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Application of cesium lamps for indoor lighting and preventive ultraviolet irradiation

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Abstract. An analysis of the radiation from cesium lamps has shown that the spectrum of such lamps is determined by the recombination continuum. This spectrum is close to the spectrum of the Sun not only in the visible, but also in the ultraviolet in the A and B ranges. This makes it possible to create environmentally friendly energy-efficient lighting systems with constant UV radiation based on these lamps to compensate for the lack of ultraviolet radiation at high latitudes and when working indoors without natural light. The advantages of such systems are considered in comparison with existing dual systems using conventional visible light sources and special erythemic fluorescent mercury lamps.

Keywords: gas discharge lamps, cesium pulse-periodic discharge, luminous efficacy, ultraviolet irradiation

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Использование цезиевых ламп для внутреннего освещения и профилактического ультрафиолетового облучения

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Аннотация. Анализ излучения цезиевых ламп показал, что спектр таких ламп определяется рекомбинационным континуумом. Этот спектр близок к спектру Солнца не только в видимой, но и в ультрафиолетовой области в диапазонах А и В. Это позволяет на основе этих ламп создавать экологически чистые энергоэффективные системы освещения с постоянной УФ радиацией, восполняющие недостаток ультрафиолета в высоких широтах и при работах в помещениях без естественного освещения. Рассмотрены преимущества таких систем по сравнению с существующими двойными системами с использованием обычных источников видимого света и специальных эритемных люминесцентных ртутных ламп.

Ключевые слова: газоразрядные лампы, цезиевый импульсно-периодический разряд, светоотдача, ультрафиолетовое излучение

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Mercury-free lighting lamps of a high-current pulse-periodic discharge (PPD) with cesium filling at high pressure have been developed and studied in recent years [1–10]. The radiation output in such lamps occurs mainly in the recombination continuum (6P and 5D). The pulsed mode with a low duty cycle makes it possible to realize for a short pulse time a discharge plasma concentration of 10^{17}–10^{18} cm^{-3}, which is necessary for efficient continuum radiation, at a relatively low average discharge power and an allowable thermal load on the discharge tube.

These lamps have a very successful combination of characteristics. The large scattering cross sections of electrons and ions on the Cs atom make it possible to abandon the buffer gas, mercury, which makes cesium lamps environmentally friendly. The cross sections for the excitation of electronic levels and the cross sections for recombination at the 6P and 5D levels are almost an order of magnitude higher than those for other alkali metals, Cs has a minimum atomic ionization potential (E_i = 3.89 eV). All this provides the high luminous efficacy η of 60–70 lm/W, as can be seen in figure 1, which shows the dependence of the luminous efficacy of a cesium lamp on average power W. The average power varied due to the pulse repetition frequency f. The figure 1 shows the experimental points for pulses with different current amplitudes I_m. The indicated value of η is approximately 5 times higher than the luminous efficacy of incandescent lamps and twice that of xenon lamps, although it is inferior to LEDs. The recombination continuum with a brightness temperature of 4000–6000 K covers almost the entire visible region of the spectrum, which provides excellent “solar” quality of light: the color rendering index is R_a = 95–97 [1, 2]. The high vapour pressure of cesium provides operating currents of tens of amperes without the appearance of cathode spots, which makes it possible to count on service life even longer than that of high pressure sodium arc lamps (HPSL), which is about 15–25 thousand hours. The cost of cesium lamps should be as relatively low as that of HPSL, since the technology for the production of both lamps is practically the same, and cesium lamps can be produced on equipment for the production of sodium lamps with minimal adaptation.

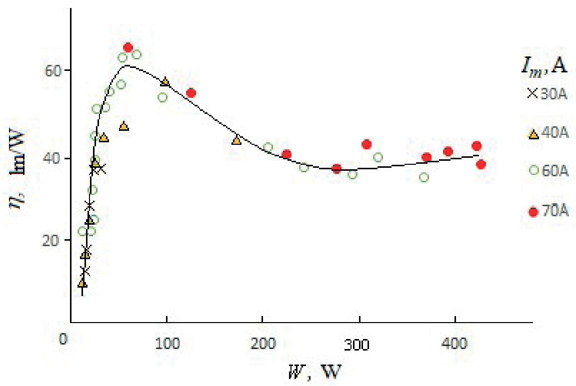

Fig. 1. The luminous efficacy η of a cesium lamp on the average power. The discharge tube radius 2.5 mm, the interelectrode distance 22 mm

The recombination continuum in the Cs lamp also generates weak continuous ultraviolet radiation. (Unlike conventional UV mercury and xenon lamps, which produce powerful monochromatic radiation in intense lines [10], and xenon flash lamps, which provide continuous but extremely intense UV radiation [11]). At the same time, in terms of spectral composition and intensity, this radiation is very close to solar radiation, which is clearly seen from figure 2. This figure shows the short-wavelength part of the standard spectrum of the Sun near the Earth's surface, which, outside the atmosphere, corresponds to the radiation of a black body with a temperature of 5900 K [12, 13]. For comparison, a typical cesium PPD spectrum with a similar plasma temperature on the discharge axis (about 6000 K) is shown, normalized to the solar spectrum at λ = 550 nm. The lamp spectrum was not recorded in the short-wavelength region (less than 350 nm), but in this region the lamp radiation is determined by the recombination continuum. Therefore, it is possible to model the radiation of a lamp in the short-wavelength region by the functional dependence of the continuum on the wavelength. The result is shown by a smooth blue curve 3. It can be seen that the spectra are close in the visible region and coincide well in the ultraviolet A region (400–320 nm), worse – for the B region (320–280 nm).

The spectra of the Sun and a cesium lamp depend on external conditions. So for the Sun, with a decrease in its height above the horizon, the short-wave part of the radiation is absorbed more than the long-wave part, therefore, the relative fraction of UV radiation drops especially for regions B and C. For a cesium lamp, the fraction of ultraviolet depends on the discharge mode, increasing with increasing temperature of the discharge plasma. In this case, the UV spectrum of the lamp, as can be seen from figure 2, is significantly affected by the transmission of the lamp bulb. So, in general, and for region B, it is always possible to achieve a general similarity of the spectra. This means that cesium lamps can simultaneously provide high-quality indoor lighting and the necessary dose of "sunny" UV during ultraviolet deficiency in winter at high latitudes (> 60 degrees [14, 15]).

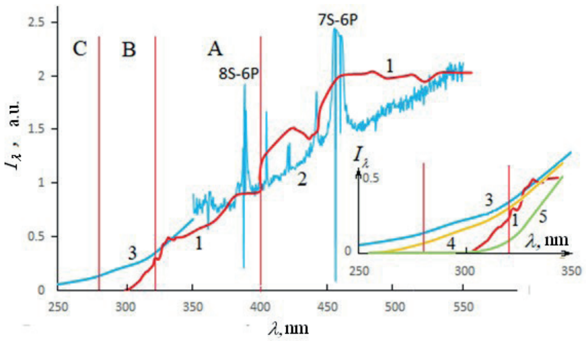

Fig. 2. Comparison of the spectra of the Sun and a cesium lighting lamp (the inset: short-wave region of the spectra). 1 — the Sun at sea level at its zenith, 2 — lamp, 3 — extrapolation to the short-wavelength region of the lamp spectrum in a quartz bulb, 4 and 5 — the same for bulbs made of different UV-glasses

It is known that UV radiation is a vital factor, and its prolonged lack leads to the development of a kind of symptom complex called "light starvation" or "UV deficiency". Those experiencing "UV deficiency" include workers in mines, metro, people working in workshops without access to daylight, engine rooms and, most importantly, residents of the Far North. To compensate for UV deficiency, at present, as the most effective means for industrial, educational, office premises, combined lighting systems are used with parallel switching on of special fluorescent mercury erythema lamps (LE, LA, LAR), emitting a relatively weak flux of ultraviolet radiation in areas A and B. Placement and the power of the lamps is calculated in such a way that during the stay in the room (4–8 hours) a person receives at least 1/8 (prophylactic dose) and no more than 3/4 of the erythemic radiation dose. The medical erythema dose is determined experimentally by the reddening of the skin from exposure to UV radiation. It is individual, but on average it is assumed to be approximately 200 J/m^2 [15].

Figure 3 shows a typical discharge spectrum in the near UV and part of the visible region in absolute energy units for a mode with the luminous efficacy of 55 lm/W, which is close to the maximum in figure 1. The spectrum was recorded at the end of the current pulse (the pulse duration 30 μs) at a maximum current value of 60 A, W = 107 W, f = 1310 Hz. The plasma temperature (8000 K) in this mode is higher than for the mode in figure 2. Therefore, the radiation here decays more slowly to the short-wavelength range of the spectrum. Based on the data in Figure 3, it is possible to estimate the dose of UV radiation in the B range, which is given by a cesium lamp that provides standard lighting in the room, with a constant stay with this lighting

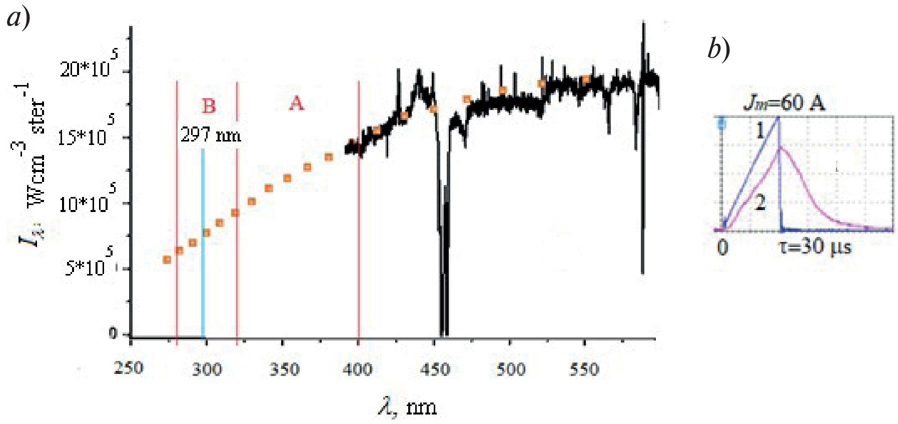

Fig. 3. The spectrum of a lamp with the interelectrode distance 22 mm and a quartz bulb. Squares — recombination continuum in the short-wavelength region (*a*); oscillogram of current 1 and luminous flux 2 (*b*)

(t = 8–16 hours). Regulatory lighting usually varies in the range of 100–500 lx, depending on the purpose of the premises, on average 250 lx. The flux of visible radiation in this mode is 5800 lm. For an occupancy time of 8 hours, the resulting UV dose would be 100 J/m^2. This value is in the middle between the prophylactic and erythemal doses, i.e. the ratio of the intensity of the visible and UV parts of the spectrum of cesium lamp is really close to optimal. This ratio can be changed by changing the mode of the lamps.

Thus, cesium lamps with their own UV radiation will have an advantage over combined lighting in all major parameters. First of all, eliminating the need to create a parallel UV irradiating system makes it easier and cheaper to switch to UV-enriched light. It should be especially noted that even when LEDs are used in the combined lighting system as the most efficient sources of visible light, the resulting luminous efficacy of the entire system will be at the level of the luminous efficacy of cesium lamps. This can be shown with a specific example. In [16], a calculation of the UV system for combined lighting for a room with an area of 50 m^2 is given, according to which it requires 8 LE-30 lamps with a total power of 240 W. To achieve lighting of 300 lx by LED sources in such a room, a luminous flux of ~ 25000 lm is required. At the current maximum the luminous efficacy of 150 lm/W (cylindrical LED sources from Philips), such a flux will require a power of 160 W, and the resulting luminous efficacy will be 60 lm/W.

In addition, the spectrum of UV radiation close to the sun should be the most favorable for the body. This ensures high quality of visible light. Rejection of mercury-containing erythema lamps in accordance with the Minamata Convention on Mercury (2013) addresses the issue of environmental safety. Guaranteed safety against an overdose of UV radiation will make it possible to switch to ultraviolet enriched lighting without additional difficulties, simply by replacing conventional light sources with cesium lamps, and to widely use it not only in industrial and public premises, but also in domestic conditions.

It should be emphasized that a necessary condition for the transition to lighting with cesium lamps should be the development of their power line in the range of 10—30 W with electronic ballasts in the base, which is realistic with modern element base. For lamps of high power (P > 30 W), it will be essential to develop compact electronic ballast. But, of course, the positive results of relevant biomedical studies of their radiation on the human body should play the main role in the implementation of using cesium lighting lamps. These studies can be carried out on the basis of already developed experimental samples of such lamps. Only such studies will make it possible to optimize the ratio of the visible and UV parts of the lamp spectrum and select the appropriate discharge modes.

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