectrum.

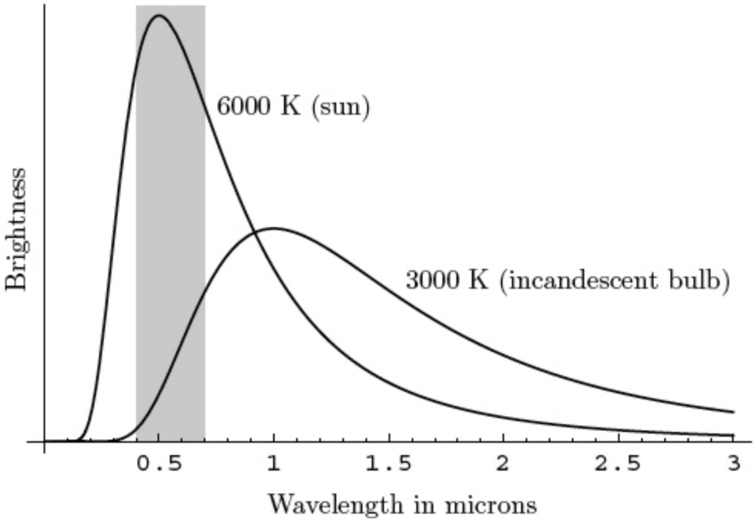

Fig. 6. Sample spectrum light bulbs and the sun [7]

Rys. 6. Przykład widma żarówki oraz widma słonecznego [7]

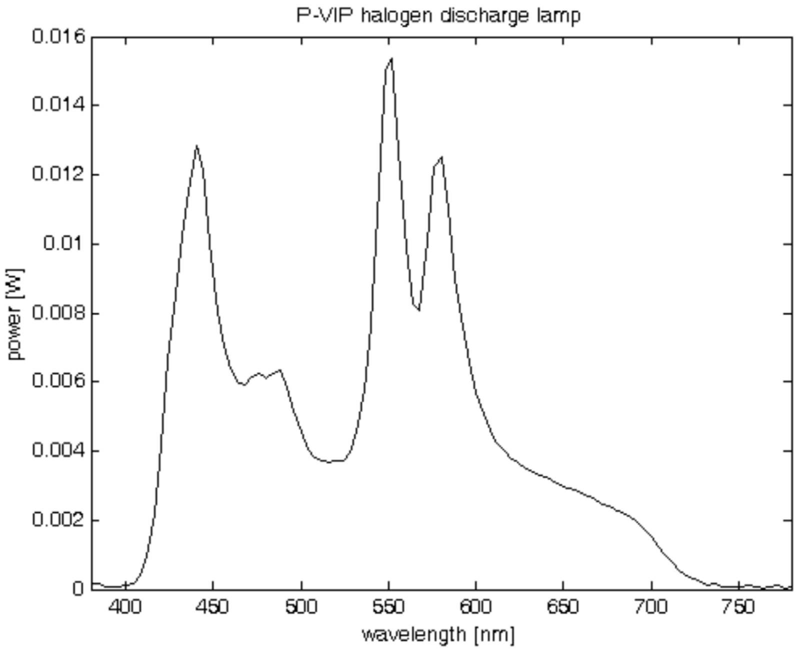

Fig 7. The spectrum of P-VIP lamp halogen discharge [8]

Rys. 7. Widmo lampy halogenowej P-VIP [8]

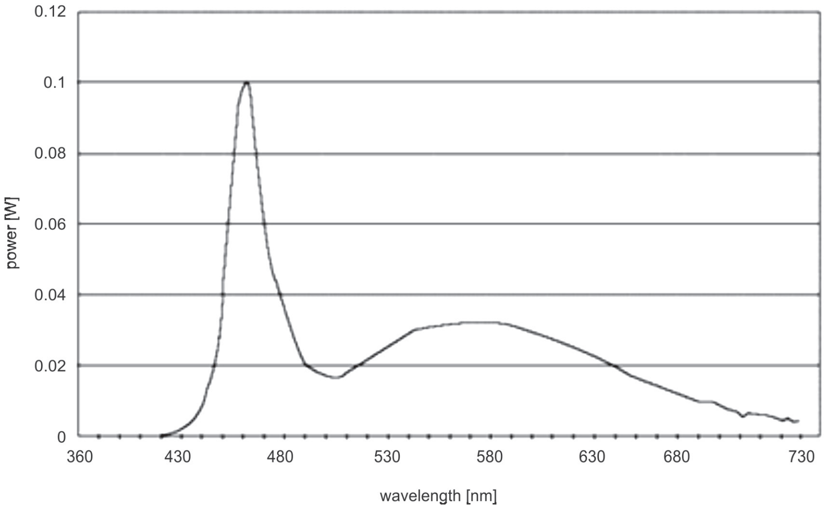

Fig. 8. Sample spectrum of white LED [9]

Rys. 8. Przykład widma światła białego LED [9]

The latest technology of organic LEDs is hoping for a cheap and healthy source of light. The current spectrum is very similar to the solar spectrum. This gives great hope for the future that healthy light will be available to all. Figure 9 is an example of spectrum for BAlq {aluminum (III) bis(2-methyl-8-quninolinato)-4-phenylphenolate} OLED. Research is still going on even more similar spectrum of OLED.

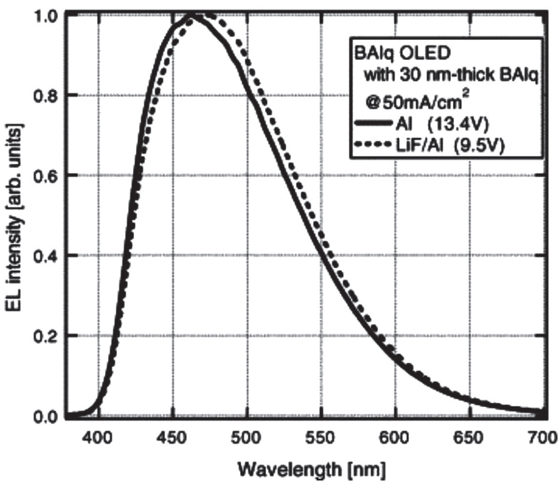

Fig. 9. The Electroluminescence spectrum of BAlq OLED with Al cathode and BAlq OLED with LiF/Al cathode at the current density of 50 mA/cm^2 [10]

Rys. 9. Widmo elektroluminescencyjne bis(2-metylo-8-chinolino)-4-fenylofenolan glinu (III) (BAlq) OLED z katodą glinową oraz BAlq OLED z katodą LiF/Al dla gęstości prądu 50mA/cm^2 [10]

4. Conclusions

In the above work have been presented different types of lighting. Presented lamps are different methods of generating light and their impact on human eyes. The evolution adapted our eyes to the sun light, that is, the light of which the most often encounter. Therefore, in our discussion constantly comparing various sources to sunlight. To sum up this analysis, it can be stated unequivocally, that OLED is the future of not only technological, but also health. By adjusting the light to our needs, we will be able to work longer, and thus more efficient than the older light sources. Even so popular energy-saving light bulbs are not able to produce as a healthy light as organic LEDs. With OLED toys for children will no longer harm the eye from a young age. Our future is in organic LEDs.

References

[1] Wiśniewski A., *Electric light sources*, Warsaw University of Technology, 2009.
[2] Žukauskas A., Shur M., Gaska R., *Introduction to solid-state lighting*, J. Viley, 2002.
[3] Helbig E., *Podstawy fotometrii*, Wydawnictwo Naukowo-Techniczne, 1975.
[4] Beckmann P., Spizzichino A., *The Scattering of Electromagnetic Waves from Rough Surfaces*, Pergamon Press Oxford, London, New York, Paris, 1963.
[5] Wright D.W., *The measurement of colour*, Hilger & Watts Ltd, London 1958.
[6] Bielecki Z., Rogalski A., *Detekcja sygnałów optycznych*, Wydawnictwo Naukowo--Techniczne, 2009.
[7] http://www.sciencebuddies.org/science-fairprojects/project_ideas/
[8] Beretta G., *Hot body, excited particles, and the north sky*, The Mostly Color Channel, 2007.
[9] http://www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org/chap21/chap21.htm
[10] Hyoung K., Sang-Hwan C., Jeong O., Yong-Hee L., Jun-Ho L., Jae-Gab L., Soo-Kang P., Young-Il P., Jong-Wook P., Young P., *Deep blue, efficient, moderate microcavity organic light-emitting diodes*, Organic Electronics, 11, 2010.