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ULTRAVIOLET LEDs AND THEIR APPLICATIONS

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Rezumat. *Diodele în ultraviolet (UV) obțin de la an la an din ce în ce mai multe aplicații. În articolul de popularizare propus este expus pe scurt principiul de funcționare a diodei LED, fiind examinate mai detaliat cele trei domenii spectrale principale UV (A, B și C). Sunt prezentate cele mai importante domenii de aplicare a diodelor LED în fiecare domeniu spectral. Pandemia de Coronavirus COVID-19 a avut un impact major asupra industriei iluminatului. Principala direcție în care sunt orientate în prezent eforturile oamenilor de știință și inginerilor este aplicarea diodelor LED care emit în domeniul ultraviolet pentru dezinfecție și combaterea virusului.*
Cuvinte-cheie: *diodă emițătoare de lumină (LED), UVA, UVB, UVC.*

Abstract. *UV diodes find more and more applications every year. In the proposed popular science article, the principle of operation of LED is briefly considered and the three main UV ranges (A, B and C) are highlighted in more detail, and the most important and interesting areas of LED applications are shown for each range. The COVID-19 Coronavirus pandemic has already had a big impact on the lighting industry. The main area where the efforts of scientists and engineers are currently being made are LEDs emitting radiation in the Ultraviolet C range for disinfection and fighting viruses.*
Key words: *light-emitting diode (LED),* UVA, UVB, UVC.

Резюме. *Ультрафиолетовые (УФ) диоды с каждым годом находят все большее и большее применение. В предлагаемой научно-популярной статье кратко рассмотрен принцип действия светодиода и более подробно освещаются три основных диапазона УФ (A, B и C). Для каждого диапазона показаны наиболее важные и интересные области применений светодиодов. Пандемия коронавируса COVID-19 уже оказала большое влияние на светотехническую промышленность. Основное направление, в котором сейчас прилагаются усилия ученых и инженеров - это использование светодиодов, излучающих в ультрафиолетовом диапазоне УФС, для дезинфекции и борьбы с вирусами.*
Ключевые слова: *светодиоды, УФА, УФВ, УФС.*

1. Physics of light generation and emission in LEDs

A light-emitting diode (LED) is a semiconductor light source that emits light when the electric current flows through it in a forward direction. Electrons in the semiconductor recombine with holes, releasing the energy as photons. The color of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor [1].

Fig.1. LEDs of different colors

2. Multi-colored LEDs

In LEDs, direct-gap semiconductors with permitted direct optical zone-to-zone transitions are used. The color of a light-emitting diode depends on the band gap, in which the electrons and holes recombine. By selection of different semiconductor materials, single-color LEDs emitting light in a narrow band of wavelengths can be made. The wider the band gap and the higher the energy of the quanta, the closer to the blue color is the emitted light. By changing the composition, it is possible to achieve the luminescence in a wide optical range - from the infrared to the ultraviolet radiation. To obtain just an ultraviolet radiation, semiconductors with a wide band gap are needed [2]. For this, materials such as gallium aluminum arsenide, gallium nitride, aluminum nitride, etc. are used [3-9]. As a result, LEDs are obtained with a radiation spectrum in any range from 100 to 400 nm (near the UV range).

3. The structure of LEDs

To create a luminous flux, the design of the LED provides for the presence of two semiconductors, one of which must contain free electrons (n), and the other - their lack or "holes" (p). If one connects such semiconductors with (p) and (n) regions, then a "p-n" junction occurs between them. As a result, electrons from the donor (n-type) semiconductor transfer to another semiconductor (p-type) and occupy the free holes with the release of photons. This reaction takes place only in the presence of a constant current source.

The recombination of charge carriers occurs in the p-type material, and hence the p-material is the surface of the LED. For the maximum emission of light, the anode is deposited at the edge of the p-type material. The cathode is made of gold film and it is usually placed at the bottom of the n-region. This gold layer of cathode helps in reflecting the light to the surface.

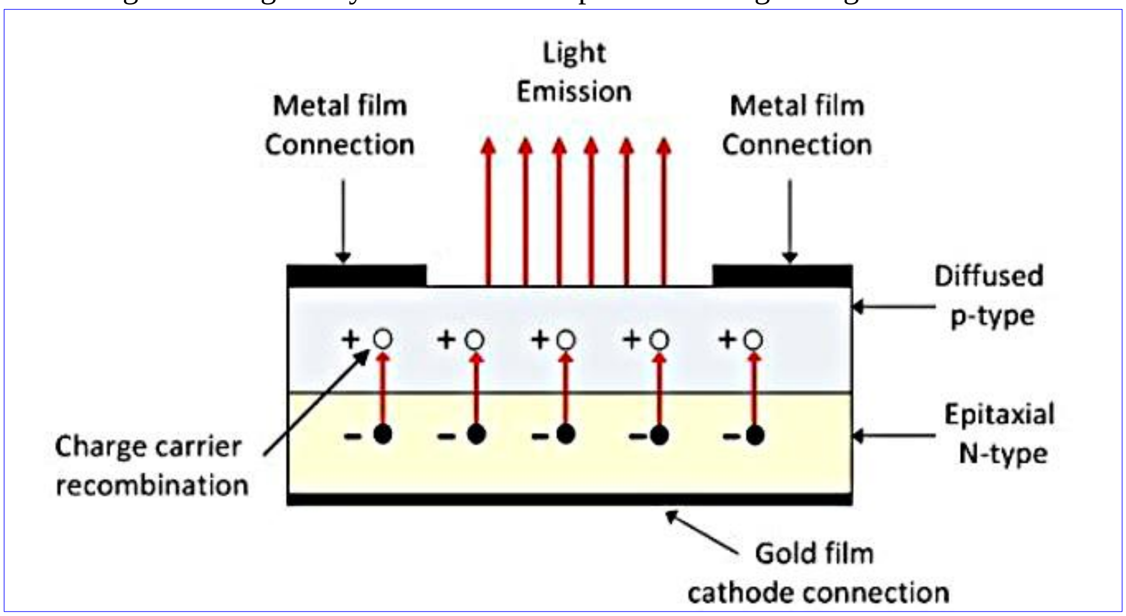

Fig. 2. The s**tructure** of a LED

4. The operating principle

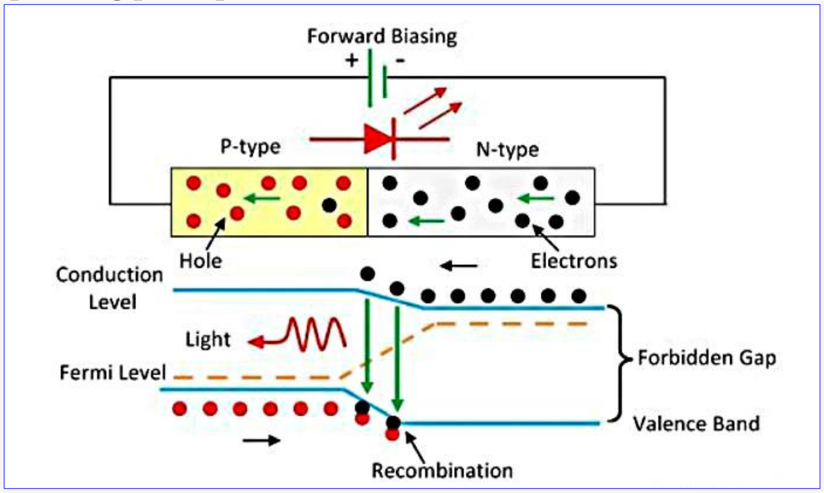

Fig.3. The *p-n* junction scheme

In fact, there is no significant difference in the principle of operation of a conventional LED in the visible and ultraviolet ranges.

When the power is turned on directly, holes from the p-semiconductor region and electrons from the n-semiconductor region will move towards each other. As a result, a recombination occurs. The recombination shows that electrons move from the conduction band to the valence one and emit electromagnetic energy as photons. The energy of photons is equal to the gap between the valence and the conduction bands [10, 11].

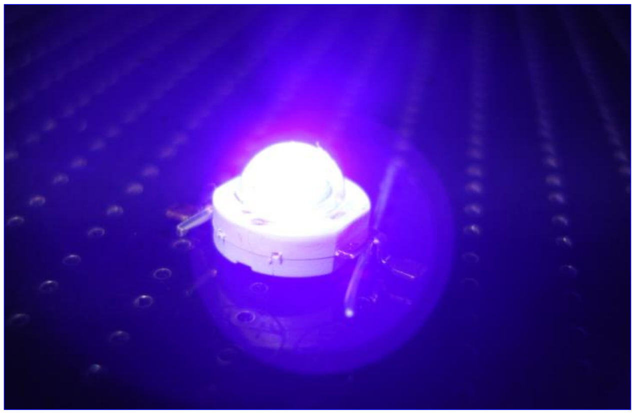

Fig.4. The ultraviolet LED.

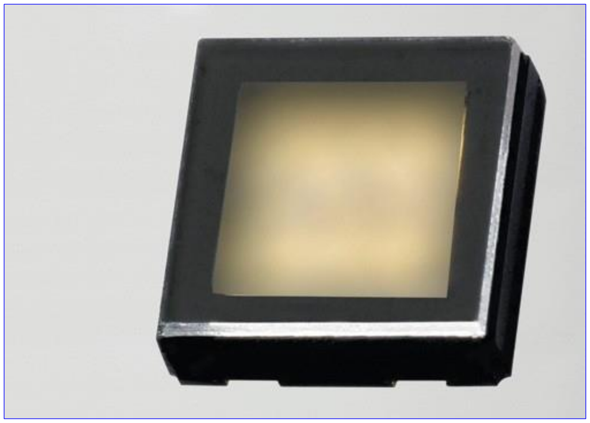

Fig.5. An Everlight UVC LED with a protective quartz glass.

A real Everlight UVC LED is shown in Fig. 5. If the radiation is emitted in the ultraviolet range, the diodes are called ultraviolet LEDs. Ultraviolet light gets its name after the “violet” color it produces in the visible portion of the spectrum, although much of the UV light is not visible to the human eye.

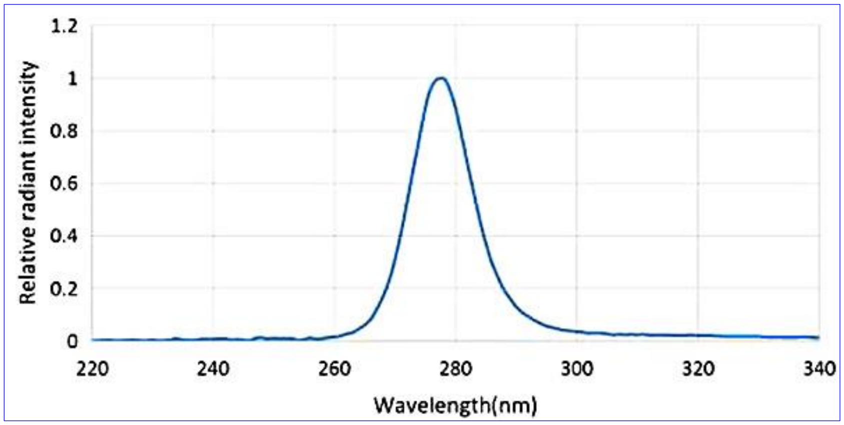

Fig.6. The spectral characteristic of Everlight UVC LED with a maximum near 275 nm.

UV LEDs have seen tremendous growth over the recent years. This is not only the result of technological advances in manufacturing solid state UV devices, but also the ever increasing demand for environmentally friendly methods of producing UV light, which is currently dominated by mercury lamps. Currently, the offer of UV LEDs in the optoelectronic market consists of products in the range from approximately 265 nm to 420 nm, covering a variety of package styles including through-hole, surface mount and COB (Chip-On-Board). There are many unique applications for UV LED emitters; however, each is greatly dependent on the wavelength and output power.

The brightness of the glow is controlled by changing the current strength, and the directional pattern is formed by the secondary optics of the lamp or a lens located directly above the light-emitting crystal (Figs.4 and 5). The development of the UV LED was made possible by the development of a blue light LED based on gallium nitride (GaN) in 1991-1994 [12-14]. Shuji Nakamura, an engineer at Nichia, received the 2014 Nobel Prize in Physics for this work.

5. The electromagnetic spectrum

Ultraviolet light occurs between the visible and X-ray spectra. The Ultraviolet wavelength range is specified as 100 nm to 400 nm

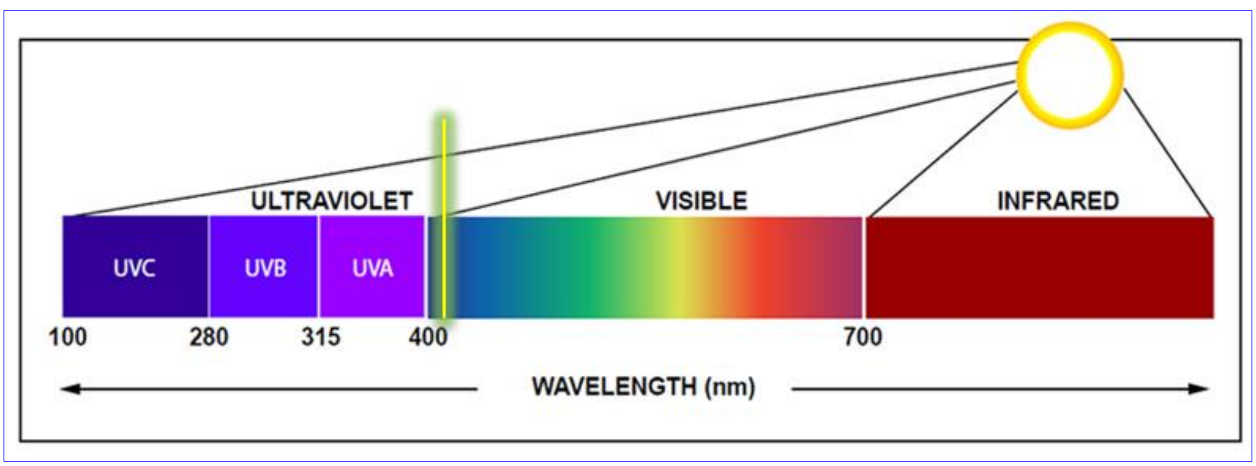

Fig.7. The color electromagnetic spectrum highlighting UVA, UVB, and UVC.

In general, UV light for LEDs can be divided into 3 general areas. These are classified as UVA, UVB and UVC.

Name	Abbreviation	Wavelength Range
Ultraviolet A	UVA	315 – 400 nm
Ultraviolet B	UVB	280 – 315 nm
Ultraviolet C	UVC	100 – 280 nm

UVA rays have the longest wavelengths, followed by UVB and UVC rays with the shortest wavelengths. While UVA and UVB rays are transmitted through the atmosphere, all UVC and some UVB rays are absorbed by the Earth’s ozone layer. So, most of the UV rays you come in contact with are UVA with a small amount of UVB.

UVA is known as long wave ultraviolet light with the wavelength in the range of 315 nm to 400 nm. In practice, the UVA range is conventionally subdivided into three more categories:

"Upper" UVA (wavelength range 390 - 420 nm)

The “upper” UVA type devices have been available since the late 1990s. These LEDs have been traditionally used in applications such as counterfeit detection or validation (Currency, Driver’s license, Documents etc.) and Forensics (Crime scene investigations), to name a few. The power output requirements for these applications are very low and the actual wavelengths used are in the 390– 420 nm range. Lower wavelengths were not available at that time for production use. As a result of their longevity in the market and the ease of manufacturing, these types of LEDs are readily available from a variety of sources and the least expensive of all UV products.

"Middle" UVA (wavelength range 350 - 390 nm)

The “middle” UVA LED component area has seen the greatest growth over the past several years. The majority of applications in this wavelength range (approximately 350–390 nm) are for UV curing of both commercial and industrial materials such as adhesives, coatings and inks. LEDs offer significant advantages over traditional curing technologies such as mercury or fluorescent due to increased efficiency, lower cost of ownership and system miniaturization. The trend to using LEDs for curing is increasing as the supply chain is continually pushing to adopt the LED technology. Although the costs of this wavelength range are significantly greater, than the upper UVA area, rapid advances in manufacturing as well as increasing volumes are steadily driving down prices.

"Lower" UVA (wavelength range 300 - 350 nm)

The “lower” UVA and “upper” UVB ranges (approximately 300–350 nm) are the most recent introduction to the market place. These devices offer the potential to be used in a variety of applications including UV curing, biomedical, DNA analysis and various types of sensing.

There is significant overlap in all 3 of the UV spectral ranges; therefore, one must consider not only what is best for the application, but also what is the most cost-effective solution, since the lower in wavelength, typically the higher the LED cost.

6. Applications of UVA LEDs:

1) Cosmetology

In nail salons, ultraviolet lamps are effective in drying gel polish and building nails using helium formulations.

LED lights work similarly UV lamp, but they emit narrower UV wavelengths with higher concentration and more energy. These light emitting diodes target specific photo-initiators in the gel polish, which enables the gel to cure much faster than UV lamp.

For the distinct reason that UVA LED nail dryers offer a faster drying time compared to UV lights, they are said to be safer, than UV lights. A faster curing time equals less time one is exposed to harmful radiation, so this is a definite advantage for clients. It takes UV lights anywhere from 8 to 10 minutes to cure gels, while LED lamps take 30-45 seconds.

2) Show business

3) Dentistry: for hardening the composite dental fillings. Also, LED curing light cures material much faster, than halogen lamps.

4) Pharmacology: in the production of medicines.

Fig. 8. Clothes glow in the dark.

Fig. 9. Using UV light to test the medicines.

5) Medicine.

The area of medical applications are the light therapy and physiotherapy using UV radiation.

LED, or light emitting diode therapy, is a skincare treatment that uses varying wavelengths of light, including UVA.

As for the long-wave ultraviolet radiation from group CVA (320 - 400 nanometers), its main therapeutic effect is the immune-stimulating effect on the tissues of the body, which significantly increases the level of the body's resistance to pathogenic bacteria and viruses. Due to this, long-wave ultraviolet radiation has found wide applications in the fight against a large number of skin diseases, in particular, psoriasis, lichen and eczema, in the treatment of chronic diseases of the respiratory system, as well as the effects of frostbite and various injuries [15].

Also, researches are currently underway, based on the results of which it is planned to use ultraviolet light for the prevention and treatment of cancer.

6) Industry

There are very wide and varied applications. Just one example: in some industries, ultraviolet sources are used to accelerate the polymerization process of adhesives and compounds. UV rays accelerate the curing (drying and curing) of an adhesive, paint, or a special resin called a compound.

7) Financial sphere

Such UV diodes are used in money checking machines. The lamp helps to determine the authenticity of banknotes, to count the bank marks applied to the paper.

Special counting machines can simultaneously count the number of bills and check their authenticity.

Fig. 11. 380 nanometer UV LED in money checking machines.

Fig. 10. Light therapy

8) Forensic science and forensics (crime scene investigations).

Checking forgeries (driver's licenses, passports, various documents, etc.). UVA LEDs are used in surgical procedures to detect traces, body fluids and particles. Traces of blood and other substances that are invisible under normal light can be detected.

9) Crop production. Short-term irradiation of plants in greenhouses stimulates the production of polyphenols with antioxidant properties. Moderate exposure to ultraviolet light in vegetables accelerates the production of polyphenols that are beneficial to human health.

Fig.12. Fingerprints in ultraviolet light, invisible in normal light.

In normal latitudes, the amount of light sufficient for plant growth is available only in summer, and then if there are no prolonged rains. The rest of the time, plants, especially domestic ones, suffer from a lack of light. To help them, you can install a lamp that, in addition to normal light, emits a special wavelength in the UVA range, which is necessary for photosynthesis.

Fig.14. Plant under a LED lamp.

Fig.13. UV mercury lamp for plant illumination

In addition to fluorescent (gas) lamps for plants, there are recently being used many varieties of UVA LEDs. They are more compact and serve longer [16, 17].

10) Ultraviolet lasers

Direct UV-emitting laser diodes are available at 355 nm.

This compliant Ultra-Violet 355nm DPSS Laser System is ideal for a wide range of scientific applications.

Ultraviolet lasers have applications in industry (laser engraving), medicine (dermatology, and keratectomy), chemistry (MALDI), free-air secure communications, computing (optical storage), and manufacture of integrated circuits.

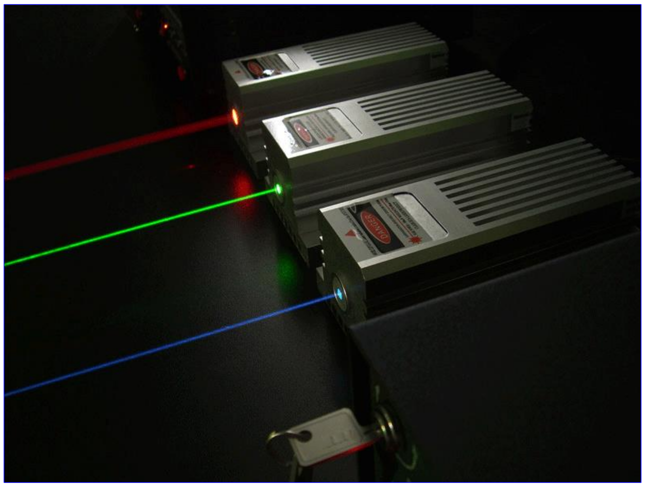

Fig. 15. The 355 nm UV dpss (diode-pumped solid-state) laser system.

7. UVB

UVB is known as a medium-wave ultraviolet light with the wavelength in the range of 280 nm to 315 nm. By its applications, it is also conventionally divided into two categories:

The UVB range of 300 - 315 nm is responsible for tanning. Such rays from the Sun pass through the Earth's atmosphere, and we often use them on the beach or in the mountains. UVB lamps and LEDs operating in this range are mainly used in tanning salons.

The UVB range of 280 - 300 nm can be partially used for bactericidal and sterilization purposes.

For more details on the prevention of infectious diseases, see and read UVC LED and its applications.

The “lower” UVB and “upper” UVC ranges (approximately 250 – 300 nm) is an area that is still very much in its infancy, however, there is great enthusiasm and demand for this product in air and water purification systems. There are currently only a handful of companies that are capable of manufacturing UV LEDs in this wavelength range and even a smaller amount that are producing product with sufficient lifetime, reliability and performance characteristics. As a result, the costs of devices in the UVC/B range are still very high and can be cost prohibitive in some applications.

UVB LED Applications:

1) Solarium

Manufacturers produce LED lamps for two standards: European and American. The UVB/UVA ratio is a measure of the ratio of the number of rays of A and B types. The difference is as follows: the type A radiation is a long-wave and soft one, and gives a bronze-golden tint to the skin. It is practically impossible to get a burn from him; the type B radiation is of shorter wavelengths. It is the radiation that causes the synthesis of melanin and creates a quick tan. Be careful as it can burn you.

Fig.16. Indoor tanning

2) Medicine

Medium-wave ultraviolet (280-320 nm) is used to treat acute inflammatory diseases of internal organs, usually the respiratory system, musculoskeletal system, peripheral nervous system, and even abnormal metabolism. The effect of such UV radiation on the cells of the tissues of the body provokes changes in the structural organization of protein compounds, changing their physicochemical properties, which activates various positive processes in tissues and, as a consequence, restores the normalization of their functions [18].

UVB phototherapy does not require additional medications or topical preparations for the therapeutic benefit; only the exposure is needed.

8. UVC

UVC is a short-wavelength ultraviolet radiation ranging from 100 nm to 280 nm.

Under normal conditions, UVC rays do not reach the Earth's surface, being trapped in the atmosphere. A part of this spectrum emission can be found on the tops of mountains.

The light of these wavelengths is not only harmful to micro-organisms, but also dangerous to humans and other forms of life that may come in contact with it. These LED lamps should always be shielded and never be viewable to the naked eye even though it may appear that little or no light is emanating from the device. Exposure to these wavelengths may cause skin cancer and temporary or permanent vision loss or impairment.

UVC LED Applications:

UV LEDs can play a useful role in the prevention of infectious diseases.

They can be used to prepare drinking water, replace chlorine as a disinfectant for swimming pool water, kill germs in washing machines and dishwashers, kill airborne germs in air purifiers and HVAC systems, and disinfect surfaces in hospitals, kitchens, schools, offices and home nursing facilities

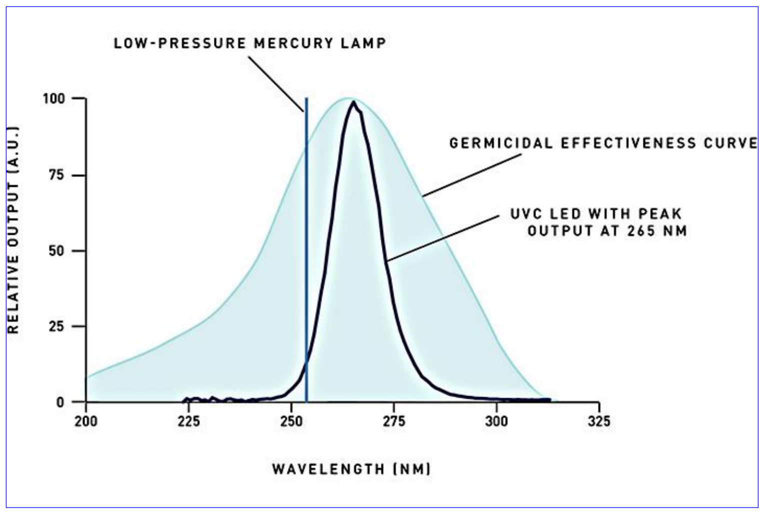

Fig.17. Spectral comparison of low-pressure mercury lamp versus UVC LED in relation to germicidal effectiveness curve

The most recent application of UVC LEDs is in the fight against the COVID-19 virus. The UVC radiation is bactericidal and very effective in disinfection. The radiation in the range from 205 to 315 nm is capable of destroying bacteria and viruses.

The principle of struggle is to destroy the DNA of pathogens. Moreover, as scientific studies have shown, such a struggle is most effective at a wavelength of 265 nm, which is close to the radiation wavelength of Mercury at 254 nm. The closer the source radiation is to 265 nm, the better it copes with the task. All mercury lamps emit a constant line of 253.6517 nm, but UV LEDs can have a wide spread of radiation peaks depending on the semiconductor materials used, and as a result they differ significantly in the efficiency of disinfection.

9. COVID-19

The COVID-19 coronavirus pandemic has already had a big impact on the lighting industry. The main areas where the efforts of scientists and engineers are currently being made are LEDs, which emit radiation in the ultraviolet C range for disinfection and fight against viruses. The principle of control is to destroy the DNA of pathogens.

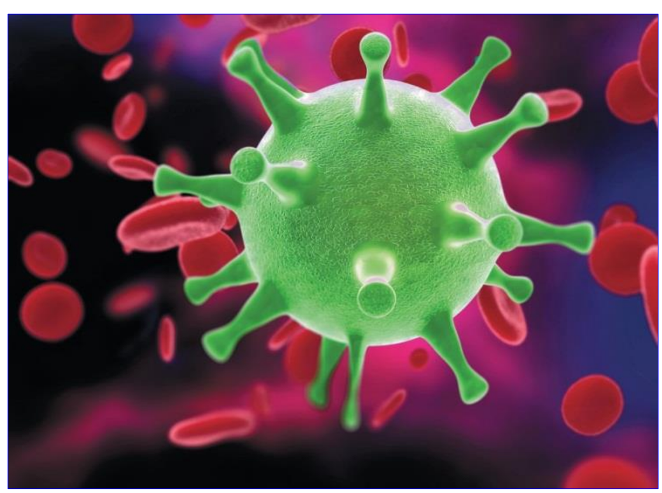

Fig. 18. COVID-19 coronavirus.

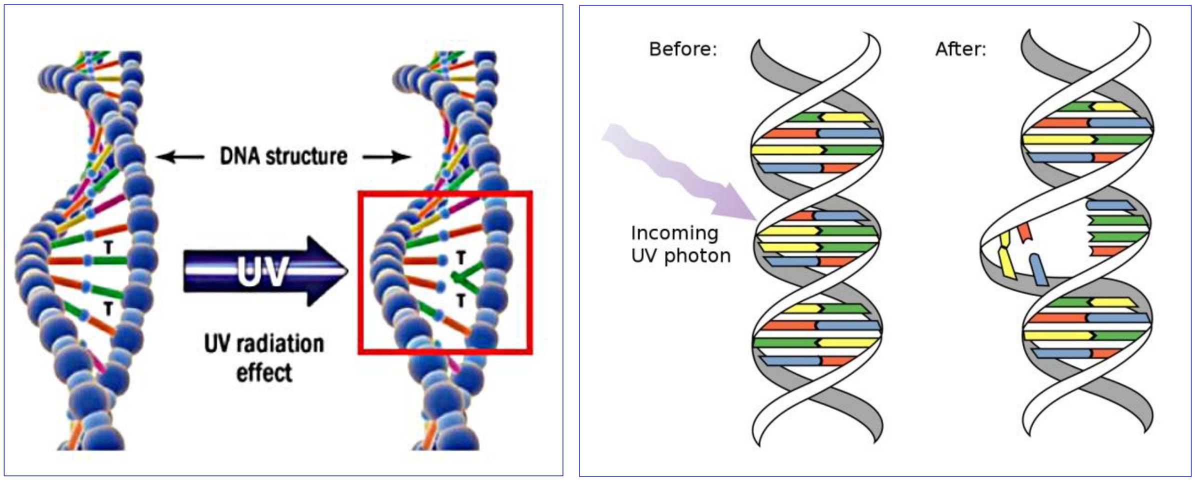

Fig. 19. UV light attacks the DNA structure of many cells, rendering them inactive.

Ultraviolet photons harm the DNA molecules of living organisms in different ways. In one common damage event, adjacent thymine bases bond with each other, instead of across the "ladder". This "thymine dimer" makes a bulge, and the distorted DNA molecule does not function properly [19].

UV light in the spectrum from 100 to 280 nm has the ability to lead to structural changes in the DNA and RNA of living organisms. That is why, under the influence of large doses of such ultraviolet radiation, viruses are losing their ability to reproduce, on the one hand, and many of their functions, on the other [20].

The use of LED radiation sources instead of conventional bactericidal lamps makes it possible to more accurately focus the radiation on the disinfected object, significantly reducing the weight of the installation, and use the radiation of the most effective wavelength of 265 nm [21].

10. Disinfection and sterilization of instruments

Fig.20. Disinfection of medical instruments with a LED germicidal lamp.

11. Conclusions

The UV spectrum encompasses all wavelengths between 100 and 400 nm. It's commonly broken down into three distinct subfields:

• UV-A: 315 to 400 nm (also known as long-wave UV)
• UV-B: 280 to 315 nm (also known as medium-wave UV)
• UV-C: 100 to 280 nm (also known as short-wave UV)

The ultraviolet diodes UVA, UVB and UVC, every year, find more and more applications in various areas of our life and activity. They significantly complement the capabilities of LEDs in the visible range, and often surpass them in terms of variety and breadth of use. UV LEDs provide several environmental benefits compared to alternative technologies. They consume up to 70% less energy, than cold-cathode fluorescent lamps (CCFLs). Further, UV LEDs don't contain the toxic Mercury often found in CCFL technology. They are much smaller and more durable, than CCFLs and are more resistant to vibration and impact, resulting in less product breakage and reduced waste and maintenance expenses as well.

The future belongs to them.

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