Microwave Energy and Light Energy Transformation: Methods, Schemes and Designs

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Abstract

Nowadays, electrodeless sulfur lamps with microwave excitation (ESLME) are finding ever-widening application in energy-efficiency lighting systems. A reason of increased interest to these lamps is due to high values of their parameters including a high light flux (120-145 klm), a light intensity (~ 9000 cd), a high value of light output (80-110 lm/W), color rendition coefficient (Ra ~ 90), as well as an application of environmentally friendly materials (argon and sulfur). This chapter presents a novel approach of creating an energy-efficiency lighting source on the basis of the ESLME. For an electrodynamic structure of the lighting system, one can propose to use an optically transparent (mesh) waveguide instead of a microwave cavity. It is shown that the use of proximity of the spectra of optical radiation generated by the sulfur lamp and solar radiation allows more efficiently (in comparison with other light sources) their application as the simulators of sunlight for testing photoelectric converters and solar cells. For extending application of the lighting systems on the basis of the sulfur lamp and further increasing an energy efficiency of these systems, their integration with other electron devices (for example, solar cells) is proposed.

Keywords: lighting system, electrodeless sulfur lamp, magnetron, electromagnetic field, microwave excitation

1. Introduction

According to the estimates of the International Energy Agency (IEA), almost a fifth of all consumed electricity in the world is spent on lighting. One way to reduce the proportion of consumed electricity and its economical expenditure is the development of new energy-efficient light sources and lighting devices based on them. Requirements for such light sources are dictated by market demands, as well as the development and capabilities of modern technologies. Modern light sources must satisfy a number of parameters, combining high light output and efficiency with the comfort of perceiving generated radiation by the eye (a wide spectrum of radiation and color rendering), durability and environmental friendliness with low cost and a wide range of applications.

It is known that the problem of lighting is being solved by converting electrical energy into optical energy (visible light) with the help of various media and the processes occurring in them: metals and thermal processes (incandescent lamps (IL)), gaseous media and discharge (including plasma) phenomena (fluorescent (FL) and metal halide (MHL) lamps, etc.), as well as semiconductor materials and processes of spontaneous recombination of injected minority carriers (light-emitting diodes (LEDs)). Comparative efficiency of existing light sources is shown in **Figure 1**. It can be seen that the heat sources of light (incandescent lamps) in view of their low efficiency (only 3% of the supplied electric energy is converted into the energy of light waves) are much inferior to discharge lamps and LEDs.

Among the existing promising sources of light, special attention is paid to the development of plasma lighting devices based on the use of an electrodeless sulfur lamp with microwave excitation (ESLME). For the first time, such kind of lamp was presented in 1992 at the VI International Symposium on the Science and Technology of Light Sources in Budapest [1]. Later, based on it, Fusion Lighting Co. company created the lighting system Solar 1000 (1994), as well as its modification Light-drive 1000 (1997). Significant efforts to expand the use of these lamps were made by the Korean company LG Electronics, which, in 2005, held a presentation of the plasma lamp Plasma Lighting System (PLS), and also organized a series production of a number of designs of such light sources in the form of a ceiling lamp and spotlight lamp. In parallel, studies of electrodeless sulfur lamp with microwave excitation

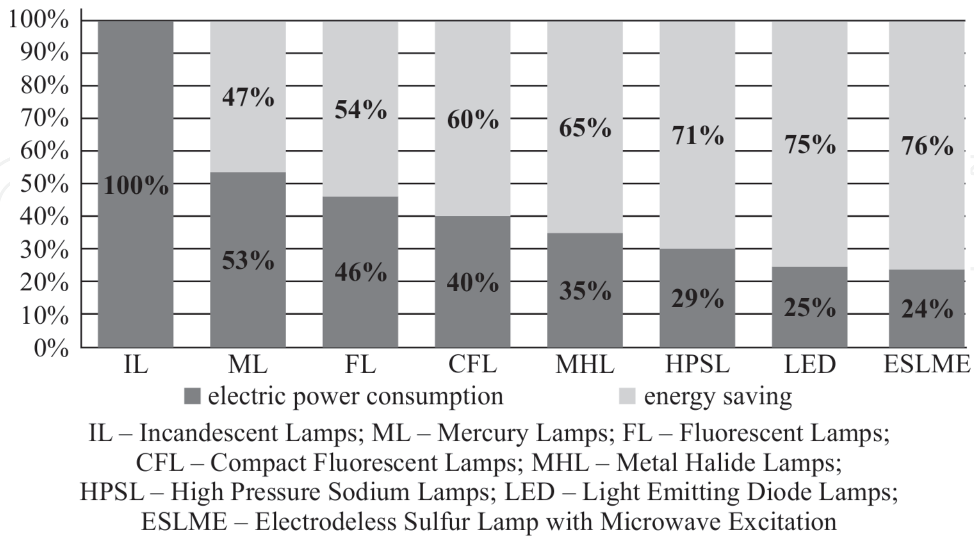

Figure 1. Evaluation of the effectiveness of light sources.

were conducted in Europe by Plasma International Group [2]. In 2010, the lighting system AS1300 was presented, consisting of a power supply, a microwave generator (magnetron) and the light module. However, their production was complicated by the complexity of the design and the high cost of the lighting device.

Recently, there have been designs of relatively low-power plasma lighting devices based on light emitting plasma (LEP) lamps with power from ~160 W to 300–400 W, in which solid-state microwave generators are used as an electromagnetic field source [3]. Now, the scope of such lamps is growing: from architectural lighting and street lighting to their application in the automobile industry.

The peculiarity of the topic of plasma light sources with microwave excitation is the long and constant interest to them (more than 25 years), which is expressed in a great number of scientific publications, including monographs, articles, patents obtained in different countries of the world. What is the heightened interest to the lighting systems based on plasma lamps with microwave excitation in? The answer to this question lies in the unique combination of their technical and lighting characteristics and parameters that most fully meet the requirements for light sources formulated above. For example, light generated by these lamps is characterized by high light flux (120–145 klm), light intensity (~9000 cd) and brightness, as well as good light output (80–110 Lm/W). Technical parameters of lighting devices based on plasma light sources with microwave excitation are characterized by relatively low power consumption, a continuous spectrum close to natural (solar) illumination with a color coefficient $R_a > 90$ (with a maximum value of 100) and the ability to control the intensity of light. An important advantage is also their environmental friendliness, which is due to the lack of mercury and the use of environmentally friendly materials—argon and sulfur.

Among the problems that need to be addressed, we should note the insufficiently long service life of magnetrons and the uneven heating of the surface of the lamp bulb, which requires to provide its rotation in the cavity space as well as studies aimed at selecting new materials. This will increase the durability of the lamp, which today does not exceed ~50 thousand hours.

This chapter is organized in five main sections. Section 1 describes the construction of a lighting device based on an electrodeless sulfur lamp with microwave excitation, gives a brief characteristic of its main components and analyzes their operation parameters. Section 2 considers an application of the electrodeless sulfur lamps with microwave excitation as the simulators of solar radiation, gives the comparative characteristics of such lamps with other lighting sources. Section 3 concerns promising directions for practical application of a lighting installation based on an electrodeless sulfur lamp with microwave excitation, in particular, for using in greenhouses. Section 4 presents the construction of the lighting system with the possibility of regenerating the energy of optical radiation into direct current energy for increasing its full efficiency. The main conclusions are formulated in Section 5.

2. Principle of operation and designs

A general scheme for the generation of optical radiation in the visible wavelength range (visible light) using plasma illuminating devices based on an electrodeless sulfur lamp with microwave excitation is shown in **Figure 2**. It is necessary to note that these devices use the transformation of electrical energy into the energy of light waves by stages. In the first stage, the secondary power source 1 converts the alternating voltage of 220 V and the frequency of 50 Hz into a constant voltage of 3.8–4.2 kV, which is fed to the anode of the magnetron.

In the second stage, the magnetron generator 2 converts the DC energy into the energy of electromagnetic oscillations. As a result, at the output of the magnetron in the waveguide 4, there are oscillations having the frequency of 2.45 GHz and the output power of about ~900 W. These oscillations excite the electromagnetic field in the electrodynamic structure 5, at the maximum of the electric field of which the sulfur lamp is placed.

At the third stage, physicochemical processes proceed in the inner space of the sulfur lamp under the influence of an electromagnetic field, as a result of which is the generation of optical radiation in the visible wavelength range (380–780 nm). This radiation is focused and output into the free space.

In order to determine the energy efficiency of the lighting system, the power consumed by the magnetron generator from the external (primary) network was investigated. The results of these studies are shown in **Figure 3**. It can be seen that the power consumed from the network by the lighting system is constantly increasing until the appearance of the primary glow of the lamp, which corresponds to 1700–1750 W of power consumption. Thereafter the power consumption from the network is stopped; the energy of the electromagnetic field is absorbed at once by the argon-sulfur mixture. As result, the generation of optical radiation takes place. The lighting system consumes ~2000 W in a stationary mode providing stable light emission.

The main elements of the lighting device and values of its main parameters are shown in **Figure 4**.

An important element of the lighting device on the basis of the sulfur lamp is the construction of an electrodynamic structure, the main purpose of which is to form a special structure of the electromagnetic field required to excite (pump) an electrodeless sulfur lamp. A bulb of the sulfur lamp is placed at the maximum of the electrical component of the electromagnetic field excited in the electrodynamic structure.

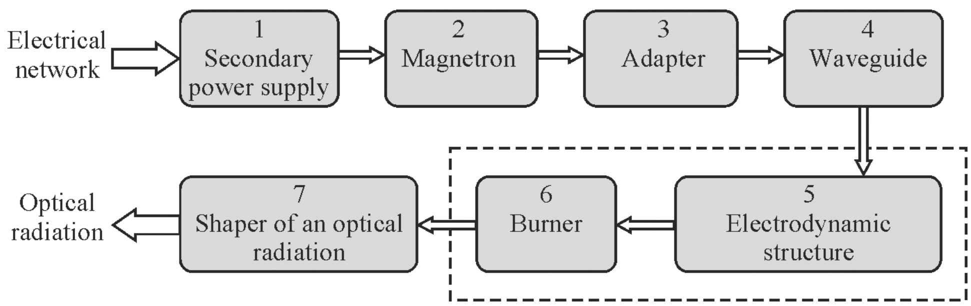

Figure 2. General scheme of converting energy in the plasma lighting device.

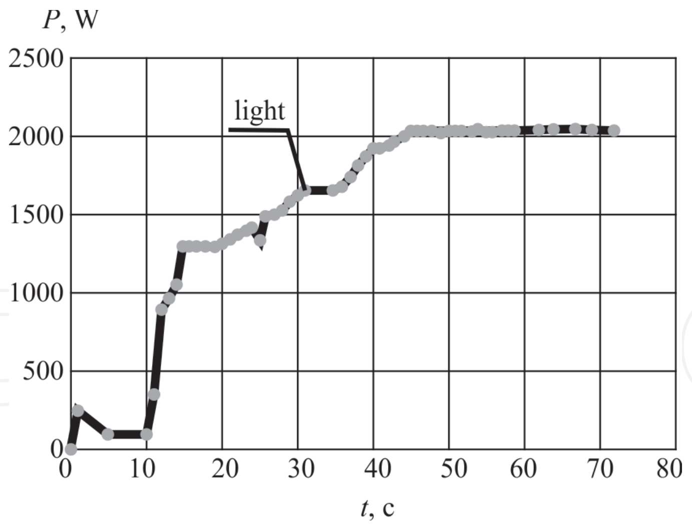

Figure 3. Dynamics of the power consumed by the magnetron generator.

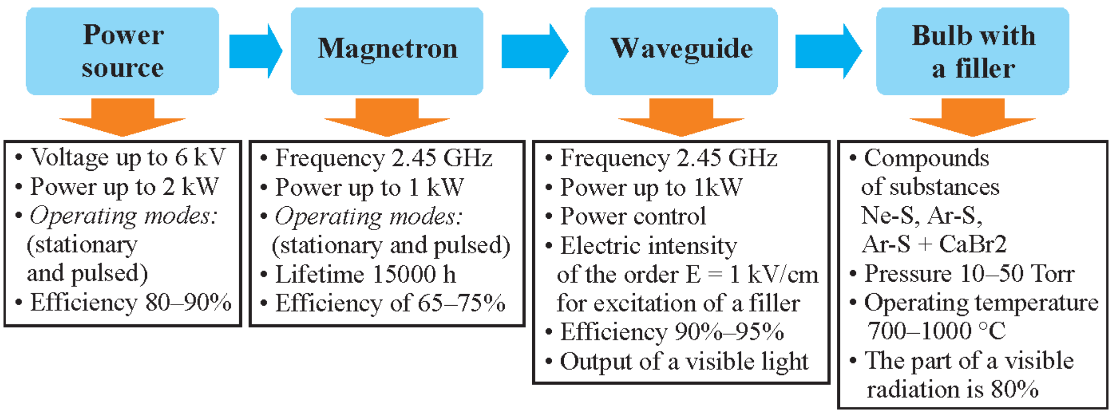

Figure 4. List of basic parameters of the elements of the lighting device based on an electrodeless sulfur lamp with microwave excitation.

As an electrodynamic structure, one is usually used optically transparent (mesh) cylindrical microwave cavity, inside of which a quartz bulb of the sulfur lamp is placed [4]. The outside surface of the cavity is done from thin wire and has mesh surface for free passage of optical radiation. A general view of the cavity with a bulb of the sulfur lamp is shown in **Figure 5**.

The main requirement for a resonant method of excitation of the electrodeless sulfur lamp is to maintain a mode of stable oscillations of the electromagnetic field in the cavity (resonance) (for example, for cylindrical cavity, one can use the following modes of oscillations: TE_{111}, TE_{112}, TE_{011}, TM_{010} and TM_{111}). The use of a cylindrical cavity allows reasonably simply to hold the sulfur lamp along its longitudinal axis, to ensure its stable rotation for uniform cooling of its surface and thus to select an optimum temperature regime for its operation.

In addition to the resonant method of exciting the sulfur lamp, of great interest is the method enabling to form an electromagnetic field in a waveguide by adding two counter-propagating coherent monochromatic waves $\vec{E}_1$ and $\vec{E}_2$ possessing the identical linear polarization [5]. The general view of the lighting device in which used this excitation method of the sulfur lamp is shown in **Figure 6**.

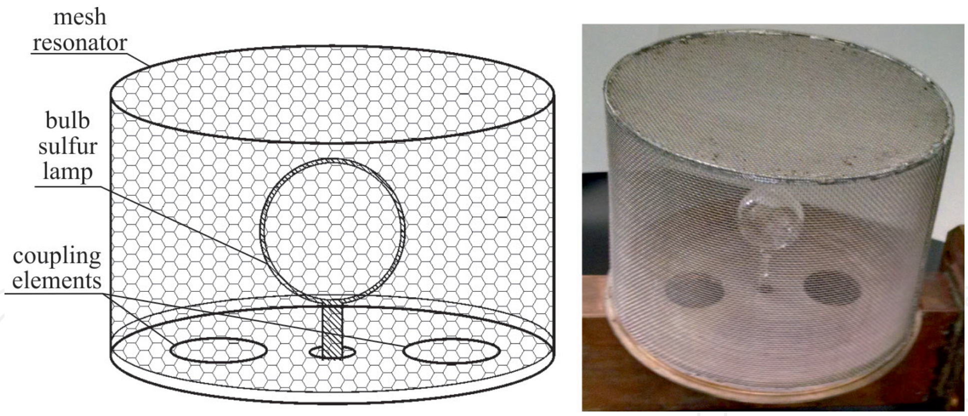

Figure 5. General view of the cavity with a sulfur lamp bulb.

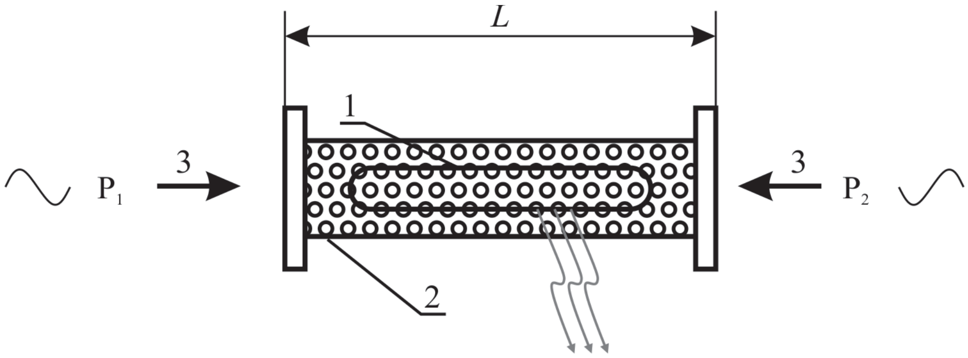

Figure 6. Schematic of the sulfur lamp in a waveguide. 1—a bulb of the sulfur lamp; 2—a waveguide; 3—optical radiation (light).

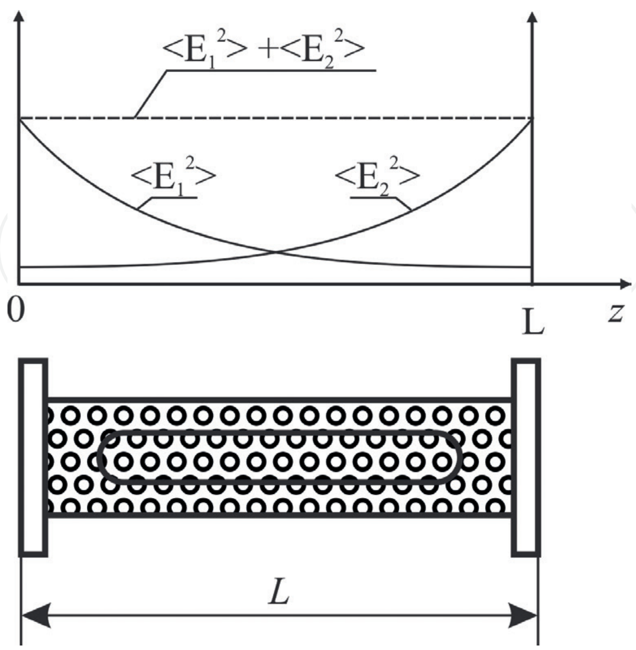

Figure 7. The distribution of energies of the electromagnetic waves in a waveguide.

In this case, there is a condition satisfied for the frequencies of these waves to be the same ($\omega_1 = \omega_2 = \omega$) and their propagation constant to be complex and equal to $\gamma = \alpha + j\beta$, where α is the attenuation constant determined by plasma parameters and β is the phase constant of the traveling electromagnetic wave. According to the principle of superposition, the intensity of the resultant electromagnetic field is

$$\vec{E} = \vec{E}_1 + \vec{E}_2 \tag{1}$$

Herein consider the energy description of the wave processes and put the first expression (1) in the square. After averaging over time, we finally obtain

$$< E^2 > = < \left(\vec{E}_1 + \vec{E}_2\right)^2 > = < E_1^2 > + < E_1^2 > + 2 \cdot < \vec{E}_1 \cdot \vec{E}_2 > \tag{2}$$

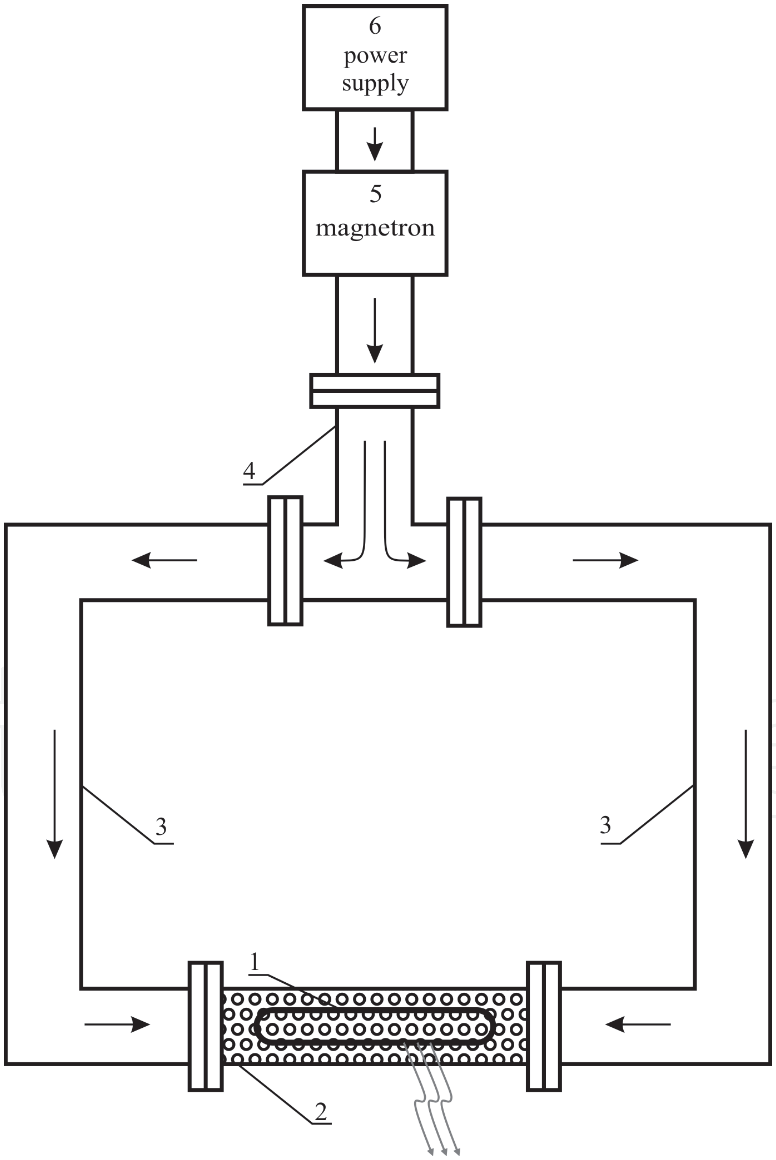

Figure 8. Schematic diagram of lighting device based on an electrodeless sulfur lamp with microwave excitation.

In the second expression (2), the total average total energy $< E^2 >$ depends on the value of the interference term $< \vec{E}_1 \cdot \vec{E}_2 >$. In the case when $< \vec{E}_1 \cdot \vec{E}_2 > = 0$ (there is no interference), the total energy in the waveguide is equal to the sum of the energies of the main and counter electromagnetic waves. When the condition is fulfilled, when $< \vec{E}_1 \cdot \vec{E}_2 > \neq 0$, the total energy is not equal to the sum of the energies of the waves running toward each other, but in the waveguide, there is interference of the waves.

Of practical interest for exciting a sulfur lamp in a waveguide causes is the case when the condition $< \vec{E}_1 \cdot \vec{E}_2 > = 0$ is fulfilled. As a result, it is possible to ensure a uniform distribution of the total electromagnetic field in the region of the electrodeless lamp location and a stable gas discharge in the lamp by creating a standing wave in a waveguide of arbitrary length L with optically transparent outside surface (mesh surface).

Figure 7 shows the distributions of full energy of the electromagnetic waves $< E_1^2 > + < E_2^2 >$, which is introduced from different ends of the waveguide as fundamental $< E_1^2 >$ and counter-propagating $< E_2^2 >$ electromagnetic waves. **Figure 8** schematically presents diagram of lighting devices on the basis of the electrodeless sulfur lamp with microwave excitation.

Figure 8 demonstrates a schematic diagram of lighting device based on an electrodeless sulfur lamp in the case excitation by adding two counter-propagating coherent monochromatic waves. For this excitation method, an electromagnetic wave is generated by a magnetron 5 and through a waveguide tee 4 through waveguide 3 enters a mesh waveguide 2 within which an electrodeless sulfur lamp 1 is located.

3. Simulators of solar radiation

Simulators of solar radiation (SSR) are radiation sources that form and direct a light stream into a fixed area. Such devices can be used for investigating the light characteristics of the photoelectric converter and solar batteries for space and ground applications as well as for carrying out high-temperature studies and tests on the resistance to light effects of various dyes and paint coatings, paper and labels, optical components, etc., [6–8]. The SSRs create a stream of pulsed or continuous optical radiation whose spectral characteristics are close to those of solar radiation. Ideally, the simulators should, with the best approximation, reproduce all the parameters of solar radiation including its spectral composition, flux density, parallelism of rays, stability in time and uniformity of illumination. However, such devices are extremely complex and expensive, demand qualified maintenance, and therefore, as the specific purpose requires, the specialized simulators are created (for example, large SSR for testing space vehicles [7]).

The solar simulators include powerful gas discharge, halogen or other lamps, correcting filters and also serving subsystems. There are quite a lot of familiar artificial light sources used to simulate solar radiation beginning with the carbon arc lamp; with sodium lamps, argon arc lamps, quartz-tungsten halogen lamps, mercury xenon lamps, arc xenon lamps, xenon flash lamps, metal halide lamps, light-emitting diodes and super sources of continuous laser radiation also being applied, but only incandescent and gas-discharge lamps were used in PC studies.

Figure 9 presents a comparison of the spectral characteristics of extra-atmospheric solar radiation and the simulators of solar radiation on the basis of lamps of the artificial lighting.

For testing the photoelectric converters and solar batteries, as a rule, the incandescent and gas-discharger lamps are applied in the SSRs as the light sources. This is due to the requirements to get the values of parameters such as the identity of the SSRs emission spectrum and spectrum of solar radiation, the color temperature (the color temperature of the extra-atmospheric solar radiation is ~5900 K), the high stability of the radiation flux and the small nonuniformity of energy illumination that determines the adequacy of measuring the parameters of the photoelectric converters and solar cells [8]. At the same time, for example, a necessity of temporal stability of the radiation flux is a significant limiting factor for using a number of arc sources in photovoltaic investigations, although their spectral composition is most consistent with the solar emission under conditions of zero atmospheric mass (AM0). The use of pulse gas-discharge lamps having a satisfactory spectral composition, in addition to the indicated temporary instability associated with the characteristics of their launch systems, requires to use high-speed measuring equipment, which significantly increases the expenses for creating the entire installation. According to the above parameters, the greatest interest can be found in such sources as:

1. The mirror incandescent and quartz halogen lamps that provide a satisfactory spectral composition of the radiation located in the range of 0.4–1.1 μm. These lamps are used in simple SSRs in order to simulate solar radiation for research and technological purposes in the tests of photovoltaic cells.
2. The arc-shaped gas-discharge xenon lamps (including with combined gas filling) for high-quality SSRs, used in precise measurements of the photovoltaic convertors parameters.
3. The most widely used are arc xenon spherical lamps, which have a spectrum very close to the solar one (see **Figure 9**); however, owing to an energy release in the infrared region of its spectrum, it is necessary to use corrective optical filters in the SSRs that use the lamps of this type.

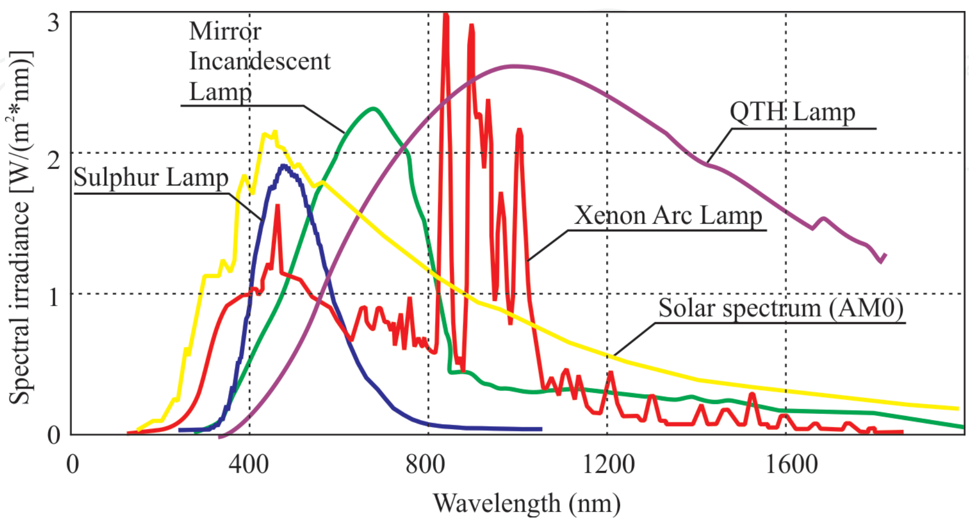

Figure 9. Spectral emission curves of the extra-atmospheric solar emission and sources of radiation for SSRs.

Characteristic	Halogen lamp KG-220-10000	Gas discharge xenon lamp OSRAM XBO 10000	Sulfur lamp Plasma-i AS1300
Power consumption (kW)	10	10	1.3
Light output (lm/W)	26	50	140
Luminous flux (lm)	260,000	500,000	163,000
Color temperature (K)	3200	6000	6000
Operating time (h)	2000	500	50,000

Table 1. Characteristics of lamps.

As shown in **Figure 9**, the spectral characteristic of the electrodeless sulfur lamp has a continuous quasisolar spectrum of optical radiation and is very close to the solar spectrum in its visible region. The second advantage of this lamp worth noting is its durability, which is important for its application in the SSRs [9].

Table 1 demonstrates the comparison of the lamps' characteristics that are most widely used in SSRs, as well as the parameters of the electrodeless sulfur lamp with microwave excitation.

Analyzing the characteristics of the electrodeless sulfur lamp with microwave excitation and comparing them with other light sources that applied in the SSRs, we can say that this lamp can also be successfully used in SSRs enabling to produce not only high-precise measurements of the characteristics of the photovoltaic convertors and solar cells of space application, but also to provide correct modeling of various modes of their operation under laboratory conditions.

4. The features of application of the lighting systems in greenhouses

The advent of the energy-efficient light sources on the basis of the electrodeless sulfur lamps with microwave excitation having a wide spectrum of radiation in visible region of electromagnetic spectrum (from 0.38 to 0.78 μm) allows to extend practical application of artificial light sources. In particular, the greatest interest is an application of such lighting sources in modern greenhouse and cattle-breeding farms for raising the level of crop yield and cost saving. On the one hand, the portion of the sectorial electricity consumption in the technological processes of the greenhouse farms using optical radiation is 10–15%, and the losses in them reach to ~40%. To reduce electricity consumption, it is necessary to modernize lighting systems with energy-intensive light sources to modern energy-efficient and economical ones. On the other hand, choosing artificial light sources that must have a certain spectral characteristic, the influence of optical radiation on the efficiency of the main photochemical processes of the plant is first of all taken into account. This is because each pigment has its own individual absorption spectrum and, thereafter, its own spectral characteristic of the light activity of the exciting radiation.

The most important and energy-intensive process is the process of photosynthesis. As shown, an investigation of the spectrum efficiency of the photosynthesis, that was carried out in [10, 11], the leaves of different systematic groups had approximately the same spectra of photosynthesis activity. An average curve of the spectrum of photosynthesis activity of the green leaf is shown in **Figure 10**.

All parts of the solar spectrum are important for the normal outgrowth of plants. More detailed information about results of an impact of the optical radiation having spectrum close to the solar spectrum is shown in **Table 2**.

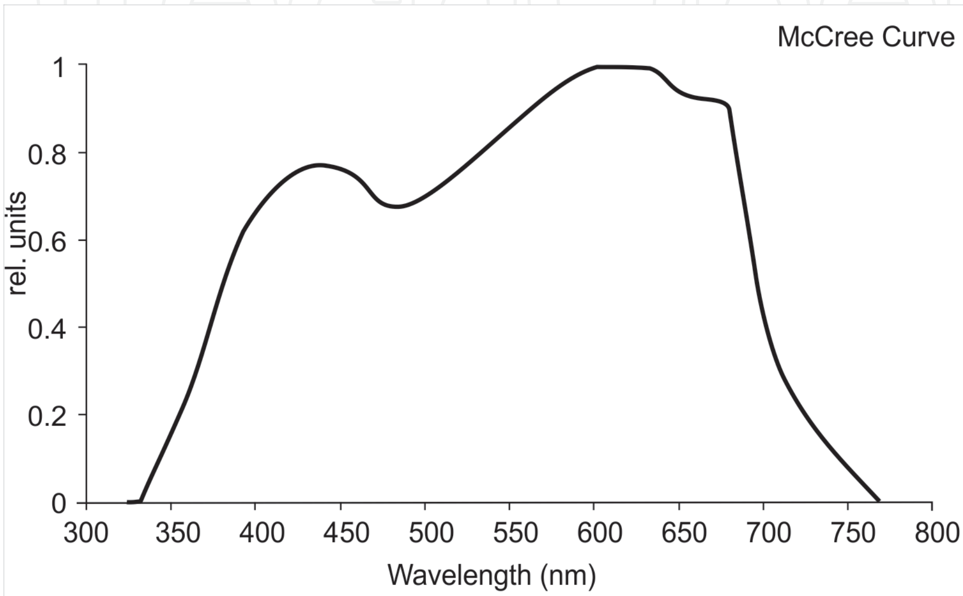

Figure 10. Averaged curve of the spectrum of photosynthesis activity of green leaf.

Wavelength	Effects on plants
280–320 nm	Harmful to plant growth and development. Some plants require a low effect of this spectrum for normal development.
320–400 nm	It influences the regulatory processes in the development of plants. The presence of this range should be a few percent of the radiant flux.
400–500 nm ("blue")	Absorbed by yellow pigments, is the second peak of absorption by chlorophyll, the second peak of photosynthesis. Included to ensure photosynthesis and regulation. However, its excess leads to the formation of stunted plants with thickened stems.
500–600 nm ("green")	It has a high penetrating power, is useful for photosynthesis of optically dense leaves, leaves of lower layers, thick plantings, the smallest physiological reaction. Its surplus leads to the formation of plants with elongated axial organs and thin leaves.
600–700 nm ("red")	The zone of the maximum photosynthetic effect of chlorophyll synthesis, the most important site for the development and regulation of processes. Required in a radiant stream. However, its excess can lead to abnormal development or to the death of the plant.
700–750 nm ("far red")	In general, the effect of stretching the stem, a pronounced regulatory action; a few percent in the radiant flux is sufficient.

Table 2. Effect of the spectrum of optical radiation on plants.

The part of the solar radiation reaching the plants and used for the process of photosynthesis is called photosynthetically active radiation (PAR). PAR is the density of the photosynthetic photon flux, that is, the total number of photons emitted per second in the wavelength range from 400 to 700 nm (μmol m^{-2} s^{-1}·). Different plant species, as well as the identical species at different age stages, may have different requirements for the PAR spectrum. To obtain full-fledged plants when growing under artificial light conditions, a certain ratio of energy over the spectrum in used lamps is required: 20–25%—in the blue area (380–490 nm); 20–25%—in the green one (490–600 nm) and 60–50%—in the red one (600–700 nm).

The use of the sources of artificial light in crop production is diverse, but not all of them are effective and safe. The characteristics of widely used lamps in the lighting systems of greenhouses are presented in **Table 3**.

As can be seen, the most perspective lamps for practical application as a modern source of visible radiation are light-emitting diode (LED) lamps and electrodeless sulfur lamps with microwave excitation [12–14]. The LED and sulfur lamps are durable, economical, have a high PAR efficiency (LED: 30–45%, sulfur lamp: 70–80%), are environmentally friendly (do not

Lamp type	Source of radiation	P, kW	τ, thousand hours	Efficiency PAR, %
Fluorescent lamps	FL-40	0.04	12	22
	Osram Fluora	0.018	10	20–22
High-pressure mercury lamps	DRLF-400	0.4	1	11
	DRF-1000-04	1.0	2	—
High-pressure sodium lamps	MASTER SON-T PIA Agro-400	0.4	17	28
	DNaZ-400	0.4	12	26
	DNaZ-600	0.6	18	30
	Sylvania Grolux SHP-TS	0.25	24	26–28
	Sylvania Grolux SHP-TS	0.4	24	26–28
	MASTER GreenPower	0.6	10	26–28
	PLANTASTAR	0.6	12	35
Metal halide lamps	Growmaster HIT	0.25	10	25
	DRI 2000–6	2.0	2	26
Xenon lamps	DKSTL 10000	10.0	<1	12–16
	DKSTV 6000	6.0	<1	—
LED lamps	LED GLOW-E27	0.135	50	20–35
	AGRO-24	0.024	50	30–35
Sulfur lamp	PLS-PSH07	0.73	60	70–80

Table 3. Characteristics of radiation sources.

contain mercury and do not require disposal). However, there are a number of differences between these lamps that allow them to occupy different fields of application.

The LED lamps are low power and effective when the light flux is about ~100 lm, so they can be used for small rooms. Besides, the LED lamps have a narrow band of optical radiation. In order to obtain the entire range of the visible spectrum, it is necessary to use LEDs with different spectral characteristics, the overall spectrum of which can cover the entire region (380–700 nm). This complicates the technology of manufacturing the LED lamp, since the corresponding currents have to be selected for each LED.

The electrodeless sulfur lamp with microwave excitation, on the contrary, is a powerful light source having a quasisolar emission spectrum with reduced intensity in the region of ultraviolet and infrared radiation (**Figure 11**), and providing light fluxes of ~140 klm, which is three orders of magnitude higher than that of the LEDs as well as color temperature of ~6400 K. Also, the electrodeless sulfur lamp with microwave excitation has the ability to control the radiation power, which allows imitating the modes of sunrise and sunset.

Thus, the modern lighting system under conditions of protected soil (greenhouses) has to economically reduce electricity costs, as well as raise the quantity and quality of the crop yields. The promising sources of artificial lighting are LED and electrodeless sulfur lamps with microwave excitation. The LED lamps are most successfully used in small greenhouses, while the sulfur lamps are suitable for larger greenhouse complexes.

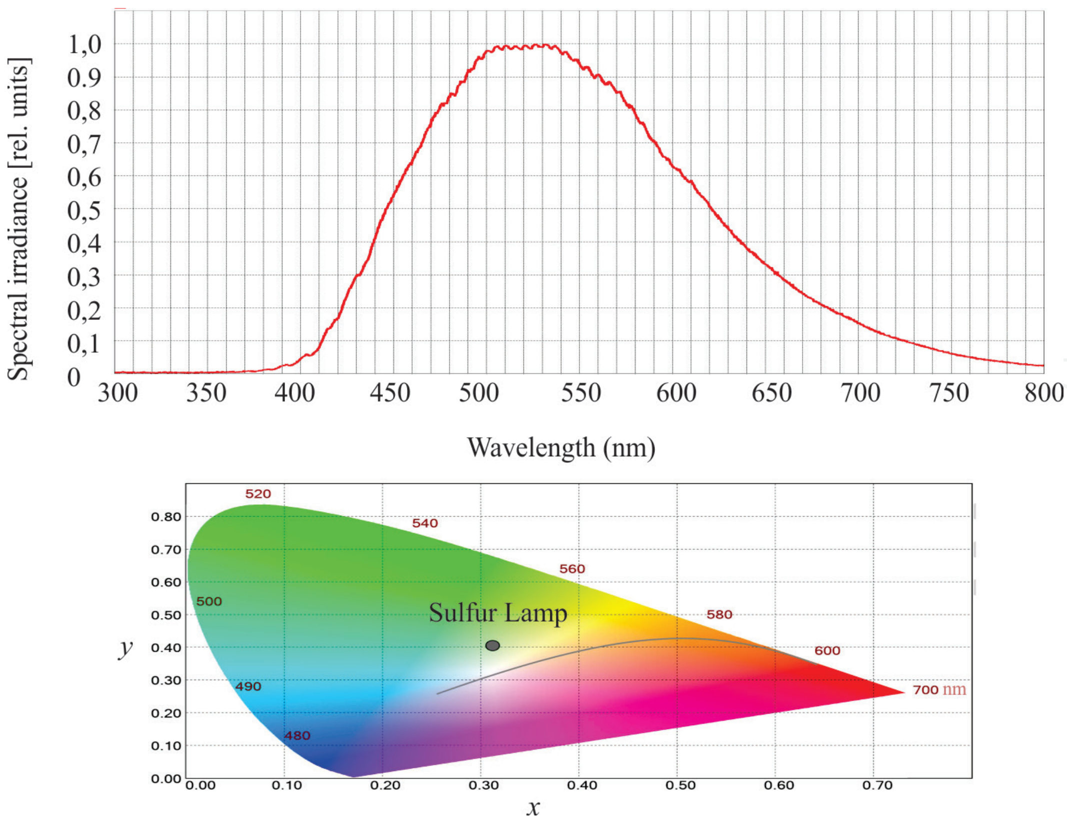

Figure 11. Spectral and color characteristics of electrodeless sulfur lamp with microwave excitation.

5. The prospects of evolution and application of the lighting systems

Despite the fact that electrodeless sulfur lamps with microwave excitation are still very young, powerful lighting devices based on them have opened a new direction in lighting and found a new application of microwave technologies, which can become even more massive than the use of microwave ovens.

Due to the positive qualities of the lighting characteristics, an area of application of optical radiation sources on the basis of the electrodeless sulfur lamps with microwave excitation is considerably extended [15, 16]. From problems of a lighting technology associated with lighting by a narrow, intense beam of light (spotlamp) or lighting of streets, large areas, tunnels, decorative lighting of interiors, lighting fountains, architectural monuments and other municipal facilities and services, to the integration of lighting systems in various technological processes. The implementation of new technical solutions for the design of lighting systems on the basis of the electrodeless sulfur lamp with microwave excitation has become possible due to the use of its positive qualities and advantages as, for example, the availability of a quasisolar spectrum of radiation with reduced level of radiation in the ultraviolet and infrared regions of an electromagnetic spectrum. This allows apart from the creation of therapeutic and preventive effects on humans and other wildlife to provide also safe working conditions, excluding the destructive, dangerous or other harmful effects of ultraviolet and infrared radiations on illuminated objects and the environment, especially at high illumination levels.

Further progress of the electrodeless sulfur lamps with microwave excitation can be their integration with other electron devices for creating the power energy-efficient lighting systems. As an example of such system, one can be considered a lighting device developed on the basis of linking the electrodeless sulfur lamp with microwave excitation and solar batteries [17]. A general view of block diagram of proposed lighting device is schematically shown in **Figure 12**.

The solar batteries allow to achieve partial regeneration of the electric power, which are connected to the control unit by an illumination system, a store of electric energy and an external power network. The principle of operation of the lighting device on the basis of the electrodeless sulfur lamp with microwave excitation is in employing solar batteries 2 for converting the optical radiation generated by the lighting system 1 directly to the direct current. A control unit of the lighting device controls a process of charge-discharge of the storage batteries 4, and in the case of their low voltage, it switches to an external power network 5.

Taking into account the spectrum of radiation of the sulfur lamp close to a spectrum of natural (solar) radiation as the solar batteries, one can use their standard construction, which usually applies for transformation of natural (solar) light flux in direct current.

The solar batteries are located inside the structure of premises (for example, greenhouses), allowing several advantages: firstly, it facilitates the maintenance of the solar batteries (avoiding snow, rain, hail and other natural phenomena); secondly, with reducing sunny days, the necessity to use artificial light increases (for example, when the plants get supplementary

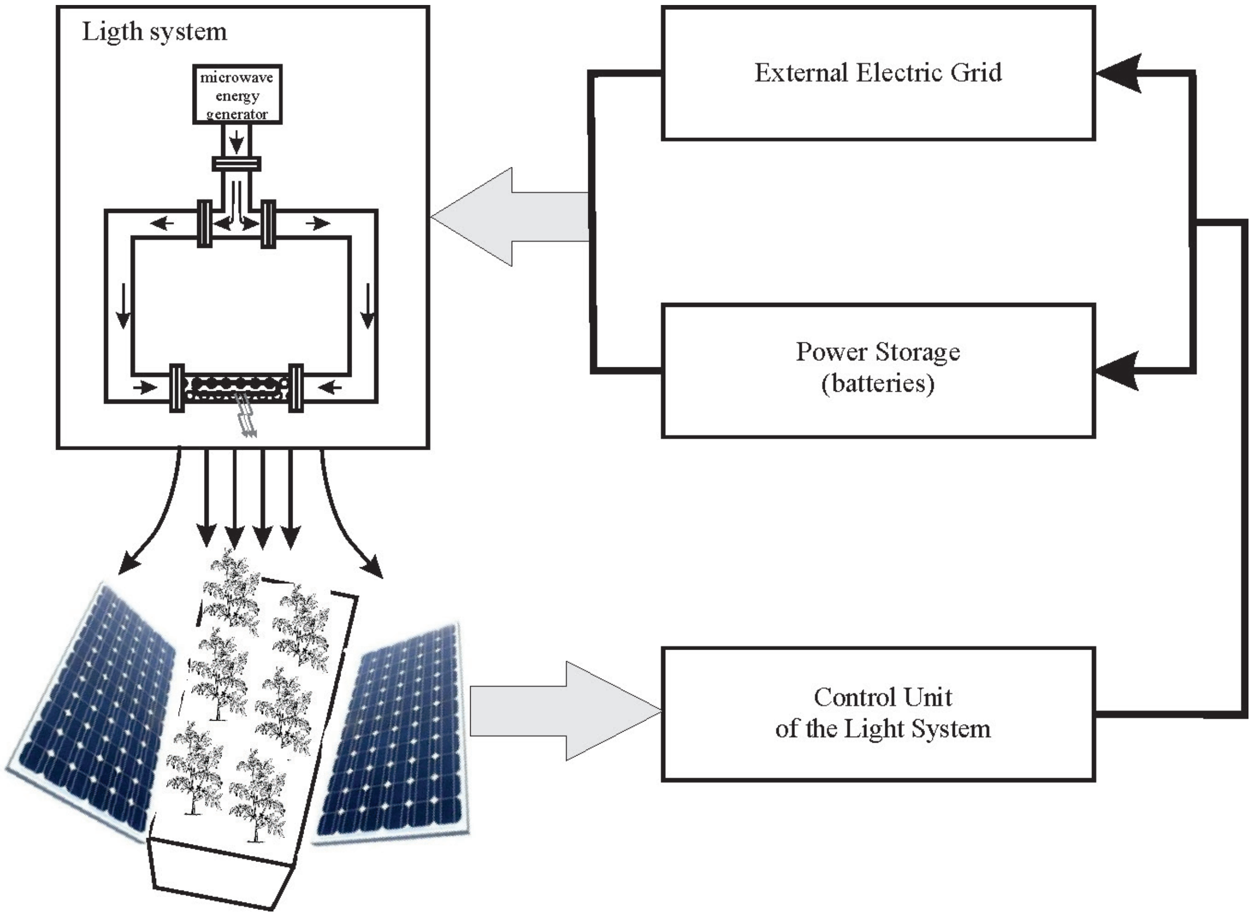

Figure 12. General block diagram of a lighting device on the basis of linking an electrodeless sulfur lamp with microwave excitation and solar battery. 1—electrodeless sulfur lamp with microwave excitation; 2—solar batteries; 3—control unit for lighting system; 4—electric power accumulator (storage batteries); 5—external power network.

lighting in greenhouses), but if the lighting devices have a spectrum close to that of the sun, solar batteries can more effectively produce electricity and reduce the prime cost of production as a whole (for example, in a greenhouse farm when growing agricultural products).

Thus, when using a light-emitting device on the basis of an electrodeless sulfur lamp with microwave excitation in combination with solar batteries, one has an additional regeneration of electricity for its further use in the work of both the lighting device itself and other electrical equipment or to feed it into the power network.

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