*Editorial*

# Optoelectronics and the SPQEO journal

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**Abstract.** This article touches on the main trends in the development of optoelectronics, namely its fundamentals and possible applications, and provides a general overview of the research results in this field published by SPQEO over the past decade. We will emphasize the relationship between the development of optoelectronics and the sixth technological wave related to nano-, bio-, information and cognitive technologies. For convenience, we will conventionally divide the discussion into the optoelectronics fields such as photonics, terahertz and infrared electronics, photovoltaics, etc. This article is devoted to one of these fields, namely LEDs and their applications in LED lighting systems, which use in “smart” home and city projects opens up new opportunities for creating adaptive lighting environments that can be adjusted to the needs of users.

**Keywords:** SPQEO journal, optoelectronics, photonics, electrooptics, photovoltaics, light-based technologies, LED lighting system.

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### 1. A brief overview of optoelectronics

The main goal of optoelectronics (OE) is to develop and produce devices that emit, modulate, transmit and convert light waves. During the last two decades, a huge number of monographs and original papers on optoelectronics have been published, see e.g. [1-6].

It was noted in [5] that “Technical gaps and grand challenges in the areas of materials, devices, system designs and manufacturing processes are presented that pave the path for future research directions for developing energy efficient products and green technologies that incorporate advanced materials, multi-functional devices and intelligent operational protocols.”

The importance of light technologies for human development is emphasized by the fact that the United Nations General Assembly declared the 2015 as the International Year of Light (IYL) and the Year of Light-based Technologies [7]. The International Year of Youth coordinated activities at national, regional and international levels. Indeed, this activity has continued up to present days with a large number of conferences in optoelectronics under the motto of the IYL: "Optical based technologies to meet human needs and solve global challenges". This might also be the motto of OE for the coming decades.

In fact, it would be impossible to even mention all the disciplines related to OE. Therefore, we would like to refer to the large-scale projects that are being considered by OE. Figure 1 collects these projects. OE is categorized into coherent OE and incoherent OE, which includes photonics and electro-optics. Photovoltaics (PV), as a part of optoelectronics, is slightly different from classical optoelectronics, but is very close to it. Among the very important issues, it is necessary to emphasize the effects, problems, materials, techniques, structures and devices. All these issues are deeply and closely related and interact with each other.

According to M. Irawati [8], the smart street lights market is experiencing robust growth, driven by increasing investments in wireless technology for urban infrastructure and a rising preference for energy-efficient lighting solutions. Valued at USD 0.6 billion in 2023, the market is foreseen to expand from USD 0.7 billion in 2024 to USD 3.3 billion by 2032, reflecting an impressive compound annual growth rate (CAGR) of 20.8% during the forecast period. M. Irawati marked the growth drivers of the smart street lights market as follows: (i) adoption of wireless technology; (ii) energy efficiency and sustainability; (iii) government initiatives and smart city projects; (iv) technological advancements, such as adaptive lighting, real-time monitoring, fault detection, and remote management, driving their adoption in urban areas; and (v) cost savings and return on investment (ROI). Hereby, the Smart Street Lights market may be segmented

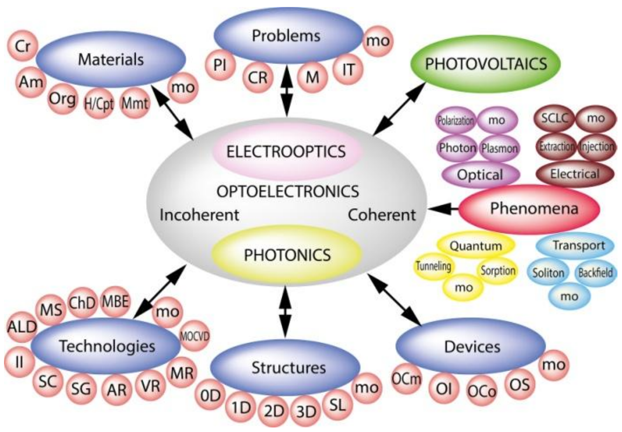


**Fig.1.** Conventional division of optoelecronics areas. Here, the following abbreviations are used. *Materials*: Cr is for crystalline materials, Am is for amorphous materials, Org is for organic materials, H is for hybrid materials, Cpt is for composites, Mmt is for metamaterials (negative index, wide variation of bandgap, double positive mediums, b-isotropic and b-anisotropic, chiral; frequency selective surfaces, elastic, acoustic, structural, nonlinear, terahertz, photonic, tunable, plasmonic). *Problems*: PI is for performance improvement, CR is for cost reduction, Mp is for mass production, IntT is for integration with other technologies. *Structures*: 0D is for zero-dimensional (nanodots, quantum dots); 1D is one-dimensional (nanorods, nanowire, wiskers); 2D is for two-dimensional (thin layers, atomic layered); 3D is three-dimensional (bulk, metamaterials); SL is for superlattice, multilayered. *Devices*: OCm is for optical communication (optical amplifier, multi-quantum-well-based LEDs); OI is for optical imaging (multi-quantum-well-based LEDs, 360-degrees video stitching); OCo is for optical computing; OS is for optical sensing systems (integrated optical devices, miniature multispectral sensors and imagers, image sensors for machine vision, microfiber Knot Resonators). *Technologies*: ALD is for atomic layer deposition, ChD is for chemical deposition, MBE is for molecular beam epitaxy, MOCVD is for metal-organic chemical vapor deposition, MS is for magnetron sputtering, II is for ion implantation, SC is for spin coating, SG is for sol-gel, AR/VR/MR is for augmented, virtual and mixed reality, mo is for many others.

based on 1) components (hardware: LED lamps, sensors, controllers; software: management and analytics platforms; services: installation, maintenance, and consulting), 2) connectivity (wired: power line communication; and wireless: RF, ZigBee, Bluetooth, NB-IoT), 3) application (main applications include residential areas, highways and roadways, public parks, parking lots, and commercial areas). Finally, M. Irawati prognoses promising future for the smart street lights market with (i) integration with smart city ecosystems, (ii) development of solar-powered smart lights, (iii) Enhanced Data Analytics and AI: Use of the advanced data analytics and AI will enable more intelligent and adaptive lighting solutions. Predictive maintenance, energy optimization, and enhanced public safety features will drive the market forward, (iv) expansion in emerging markets, and (v) focus on public-private partnerships. M. Iravati concluded that smart street lights market is set for substantial growth, driven by advancements in wireless technology, energy efficiency, government initiatives, and technological innovations. As the market evolves, the trends such as integration with smart city ecosystems, solar-powered solutions, and Enhanced Data Analytics will be the key to meeting future demands and driving further growth.

SPQEO monitors and tracks major trends in the physics and applications of OE. This paper identifies the focus areas for OE and presents the major articles published by SPQEO in the last decade in this area. The paper discusses LEDs and light-based lighting in detail. In future issues, we will continue to explore in more detail photonics, terahertz and infrared electronics, photovoltaics, and other areas of open electronics.

## 2. LEDs in SPQEO

Here, we look at some effects in LEDs based on different materials presented in SPQEO over the past decade. Degradation of semiconductor devices, especially LEDs, is one of the key issues for their application. It was shown in [9] that the degradation curve of electroluminescence intensity allows one to determine the radiation damage coefficient. For example, for GaP diodes after 2-MeV electron irradiation, it equals as $k_{\tau}=1.5\cdot10^{7}$ s·cm$^{-2}$.

Partial recovery of radiation intensity in a GaP red LED has two temperature stages, namely at 150...200 °C and 275...325 °C. After annealing at T > 350 °C, the radiation intensity monotonically decreases due to the increase of the concentration of defects in the p-region of the diode.

It was recognized in [10] that degradation processes in LED chips are caused by diffusion processes in ohmic contacts under the influence of dissipation power heating. As a result, degradation of the integrated luminescence intensity of a LED module can be described by an activation type exponential function. To calculate the reliability time of LED modules with different halfwidth of LED chip series resistance, the Monte-Carlo method was used. Separation of LED chips with different series resistance before assembling may increase the time of emission in a stable mode up to 10%. The reliability time of LED modules [5] was defined as the longest time during which 95% of the modules degrade to no more than 30% of the initial luminous flux. It is easy to see that even in such soft mode of use, the reliability time of LED modules increases by 10 percent.

The article [11] is devoted to increasing the light intensity. For example, in [11], brighter, less defective, less prone to radiation and more stable green LEDs were obtained by replacing sapphire with a ScAlMgO4 or SCAM (0001) substrate. Most importantly, such replacement provided at least 10% brighter green light emission as compared to that of a sapphire based LED structure. The article [12] has proposed a suitable LED structure with a high intensity red emission on SCAM (0001) substrate. Comparative study of an $In_{0.17}Ga_{0.83}N/In_xGa_{1-x}N/Al_yGa_{1-y}N$ system with $Al_yGa_{1-y}N$ acting as a cap layer to the $In_{0.17}Ga_{0.83}N/In_xGa_{1-x}N$ LEDs. A 2 nm $Al_yGa_{1-y}N$ cap layer with the Al composition (y) of 17% deposited on a 3 nm thick $In_xGa_{1-x}N$ QW with the In composition (x) of 35%

allows to obtain the peak emission at 663 nm with the highest logarithmic oscillator strength value ($\Gamma$ = –0.93) and perfect equilibrium lattice parameter of 3.249 Å.

Influence of various physical effects on improvement of the efficiency of LEDS is considered.

In [13], for evaluation of transient behavior of a light emitting diode with a resonant cavity called the resonant cavity enhanced light emitting diode, where the improvement of the output optical power and the rise time with the increase of extraction efficiency and in the presence of photon recycling in the light emitting diodes.

The effect of ionizing radiation on the static and dynamic behavior of a vertical resonant laser is discussed in [14]. This leads to the fact that the static and dynamic characteristics of these devices deteriorate sharply due to the radiation flux, and the devicesы gradually changes its mode of operation from laser to LED. At the same time, the devices demonstrate weak fluctuations in output power and rapid decay with increasing ionizing radiation.

It was found [15] that ultrasound causes an increase in the number of degradation-reduction processes in GaAs1-xPh LEDs. Namely, in the passive mode, this is expressed in an increase in the luminescence intensity after prolonged storage (t = 15 h), in the operating mode, the luminescence intensity decreases, and further sonication increases the efficiency of radiative recombination.

Narrow-spectrum LEDs based on InGaN-GaN 450 and 520 nm and AlGaInP-GaAs 625 nm structures have been investigated in the literature [16]. It was found that the growth and decay of the luminous flux intensity under the influence of the pulse power is described by an exponential dependence. In all three types of LED samples, they contain both fast and slow components, and the time constants of these two components decrease with increasing pulse frequency.

The article [17] presents suitable factorization of intersubband scattering rates for the temperature dependent electron transport model of mid-infrared quantum cascade lasers, where the total intersubband scattering rate is presented as a sum of individual contributions: longitudinal optical phonon, interface roughness, and acoustic phonon scattering. It was shown that the individual scattering rate is reduced to a product of the overlap integral for the squared moduli of the envelope functions and the temperature factor that depends on the transition energy and material.

The work [18] provides a very interesting and detailed analysis of the potential mechanisms that lead to high ideality factors of GaN light emitted diodes.

## 3. LED lighting systems

Modern LEDs combine high luminous efficacy, long service life, wide range of spectral compositions, and capability of flexible designing lighting systems based on them, which leads to almost complete replacement with them of all the other traditional light sources in many applications.

LED lighting systems have already become the standard in commercial and residential lighting, replacing incandescent, fluorescent and halogen lamps not only because of their energy-saving characteristics, but also due to a significant reduction in operating costs for maintenance of such systems. The wide range of possibilities for implementing intelligent lighting systems based on LEDs [19] has made them a key element in the creation of “smart” houses and cities [20], where lighting parameters can be adapted to the needs of users in real time, providing maximum comfort and resource saving.

LED lighting systems are capable of emitting light with different correlated colour temperatures [21], which allows the lighting to be adapted to specific needs of the user during different periods of work and rest. An important advantage of LED lighting systems is the high speed of switching on, off, and switching to specified spectral and energy operation modes, as well as the ability to ensure stable operation regardless of power supply parameters [22], which is critical for a wide range of applications.

An important factor contributing to the development of LED lighting systems is their impact on the architecture and design of lighting. Due to their compact size and the ability to integrate into various architectural elements and special design solutions, LEDs have opened up new horizons in the design of lighting systems [23]. They can be used to create a variety of lighting effects, which makes LED lighting an indispensable tool in interior design, exhibition spaces, facade lighting and street decor [24, 25]. LED lighting systems with adjustable spectral composition are especially important for plant lighting, where the intensity and spectral composition of light significantly effect the physiological characteristics of plant development [26].

LED lighting systems also have a significant positive environmental impact. They do not contain hazardous substances, such as mercury used in fluorescent lamps, which reduces the risk of environmental pollution. Moreover, the low energy consumption of LED lighting systems helps to reduce greenhouse gas emission, which is an important factor in the fight against global warming.

However, despite their numerous advantages, LED lighting systems can deliver their high performance only if the operating temperature conditions of the light emitting structures are met. This problem is especially acute when creating high-power LED lighting systems that concentrate large heat fluxes in small areas. That is why the problems of efficient heat dissipation from powerful light emitting structures are currently receiving particular attention to ensure high reliability and luminous efficacy of LED lighting systems [27, 28]. One of the modern promising steps in building reliable and efficient lighting systems is the use of two-phase heat transfer devices (heat pipes, thermosyphons, steam chambers, etc.) in the design of LED cooling systems.

LED lighting systems will be constantly improved by improving the efficiency of LEDs, increasing their reliability and service life, optimising spectral parameters and characteristics, and developing new advanced technologies for light emitting structures (such as e.g. organic LEDs).

## 4. Conclusion

LEDs and their application in LED lighting systems are the areas of optoelectronics that are predicted to dominate in the coming decades.

LED lighting systems have become the main elements of integrated lighting systems for domestic and industrial use due to their unique properties, replacing traditional light sources in many areas. Further development of LED lighting systems makes us possible to predict an increase in their luminous efficacy and reliability, which will help reduce the negative environmental impact of their use.

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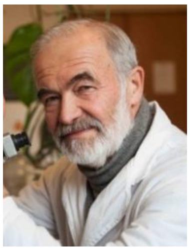

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**Sorokin V.**: resources**,** methodology, writing – review & editing.
**Maksimenko Z.**: verification, writing – review & editing.

**Оптоелектроніка та журнал SPQEO**

**П.С. Смертенко, Д. Пекур, В.М. Сорокін, З.В. Максименко**

**Анотація.** У цій статті розглядаються основні тенденції розвитку оптоелектроніки, її фундаментальні основи та можливі застосування, а також дається загальний огляд результатів досліджень у цій галузі, опублікованих ННЦ «Інститут фізики ім. О.О. Богомольця» за останнє десятиліття. Ми підкреслимо зв'язок розвитку оптоелектроніки з шостим технологічним укладом, пов'язаним з нанотехнологіями, біотехнологіями та інформаційно-когнітивними технологіями. Для зручності ми умовно розділимо обговорення на такі напрямки оптоелектроніки, як фотоніка, терагерцова та інфрачервона електроніка, фотовольтаїка тощо. Ця стаття присвячена одному з цих напрямків оптоелектроніки, а саме світлодіодам та їх застосуванню в системах світлодіодного освітлення, використання яких в проектах «розумного» будинку і міста відкриває нові можливості для створення адаптивного світлового середовища, яке може підлаштовуватися під потреби користувачів.

**Ключові слова:** журнал SPQEO, оптоелектроніка, фотоніка, електрооптика, фотовольтаїка, оптичні технології, світлодіодне освітлення.