Electrical Power Quality and Utilisation, Journal *Vol. XI, No. 1, 2005*

ON THE THICKNESS OF PHOSPHOR COATING IN FLUORESCENT LAMPS AND ITS IMPACT ON SELECTED LIGHT PARAMETERS

Antoni RÓŻOWICZ
Kielce University of Technology, Poland

Summary: **This article presents the results of research carried out on the formation of light parameters of the phosphor coatings and surfaces of fluorescent lamps. Particular attention has been paid to those parameters which influence the formation of light parameters such as light efficacy and ripple. The results of the measurements of light efficacy and light ripple are given in terms of the thickness of coatings and some of the physical parameters of phosphors used in AC powered mains frequency fluorescent lamps. On the basis of attained results the conclusions are given concerning the efficacy of light and the depth of light ripple in the function of the thickness of phosphor coating**

Key words:
Light
Light parameters
Phosphors

1 INTRODUCTION

In low-pressure discharge lamps the light is created by the excitation of mercuric vapour present between two electrodes. The effect of low-pressure discharge is the generation of two resonating lines of mercury in the ultraviolet spectrum of 184,9 and 253,7 nm and relatively weak lines of 313, 365, 405, 435 and 546 nm. The output intensity of UV rays is expressed by four main elements, that is: the pressure of mercuric vapour, the type of auxiliary gasses, the dimensions of the discharge pipe and the current density. Phosphors applied onto the outer wall of the discharge pipe should have the capacity to absorb UV rays and the emission band in turn should be tolerably wide and lying mainly in the visible spectrum. Moreover they are formed from crystals of various sizes of molecules, so the thickness of the coating of phosphor depends on the size of the crystallites and their distribution, and this in a crucial way affects the efficiency of conversion of UV radiation into a visible form.

2. TYPES OF PHOSPHORS

Fluorescent lamps use phosphors depending on their particular designation and can be divided into a number of groups but in general there are two groups which are most frequently identified [2, 4]:

- standard—as a rule these are halo-phosphates of calcium activated by antimony and magnesium,
- narrow band—most frequently aluminate or borate activated by lanthanides: europ or terbium.

Fluorescent lamp with standard phosphors typically posses a low colour rendering index CRI $\geq$ 50, which is why their use is limited. This index rating can be improved by adding different chemical compounds. The choice of compounds is made on the basis of the dispersal of phosphor emission, however the improvement of the colour return index is achieved at the cost of a drop in light parameters.

In the group of narrow band fluorescent lamps with phosphor it is possible to distinguish: tri-banded class1b having a colour rendering index of $R \geq 80$ and class 1a with a colour rendering index of $R \geq 90$. Class 1b phosphors are the product of a mixture of three phosphors (red, green and narrow blue). The phosphor layer of lamps is often applied by the wet method and is either water or thinners based. Taking into consideration the different granulations of all fluorescent powdered phosphors and the method of applying the phosphor onto the bulb one can deduce that the phosphor coatings can vary in thickness.

3. THE THICKNESS OF THE PHOSPHOR COATING IN LAMPS

The absence of recorded data on the subject of the impact of the thickness of phosphor coating on light parameters prompted the author to carry out a series of investigations in this particular area. The tests focused on the T8 class1b type fluorescent lamp with tri-banded phosphor. All the tests were conducted on lamps of the same power rating and overall dimensions. The tests for the class1b lamps of different colour temperatures were conducted with the aid of the Oxford Instruments JSM 5400 scanning electron microscope and ISIS series solid-silicon detector. The phosphor blends solutions were prepared from technological suspensions of mountain crystals (upholding the application and drying regime required in production). Figure 1shows pictures of class 1b phosphor lamps.

There is a scale marker in each one of the pictures and in each case is 20 μm. The results of the research indicate that the thickness of the phosphor coating in class 1b lamps amounts to between 17 and 22 μm (on average around 20 μm) with there being no noticeable significant dependence on the colour temperature of the lamp. However there was a noticeable trend towards a diminishing number of particles above 6 mm and at the same time a rise in the colour temperature of the lamp. This dependence stems from va-

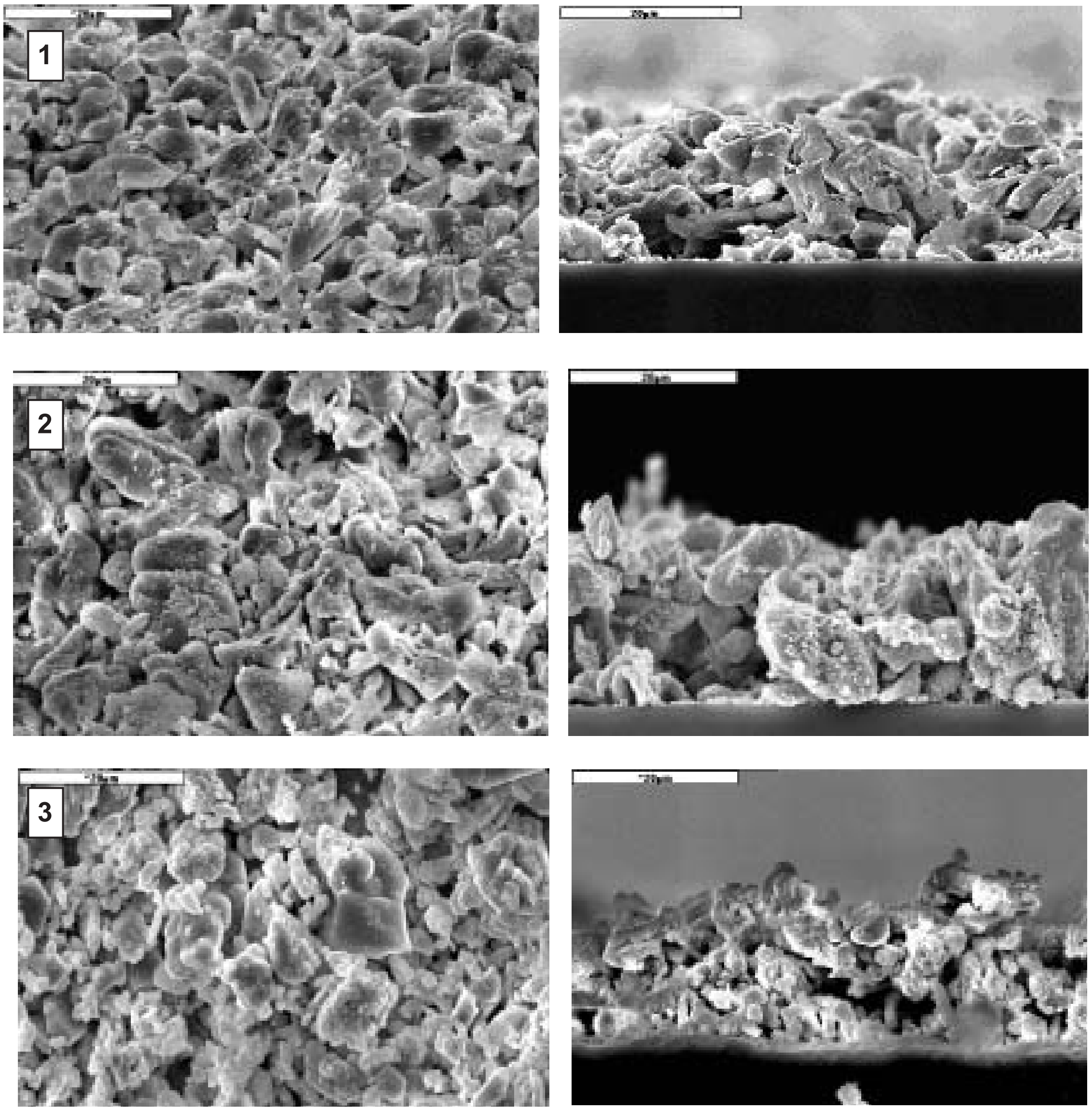

Fig. 1. Phosphors in lamps with a colour rendering index a) top view, b) cross section, 1 – T_c = 3000K, 2 – T_c = 4000K, 2 – T_c = 6000K

rious granulations of particular phosphors [7] (red, green and blue) as well as the percentage content of fluorescent powder.

Detailed research results of physical parameters of phosphor in class 1b lamps are presented in table 1.

4. THE IMPACT OF THE THICKNESS OF THE PHOSPHOR COATING ON LIGHT EFFICACY

The efficacy of fluorescent lamp luminosity (η) is defined as the relation of the generated luminous flux Φ to the electrical power P taken by the source:

$$\eta = \frac{\Phi}{P} \text{ [lm/W]} \qquad (1)$$

The value of light efficacy of fluorescent lamps (of the same type, power rating, dimensions and with the same auxiliary gasses) is determined by the conversion of UV radiation into visible radiation. And with regards to conversion efficacy itself there are many factors which determine this but in general they are associated with the phosphor. One of the more important ones is the thickness of the coating. To assess the impact of the effect of the phosphor on the luminous flux, experimental research was carried out on the T8, class 1 b type lamps (with various thicknesses of coatings) of colour temperatures 3000 K, 4000 K and 6000 K. In each of the groups of lamps (for a given colour temperature) the thicknesses of phosphor coatings averaged 0 μm, 10 μm, 20 μm, 30 μm, 40 μm and 60 μm. The choice and appraisal of the thickness of the layer of phosphor was chosen on basis of morphological tests on the phosphor coatings (shown above). The tests encompassed lamps with the same power rating, overall dimensions including being filled out with the same auxiliary gas. During measurement and recording process optimal surrounding conditions and circuit conditions were maintained making possible the comparison of results and findings. No variations in luminous flux were noticed in lamps of colour temperatures 3000 K, 4000 K, and 6000 K of the same thicknesses of phosphor coatings. The results of the conducted experimental research are presented in Figure 2 .

Table1. Phosphor coating parameters of class 1b lamps

	Diameter molecules				Thickness coating
T_c [K]	≤ 2μm	≤ 6μm	≤ 12μm	≥12μm	μm
3000	0.1	0.46	0.33	0.11	17 – 22
4000	0.1	0.42	0.36	0.12	17.5 - 21
6000	0.1	0.39	0.39	0.12	16.5 - 22

The results of the research (Fig. 2) show unequivocally that changing the thickness of the phosphor layer in lamps does to a significant extent have an effect on the value of luminous flux.

The greatest value of luminous flux was achieved with a coating layer of fluorescent powder of around 20 μm (corresponding to three and four crystallites) Increasing the thickness of the layer of phosphor to beyond 20 μm resulted in the increase of light absorption by the layers of phosphor crystals which in effect decreased the amount of light output. Whereas in the case of thinner coatings below 20 μm part of the UV radiation permeated through the crystals and into the wall of the glass and consequently was not absorbed by the phosphor crystals and converted into light. The inverse scale of the luminous flux value in the function of the thickness of the phosphor coating is the UV permeation coefficient which changes from unity to the absence of phosphor at zero at a thickness of 20 μm.

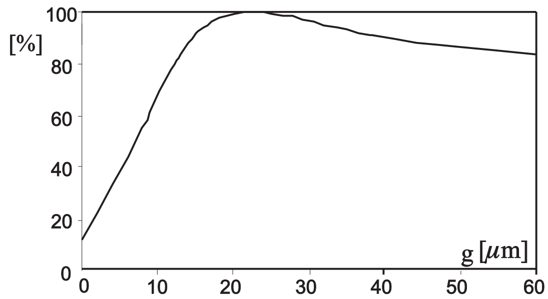

Fig. 2. The effect of the thickness of phosphor on the value of luminous flux; Φ – luminous flux, g – thickness of coating

5. THE IMPACT OF THE THICKNESS OF COATING ON LIGHT RIPPLE

The luminous flux of a discharge lamp occurs with the flow of current through the lamp. Twice for every period i.e. a hundred times a second at an electric mains frequency of 50 Hz, the current passes through neutral point, also reaching a maximum twice. A change in the intensity of light in the rhythm of the changes of alternating current from the minimum to maximum is termed as the light ripple. It is possible to elucidate the quantity of light ripple on a graph by illustrating the luminous flux as a function of time (Fig. 3). The quantity of light ripple is characterised by the depth of the light ripple with the aid of the ripple coefficient of ***w*** [1]:

$$w = \frac{\Phi_{max} - \Phi_{min}}{\Phi_{max}} \quad \textbf{(2)}$$

where:

Φ_{min}, Φ_{max} – maximum and minimum values of luminescent flux.

The research also encompassed T8, class 1b type lamps with tri-band phosphors of colour temperatures 3000 K, 4000 K and 6000 K all of which had identical overall dimensions as well as having been filled out with the same auxiliary gases. With regards to the value of the light ripple coefficient there are many determining factors. They are mainly associated

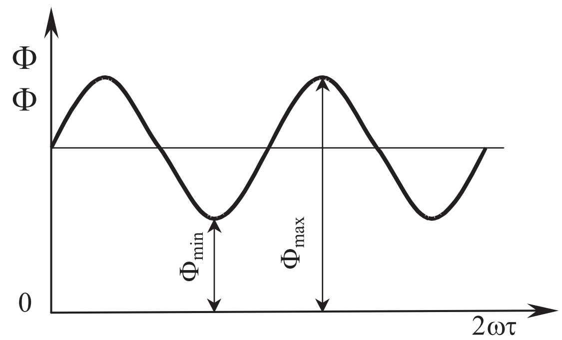

Fig. 3. The light ripple of a fluorescent lamp with AC power supply

with the properties of the phosphor [7, 8]. The most important are: the fluorescent properties of specific phosphors, [3, 5] the granulation of the phosphor powder, the percentage content of phosphors (red green, blue) in the powder and the thickness of the phosphor coating itself. Assuming that tests are carried out on lamps with the same colour temperature and where the percentage content of particular phosphors irrespective of the thickness is the same then the value of the light ripple coefficient can only be influenced by the thickness of the phosphor coating. However, for lamps of different colour temperature the percentage content of phosphors (red, green, blue) in the powder will have an additional impact on the light ripple coefficient [6].

Tests were carried out on lamps with no phosphor covering including ones covered with phosphor with thickness measuring: 10 μm, 20 μm, 30 μm, 40 μm and 60 μm. The results of the research on the coefficient of light ripple and according to thickness of the fluorescent powder (phosphor) for lamps T_c = 3000 K, T_c = 4000 K and T_c = 6000 K are presented in Figure 4.

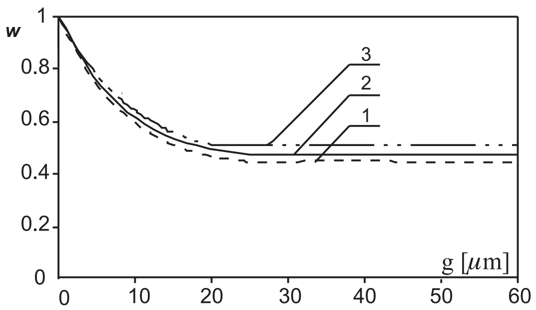

Fig. 4. The value of the coefficient depending on the thickness of the fluorescent powder: 1 – T_c = 3000 K, 2 – T_c = 4000 K, 3 – T_c = 6000 K

The obtained results indicate that there is a strong trend towards a drop in the light ripple coefficient when changes are made to the thickness of the fluorescent powder ranging from 0 μm to 20 μm. This results from the fact that thinner coatings of phosphor bring about a decrease in UV absorption which in turn also decrease the luminous flux (Fig 2) In other words, in terms of the value of the ripple coefficient in the scope of changes to thickness of the fluorescent powder in the range of 0 μm to 20 μm, the UV the coefficient of transmition comes into force. Whereas in phosphor coatings of 20 μm and above the value of the light ripple coefficient does not undergo change as the decrease is proportional $\Phi_{min} - \Phi_{max}$ (Fig. 3) and $\Phi_n / \Phi_{20\mu m}$ (Fig. 2).

The resolved differences in the light ripple coefficient value for lamps (with a phosphor coating thickness of ≥20 mm) *Tc* = 3000 K, 4000 K and 6000 K, stem from the percentage portion of phosphors (red, green and blue) in the fluorescent powder [5]. A detailed and thorough examination of the dimension of the light ripple coefficient of single band phosphor lamps (red, green and blue) were presented in an earlier paper [7]. The assigned light ripple coefficient values for lamps coated with phosphor amount to blue 1, green 0.36, red 0.59 respectively. If one takes into account the fact that with the increase of the colour temperature the percentage share of red phosphor diminishes and there is at the same time a percentage increase of blue phosphor in the fluorescent powder, one should conclude that the value of the light ripple coefficient rises, as is shown in Figure 4.

6. CONCLUSIONS

The carried out research and analyses of the luminous efficacy and coefficient of the light ripple of class 1b fluorescent lamps in the function of changes to the thickness of the phosphor coating indicate that:

— the value of the luminous flux of lamps is dependent on the thickness of the phosphor coating and the maximum luminous flux value is attained when the thickness of the layer of phosphor amounts to around 20 μm. For coatings below 20 μm. part of the UV radiation passes through the crystals into the wall of the glass tube of the lamp with no possibility of being absorbed by the phosphor crystallites, whereas above 20 μm there is an increase in the absorption of light by the layer of phosphor crystallites.

— the value of the ripple coefficient is dependent on the thickness of the phosphor coating for coating thicknesses from zero to 20 μm, whereas for a thickness = 20 μm the coefficient value is practically constant.

REFERENCES

1. Banach M.: *Light Ripples* WNT Warsaw 1970 (in Polish).
2. Blasse G., Grabmaier B.C.: *Luminescent materials.* Springer-Varlag Berlin 1994.
3. Godlewski J.: *Generation and Detection of Optical Radiation.* PWN Warsaw 1997 (in Polish).
4. Kim J.: *Luminescence analysis of fluorescent lamps*. IceCapInc. 9, 20, 2002.
5. Mayer Ch.: *Discharage lamps.* Deventer Antwerpen 1988.
6. Różowicz A.: *The workings of Florescent Lamps.* Conference of Electrical Engineering in the Building Industry, Cracow 97, (in Polish).
7. Różowicz A.: *Fluorescent materials used in low-pressure discharge lamps and their impact on light ripples*, Przegląd elektrotechniczny, 5, 2004, p. (in Polish).
8. Soules T.F., Hammer E.E., Sommeer T.J.: *Optimized phosphor systems and spectra for fluorescent lamps*. International Symposium on the Physics and Chemistry of Luminescent Materials. 198th Meeting – Phoenix, Arizona October 2000.

Antoni Różowicz
PhD Antoni Różowicz Works at the Independent Electrical Equipment Section and TWN Department at the Kielce University of Technology. Graduated in 1975 from the Department of Electricity University of Technology Częstochowa. Awarded PhD in 1987 at the Silesian University of Technology, Faculty of Electricity. He is the author of many scientific-research publications and papers on the subject of electrical power engineering and electrical lighting.
Address:
25-314 Kielce, al. Tysiąclecia Państwa Polskiego 7
tel.: 048 41 3424243
e-mail: rozowicz@tu.kielce.pl