Spectral Correction of Photoelements for Measuring of Radiation in the Blue Light Spectrum

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Abstract
The use of different sources of optical radiation and the photobiological effect they cause on humans is a contemporary problem. Investigations in the field are basically aimed to estimation of the photobiological risk from radiations in the blue part of the spectrum.

Quantitative estimation of the influence of radiations from the blue light spectrum can be conducted by:

a) radiometrical measurements of the spectral intensity of the radiation of a source and estimation of the latter by means of the function of spectral sensitivity of the eye to blue light B(λ);

b) direct measurement of integral quantities through photoreceivers with relative spectral sensitivity suited to B(λ).

Currently there are special equipment for direct measurement of irradiance from sources, emitting in the blue part of the spectrum, EB, WB/m2 and radiant luminance of the emitting surfaces, considering the blue component of the radiation, LB, (WB/m2)/sr. The spectral sensitivity of the equipment is close to B(λ), but it differs from it in some spectral ranges.

The current paper presents theoretical and experimental results from spectral correction of photoelements according to B(λ) by means of filtering elements, aiming refinement of their spectral sensitivity.

Keywords: photobiological risk from blue light, spectral correction of photoelements, filters

1. INTRODUCTION

The use of different types of sources of optical radiation and their photobiological impact on humans is a contemporary problem. It concerns especially the photobiological risk from radiations from the visible spectrum with great intensity in the blue part of it. This kind of radiation is typical for the LED light sources, without regard to the technology, used for obtaining white light Fig 1 [1]. The maximum of the function defining the level of damage of the retina from the quantity of radiation in the blue part of the spectrum, B(λ), is between 446-447nm and matches the radiation maximum of the most common phosphorus LEDs.

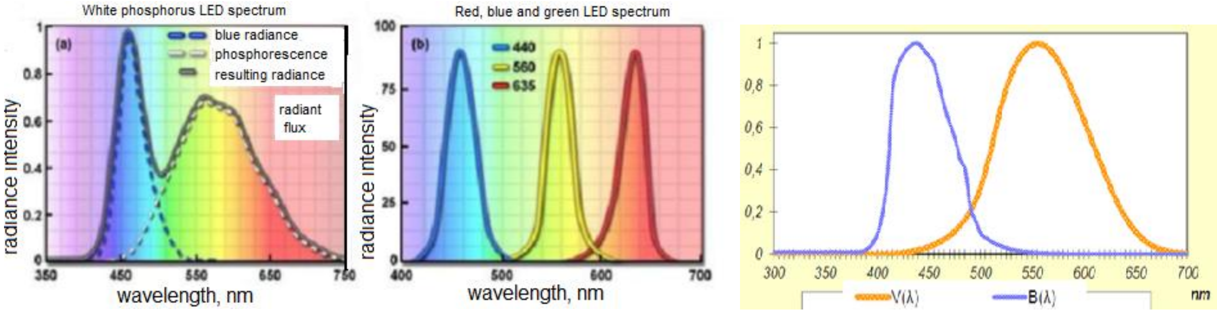

Fig. 1 Derivation of white light from LED light sources [1] and и evaluation of the photobiological impact of blue light

Subject of evaluation can be LED sources of optical radiation characterized with different spectrum and intensity of the radiation in the range of 300 to 700nm, in which the photobiological risk from blue light is estimated B(λ).

For quantitative estimation of the blue light risk two approaches are possible:

1. Radiometrical measurements of the spectral intensity of the radiation of the source and its evaluation according to the function of spectral sensitivity of the human eye to blue light B(λ), according to EN 62471:2008 [2];
2. Direct measurement of integral values, irradiance from blue light E_B - W_B/m^2 and radiant luminance of the emitting planes with respect to the blue component L_B, $(W_B/m^2)/sr$, through photoelements, with relative spectral sensitivity agreed with B(λ).

The quantitative identification of the integral values E_B and L_B, according to which the presence of photobiological risk from blue light is estimated requires coordination of the photoreceivers.

The current paper presents the results from coordination of different photoelements according to B(λ) through filters.

3. CHOICE OF FILTERING ELEMENTS FOR COORDINATION OF PHOTOELEMENTS TO THE CURVE FOR ESTIMATION OF PHOTOBIOLOGICAL RISK TO BLUE LIGHT

For photometrical measurement of the photobiological risk from blue light different photoreceivers can be used. Their relative spectral sensitivity usually differs from the function of presence of photobiological risk to blue light B(λ). Fig. 2 shows the relative spectral sensitivity of silicon photodiodes s(λ) Si* [4], most commonly used for photometrical measurements, the relative spectral sensitivity of gallium phosphide photodiodes GaP* used for measurement of blue light (according to their application manual) [5] and the B(λ) function.

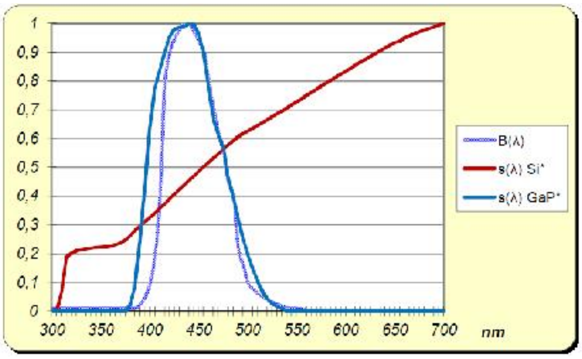

Fig. 2 Relative spectral sensitivity of Si photodiode [4], GaP photodiode [5] and sensitivity of the human eye to radiations from the blue part of the spectrum B(λ)

In order to achieve proportionality of the current i_{phr} of the photoreceiver to the effective radiant Flux Φ_B, fallen on its surface and determinant for the presence of photobiological risk it is necessary that its spectral sensitivity curve s(λ) is the same as the sensitivity of the human eye to radiations in the blue part of the spectrum B(λ) or s(λ) = B(λ):

$$i_{\phi л\_} \approx \Phi_B = \int_{300\,nm}^{700\,nm} \varphi(\lambda).B(\lambda).d\lambda \qquad (1)$$

This dependence is analogical to the principles for spectral correction of photoreceivers according to the relative spectral sensitivity of the eye [3].
Acceptance of B(λ) and s(λ) curves can be obtained in two ways:

1. Through correction coefficients K1, when the difference between the B(λ) s(λ) curves is small:

$$K_{1\text{-}LS} \,.\, s(\lambda) = B(\lambda) \qquad (2)$$

2. Through the use of filters with correction function τ(λ), so that:

$$K_2 \,.\, s(\lambda) \,.\, \tau(\lambda) = B(\lambda) \qquad (3)$$

Where K_2 is calibration parameter, accounting for the sensitivity loss of the photoelement, due to the use of filter:

$$K_2 = (B(\lambda) / s(\lambda))_{max} / \tau(\lambda)_{max} \qquad (4)$$

When B(λ) and s(λ) of the photoreceiver are known functions, the correction function of the filter τ(λ) is:

$$\tau(\lambda) = B(\lambda) / K_2 \,.\, s(\lambda) \qquad (5)$$

For determination of the correction function, different restrictions can be set, but in practice the available elements (photoreceivers and filtering elements) are considered first.
Estimation of the results received can be made through evaluation of the relative deviation of the spectral sensitivity of the human eye to blue light B(λ):

$$\delta_{B(\lambda)} = \frac{\sum_{\lambda=300}^{700} s^*_{rel}(\lambda).\Delta\lambda - \sum_{\lambda=300}^{700} B(\lambda).\Delta\lambda)}{\sum_{\lambda=300}^{700} B(\lambda).\Delta\lambda} .100\,,\% \qquad (6)$$

The so far available GaP photodiodes [5], aimed for measurement of radiation from the blue part of the spectrum have spectral sensitivity close to B(λ), but their direct use

would lead to considerable deviation from the real irradiance E_B - W_B/m^2. The relative deviation from B(λ) estimated through (6) is 18,6%.
For the current investigation different variations of properly coordinated photoelements and filters are considered (according to the catalogue data) [4, 5, 6]. While searching for proper decision a requirement is set that the absolute value of the relative deviation of the photoelement-filters set from B (λ) shouldn't be greater than 5%.
Different filters (wide-spectrum and transmitting in a defined spectral interval or defined wavelengths) with different thickness are considered. The decisions reached are for Si and GaP photoelements only.
Figure 3 shows the best results from the multivariate decisions and combinations with smaller deviation from the objective function for coordination of Si photoelements and filters.

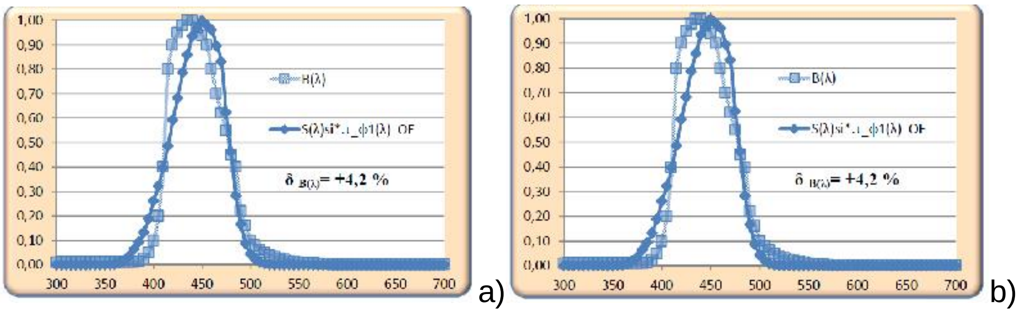

Fig. 3 Relative spectral sensitivity of the combination Si-photoelement and a) one filter with thickness of 8 mm and spectral transmittance coefficients τ_ф1(λ) and b)three filters, characterized with spectral transmittance coefficients τ_ф2,3,4(λ) and overall thickness of 4mm.

The decision shown on Fig. 3 a) meets the requirement for relative deviation of the final spectral sensitivity of less than 5%, but it has serious drawbacks. Because of the great thickness of the filter a considerable decrease of the current in the photoreceiver is detected, leading to limitation of the scope of the measured values. Also there is a shift of the maximum sensitivity of the resulting spectral sensitivity and considerable mismatches in the range between 415mn and 475nm. This may lead to great deviations of the measured values for different radiation sources, characterized by different spectrum.
Practically applicable is the second decision – Fig 3 b). For its realization three types of optical filters are necessary, but the smaller thickness and the greater transmission and cooperation are advantage.

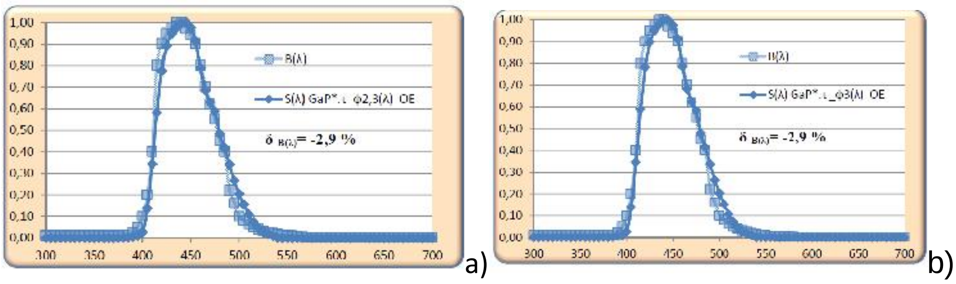

Fig. 4 Relative spectral sensitivity of the combination GaP photodiode and a) single filter characterized with coefficients of spectral transmission τ_ф3(λ) with thickness of 1mm and b)two filters, characterized with coefficients of spectral τ_ф2,3(λ) with overall thickness of 2 mm

Fig.4 shows the results from the multivariate decisions and combinations with smallest deviation from the target for GaP photoelements.
In the search for proper decision for coordination of GaP photoelements, the use of wide spectrum filters is not necessary, because they are not sensitive to wavelengths bigger than 540nm. The GaP photodiodes show deviation from the B(λ) curve in the spectral region 350 to 425nm, which eases the decision of the problem. It must be noted, that the same filtering elements with transmittance coefficients τ_ф1(λ) and τ_ф2,3,4(λ) are used for coordination of both Si and GaP photoelements. Both of the decisions reached for coordination of GaP photoelements are suitable for practical applications. The advantages of the decisions shown on fig. 4 are that less filtering elements with greater integral transmittance coefficient are used, the deviation from the target function is smaller and opportunity for measurement of low irradiance levels is better.

3. CONCLUSIONS

The results obtained are useful for construction of equipment for direct measurement of integral values, characterizing the photobiological influence of blue light on humans: E_B, WB/m2 and L_B, (WB/m2)/sr, through coordinated to B (λ) photoelements.
Correction coefficients for better coordination of the pair – photoelement – filters can be obtained after calibration of the constructed equipment for different light sources.

4. References

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