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OPTOELECTRONICS AND PHOTONIC DEVICES: CURRENT STATE AND

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Abstract. This paper reviews the physical principles, main device types and application areas of optoelectronics and photonics. Particular attention is paid to semiconductor lasers, light-emitting diodes, photodetectors, solar cells and optical modulators, and to the role of silicon photonics and integrated photonic circuits in information technology, energy, medicine and sensing.

Keywords: optoelectronics, photonics, semiconductor laser, photodetector, LED, integrated photonics, silicon photonics, optical communication.

Today, the rapid growth of data traffic caused by cloud computing, artificial intelligence and 5G/6G networks is pushing electronic devices toward their physical limits in speed and energy consumption. In metallic interconnects, signal transmission is limited by resistance, capacitance and heat dissipation, whereas photons carry no charge, do not interfere with one another, operate at very high frequencies and propagate with minimal losses [1]. For this reason, optoelectronics, which studies devices that convert electrical signals into optical ones and vice versa, and photonics, which covers the generation, transmission, control and detection of light, have become key areas of modern science and technology [2].

The operation of optoelectronic devices is based on three basic interaction processes between light and semiconductors: absorption, which creates electron-hole pairs in photodetectors and solar cells; spontaneous emission, which underlies light-emitting diodes; and stimulated emission, which underlies lasers. The emission wavelength is determined by the band gap of the material: $\lambda\ (\mu m) \approx 1.24 / E_g\ (eV)$. Direct-gap semiconductors such as GaAs, InP and GaN are therefore efficient light sources, while silicon, an indirect-gap material, is inefficient for light emission [2]. GaN-based blue and white LEDs have transformed lighting, and micro-LED and OLED technologies are widely used in displays. Vertical-cavity surface-emitting lasers (VCSELs) are applied in data centers and 3D sensing, and distributed-feedback (DFB) lasers form the basis of fiber-optic communication systems [4]. p-i-n photodiodes, avalanche photodiodes and single-photon detectors provide high sensitivity and speed for optical communication, medical imaging and quantum cryptography, while perovskite and tandem solar cells are a promising way to increase photovoltaic efficiency.

Another promising area of development is integrated photonics, which combines waveguides, modulators, detectors and filters on a single chip. Silicon photonics makes use of the existing CMOS manufacturing infrastructure, which reduces cost and simplifies mass production. Its main challenge is the lack of an efficient light source in silicon, which is being addressed by hybrid integration of III-V semiconductors on silicon [3]. Integrated photonic circuits are expected to be applied

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in optical interconnects in data centers, neuromorphic and optical computing, LiDAR systems, biosensors and quantum communications. Quantum dots, perovskites, two-dimensional materials such as graphene and transition metal dichalcogenides, as well as plasmonics and metamaterials, further extend the possibilities of miniaturization, spectral tunability and light control below the diffraction limit.

Conclusion.

Optoelectronic and photonic devices have become a foundation of modern information and communication technologies, energy, medicine and industry. Their further development is connected with integrated photonics, new semiconductor materials and hybrid electronic-photonic systems. For Uzbekistan, this field opens opportunities to strengthen scientific and practical capacity in solar energy, optical communication infrastructure and semiconductor materials science.

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