Editorial

The School of Optoelectronics at the V. Lashkaryov Institute of Semiconductor Physics: commemorating the centenary of the birth of Sergei Svechnikov, the first Editor-in-Chief of "SPQEO" (21 July 1926 – 13 April 2017)

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Abstract. The development of the school of optoelectronics at the V. Lashkaryov Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine is reviewed, with emphasis on the scientific activity and influence of the Academician Serhiy V. Svechnikov. The formation of this scientific school is considered in the context of the development of optoelectronics as an interdisciplinary field combining semiconductor physics, materials science, electronics, and photonics. The principal research directions established and developed under the leadership of S.V. Svechnikov, including optoelectronic devices and systems, photoconductivity and charge-transport phenomena, radiative recombination, photosensitive and light-emitting semiconductor materials, semiconductor heterostructures, laser technologies, and interaction of electromagnetic radiation with semiconductor structures, are discussed. Particular attention is given to the contributions of his disciples and followers, whose research subsequently expanded these directions toward silicon, silicon carbide, nanocrystalline materials, organic semiconductors, porous silicon, and other emerging materials and structures. The development of international scientific cooperation and the establishment of the journal *Semiconductor Physics, Quantum Electronics and Optoelectronics* (SPQEO), for which S.V. Svechnikov served as the first Editor-in-Chief from 1998 to 2009, are also considered as important components of this scientific school. Selected publications of S.V. Svechnikov and his collaborators in SPQEO are analyzed to illustrate the continuity and evolution of the research initiated at the Institute. The presented overview demonstrates that the Ukrainian school of optoelectronics developed as a broad and multidisciplinary scientific community, whose research directions continued to evolve in response to new materials, technologies, and applications. The 100th anniversary of the S.V. Svechnikov's birth provides an opportunity to review this scientific heritage and to emphasize its continuing influence on semiconductor physics and optoelectronics.

Keywords: SPQEO journal, optoelectronics, school of optoelectronics, 100th anniversary, S.V. Svechnikov, V. Lashkaryov Institute of Semiconductor Physics.

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1. Optoelectronics as a Future Direction in Science and Technology

Today, optoelectronics is one of the key areas of modern electronics and photonics, with applications extending far beyond optical communications to medicine, information processing and storage, sensing, imaging, energy conversion, and many other fields [1]. Optoelectronics is inherently multidisciplinary, combining concepts and methods from optics, semiconductor physics, materials science, and electronics to develop devices and systems capable of generating, detecting, controlling, and processing optical signals. The interaction between photons and charge carriers provides the physical basis for a wide range of optoelectronic devices, including light-emitting diodes (LEDs), photodetectors, laser diodes, optical modulators, and optical-fiber communication components.

The progress of optoelectronics has been closely associated with the development of semiconductor materials and technologies. By combining materials with complementary electrical and optical properties and by controlling their interfaces and structures, researchers have developed devices capable of efficient generation, detection, modulation, and transmission of optical radiation. The continuous improvement of materials, device architectures, and fabrication technologies has resulted in increasing device speed, efficiency, sensitivity, and functional integration. These developments have enabled the expansion of optoelectronic technologies into areas ranging from communication networks and data processing to medical diagnostics, imaging, sensing, and renewable energy systems [2]. Recent advances in new materials and device concepts are also opening opportunities for integration of optoelectronics with neuromorphic information processing and other emerging technologies [3].

The development of optoelectronics can be traced through a number of important scientific and technological milestones. In 1907, Henry J. Round reported observation of electroluminescence in silicon carbide [4, 5]. The invention of transistor at the Bell Telephone Laboratories in 1947 established foundations of modern semiconductor electronics [6]. In 1960, Theodore H. Maiman demonstrated the first working laser [7], while in 1962 Nick Holonyak Jr. and S.F. Bevacqua reported coherent visible-light emission from $Ga(As_{1-x}P_x)$ semiconductor junctions, marking an important milestone in the development of visible semiconductor light emitters [8]. During the 1960s, the emergence of light-emitting and light-detecting semiconductor devices and the introduction of optocoupler demonstrated potential for combining optical and electronic functions within a single device.

The subsequent development of fiber-optic communication during the 1970s and the rapid progress in semiconductor technology during the 1980s and 1990s led to increasingly efficient, compact, and reliable optoelectronic devices. Since the beginning of the 21st century, the field has expanded further through integration of optoelectronics with nanotechnology, advanced semiconductor materials, organic electronics, and, more recently, quantum and neuromorphic technologies [1, 3]. Thus, the development of optoelectronics has been driven not only by advances in individual devices but also by the emergence of new materials, fabrication methods, and interdisciplinary approaches.

This historical development created a broad scientific framework, in which semiconductor physics, materials research, device engineering, and information technologies became closely interconnected. It was within this rapidly developing field that important research directions in optoelectronics were established in Ukraine. The formation and subsequent development of the Ukrainian school of optoelectronics are closely associated with the scientific activity of the Academician Serhiy V. Svechnikov and his disciples and followers, whose work is considered in the following section.

2. Optoelectronics and school of optoelectronics in Ukraine

Development of optoelectronics in Ukraine and the former Soviet Union was closely associated with the scientific activity of the Academician Serhiy V. Svechnikov. In the early 1950s, while working on problems of non-contact control of the thickness of steel sheets in automatic rolling mills, he developed an optoelectronic system based on an X-ray emitter and a cadmium sulfide (CdS) photosensitive element [9–11]. This work, which combined radiation detection, semiconductor photoconductivity, and industrial process control, can be regarded as one of the early examples of application of semiconductor optoelectronics to industrial automation in Ukraine and the former Soviet Union.

Svechnikov's subsequent research gradually expanded from specific applications of photoconductivity toward a broad range of problems in semiconductor physics and optoelectronics. His scientific activity combined fundamental investigations of charge transport, recombination, photoconductivity, and radiation effects with development of photosensitive and light-emitting materials, optoelectronic devices, functional converters, and information-processing systems. This combination of fundamental and applied research became one of the characteristic features of the scientific school formed under his leadership.

Since many of the Svechnikov's early publications were written in Russian, a selection of his English-language papers is presented in this review [12–20]. These publications, made in collaboration with his disciples and colleagues, demonstrate the progressive development of his research interests – from CdS and CdSe photosensitive materials and semiconductor junctions to light-emitting devices, silicon-based structures, and organic optoelectronic materials.

2.1. Formation and development of the scientific school

A distinctive feature of the S.V. Svechnikov's scientific activity was his ability to combine several closely related research areas and to involve researchers with different scientific backgrounds in their development. Among his prominent disciples and followers were P.F. Oleksenko, A.N. Zyuganov, E.B. Kaganovich, T.Ya. Gorbach, L.V. Zavyalova, P.S. Smertenko, S.I. Vlaskina, L.L. Fedorenko, Yu.M. Shirshov, G.A. Sukach, L.I. Fenenko, E.G. Manoilov, V.M. Shapar, and many others [14, 15, 17–32]. Their subsequent scientific activities demonstrate the breadth and continuity of the research directions established within the school.

The research carried out under Svechnikov's leadership can be broadly grouped into four interconnected areas.

(i) Optoelectronic devices, functional converters, and information-processing systems

A substantial part of the research was devoted to development and investigation of optoelectronic devices and circuits. These studies included optocouplers and optoelectronic switches, pulse-controlled optoelectronic keys for automation and computer systems, optoelectronic functional converters, devices with positive and negative optical feedback, and systems for controlling electroluminescent panels. The research in this area was carried out in collaboration with P.F. Oleksenko, N.V. Bogolyubov, V.S. Kretulis, M.I. Sypko, A.M. Sharadkin, R.E. Boguslavsky, L.F. Zharovsky, and others.

The development of photopotentiometers, photocapacitors, photoresistor-based functional converters, high-speed optocouplers, image converters, and optical control devices further expanded the concept of optoelectronic functional elements. Later research extended these ideas toward image processing and neuromorphic information systems, including models of a visual analyzer, dynamic image classification, neuron-like structures, and optoelectronic principles of image-shape analysis.

(ii) Charge transport, injection, and recombination processes in semiconductors and semiconductor structures

Another major direction concerned physical mechanisms governing charge transport and light generation in semiconductor materials and structures. These studies included the influence of contact injection on the sensitivity and response speed of photoresistors, current-voltage characteristics of monopolar and quasi-monopolar semiconductors, high-field electrical conductivity, determination of local energy levels and concentrations of defects, and electrical and luminescence characteristics of semiconductor light-emitting structures [14, 16, 22, 24].

Particular attention was devoted to radiative recombination processes in photoconductive CdS and CdSe films and to formation of radiative recombination centers [19]. These investigations provided an important physical basis for understanding and improving photosensitive and light-emitting semiconductor materials.

(iii) Fabrication and characterization of photosensitive and light-emitting materials and structures

The development of semiconductor materials and their fabrication technologies formed another important component of the school. Early studies focused on CdS_xSe_{1-x} and CdS photosensitive films, their preparation, characterization, and application in photodetectors [15]. The research was subsequently extended to electroluminescent films, including ZnS-based materials, as well as to thin-film photoresistors and other photosensitive structures [12, 15, 23, 24].

The research group also investigated silicon carbide and related materials, including growth of SiC films on silicon substrates and characterization of SiC light-emitting structures [26]. Later work included photoluminescence of silicon, porous silicon, nanocrystalline silicon, and other semiconductor structures [17, 27, 29].

(iv) Interaction of electromagnetic radiation with semiconductor materials and structures

Interaction of X-ray, optical, and laser radiation with semiconductors represented another long-term research direction. Early investigations addressed spectral and temperature dependences of X-ray conductivity in CdS single crystals and mobility of radiation-generated charge carriers [11]. Subsequent studies examined laser-induced phenomena, including coherent waveguide scattering, photoreflection, changes in electronic properties of $Si–SiO_2$ structures, and holographic recording using laser radiation.

The development of laser-based methods also opened new possibilities for fabrication and diagnostics of semiconductor structures. Laser thermal diagnostics, laser evaporation, and laser processing were subsequently applied to multilayer optoelectronic structures, HgCdTe epitaxial layers, silicon structures, and other materials [18, 29, 31].

2.2. Evolution toward new materials and technologies

An important characteristic of the Svechnikov's scientific school was continuous expansion of its research toward new semiconductor materials and technological approaches. Although his early investigations were strongly associated with A^2B^6 compounds, particularly CdS and CdSe [11, 15, 24], later research increasingly involved silicon, gallium arsenide, and silicon carbide [17, 26, 27, 29, 40]. This transition reflected broader evolution of semiconductor optoelectronics and emergence of new materials with potentially advantageous electrical, optical, and technological properties.

Svechnikov also paid considerable attention to nontraditional materials for opto- and microelectronics. His research interests extended to organic semiconductor materials, conductive polymers, and other emerging material systems [20, 32, 43]. These studies demonstrate that the scientific school was not restricted to a particular class of semiconductor materials but evolved together with the changing requirements of optoelectronic technologies.

The same tendency can be observed in the research of his disciples and followers. Studies of silicon photoluminescence for biosensing applications [28], interferometric sensors [29], polymeric materials for photosensitive and light-emitting structures [32, 38, 40], laser-produced silicon field-emission arrays [33], and optical rotary joints [34] demonstrate progressive expansion of the original research directions into sensors, information processing, organic electronics, micro- and nanoelectronics, and optical technologies.

2.3. International scientific cooperation and SPQEO

International cooperation was an important component of the Svechnikov's scientific activity. His research collaborations involved scientists and institutions from Japan [34], South Korea [35], Germany [36], Poland [37], and Turkey [38]. He also participated in international scientific organizations and conferences, including activities associated with SPIE [39]. These collaborations contributed to exchange of scientific ideas and helped connect the Ukrainian school of optoelectronics with the international research community.

An important step in this development was the establishment in 1998 of the international scientific journal *Semiconductor Physics, Quantum Electronics and Optoelectronics* (SPQEO). The journal was founded at the V. Lashkaryov Institute of Semiconductor Physics and brought together three closely interconnected research areas represented at the Institute: semiconductor physics, quantum electronics, and optoelectronics. S.V. Svechnikov became its first Editor-in-Chief. The journal subsequently provided a common platform for dissemination and exchange of research results in these fields.

Thus, the formation of the school of optoelectronics at the V. Lashkaryov Institute was not limited to the development of individual scientific topics. It involved creation of a broad research community, in which fundamental semiconductor physics, materials science, device development, and emerging information technologies were closely interconnected. The activities of the Svechnikov's disciples and followers demonstrate how these research directions continued to evolve as new materials, structures, and technological approaches emerged. The contribution of Svechnikov and his collaborators to SPQEO, considered in more detail in the next section, provides a further illustration of this scientific continuity.

3. S.V. Svechnikov's contribution to SPQEO and the Development of the School

The scientific directions developed by S.V. Svechnikov and his disciples found a natural continuation in the journal *Semiconductor Physics, Quantum Electronics and Optoelectronics* (SPQEO). A number of papers published in the journal with the participation of Svechnikov and his collaborators illustrate the continuity of these research directions and their evolution toward new materials, structures, and technologies [42–48].

One of the early studies published in SPQEO concerned the influence of surface pretreatment on the properties of microrelief silicon wafers [42]. Four pretreatment methods were compared prior to anisotropic chemical etching: cutting; cutting followed by mechanical polishing with Al_2O_3; cutting followed by chemical polishing using an HNO_3:HF mixture; and standard industrial treatment. The results demonstrated that anisotropic chemical etching after cutting could provide surface properties comparable with those obtained using the conventional industrial process, while offering a potentially simpler and less expensive preparation route. This work illustrates the continuing interest of the school in semiconductor surface engineering and the relationship between the processing conditions and the properties of optoelectronic structures.

The photosensitive properties of porous-silicon-based structures were investigated in [43]. Electrical and optoelectrical measurements were performed on Al/porous-Si/crystalline-Si/Al sandwich structures containing porous-silicon layers of different thicknesses. For the structures with a thin porous-silicon layer, the photosensitivity was primarily determined by the porous-Si/c-Si heterojunction, whereas in the structures with a thicker layer, the contribution of the porous silicon itself became dominant. A photoconductive response of porous silicon with the maximum photosensitivity in the 400–500 nm spectral range was observed. These results represent a continuation of earlier investigations of photosensitive semiconductor materials and structures carried out within the Svechnikov's scientific school.

The electronic properties of heterojunctions based on nanocrystalline and monocrystalline silicon were investigated in [44]. Nanocrystalline silicon films were fabricated by laser ablation of a crystalline-silicon target under different deposition conditions. The study demonstrated a strong dependence of the density of interface electronic states and carrier traps on the film deposition conditions. Under conditions involving deposition from direct particle flow of erosion plume, particularly high densities of interface states and carrier traps were observed. These results provided insight into the role of local electronic states in defining electrical, photoelectrical, and electroluminescent properties of nanocrystalline-silicon/c-Si heterojunctions.

Influence of metallic impurities on optical and electronic properties of nanocrystalline silicon was studied in [45]. Electropositive metals (Au, Ag, and Cu) and electronegative metals (Al and In) were introduced into nanocrystalline silicon films prepared by laser ablation. The results showed that metallic impurities substantially affected photovoltage and trapping of non-equilibrium charge carriers both within the film and at the film/substrate interface. This work further developed the research of the school toward controlled modification of semiconductor materials and the relationship between local electronic states and optoelectronic properties.

Laser fabrication of silicon micro- and nanostructures was investigated in [46]. A direct laser-writing technique was used to produce highly uniform conical silicon tips and arrays with controlled geometrical parameters. Field emission was observed over a broad range of applied voltages and emission currents. In some structures, resonant tunneling effects were also detected, which were attributed to quantum-size effects and presence of discrete energy levels in nanostructured regions. This study demonstrates the extension of the school's earlier interest in laser technologies toward field-emission structures and nanoelectronic applications.

The investigation of new photosensitive materials was continued in [47], where thermal and optical structural transformations in $As_{40}S_{60-x}Se_x$ thin films were studied. The observed photostructural transformations involved changes in the molecular structure of the glassy matrix and were accompanied by a decrease in the number of molecular fragments containing particular covalent bonds. The pronounced photoinduced structural changes indicated potential of these materials for optical recording and holographic security applications. This research represents another example of the development of the school's long-standing interest in interaction of optical radiation with semiconductor and photosensitive materials.

Laser technologies were also applied to fabrication of ohmic contacts to α-SiC [48]. Multilayer $Ni/W/Si_3N_4/W$ structures were deposited using pulsed laser deposition and subsequently subjected to laser annealing. Combined use of fundamental ($\lambda = 1.06$ μm) and second-harmonic ($\lambda = 0.53$ μm) radiation of a Nd:YAG laser was found to provide favorable conditions for obtaining low-resistance contacts. The resulting contacts exhibited a specific contact resistivity of approximately $3–4\times10^{-4}$ $\Omega\cdot cm^2$. The proposed contact structure offered several technological advantages, including absence of gold and other expensive metals, use of tungsten for subsequent interconnection, and possibility of producing non-fused contacts.

The studies with S.V. Svechnikov's authorship published in SPQEO therefore represent more than a collection of individual scientific results. They demonstrate continued development of several fundamental directions established within his scientific school: semiconductor surface and interface physics, photosensitive materials, charge trapping and transport, silicon and silicon carbide structures, laser processing, and optical recording materials. At the same time, these investigations show gradual transition from traditional semiconductor materials toward porous and nanocrystalline structures, nanocomposites, chalcogenide materials, and advanced laser-fabricated devices.

In this broader context, the scientific directions initiated and developed by S.V. Svechnikov remain connected with the continuing evolution of semiconductor physics, materials science, and optoelectronics.

4. Conclusion

The scientific heritage of the Academician Serhiy V. Svechnikov demonstrates the important role that fundamental semiconductor research, materials science, device development, and international scientific cooperation have played in the formation of optoelectronics in Ukraine. His scientific activity subsequently encompassed a remarkably broad range of problems, including optoelectronic devices and circuits, charge transport and recombination, photosensitive and light-emitting materials, semiconductor heterostructures, laser technologies, and interaction of electromagnetic radiation with semiconductor materials.

An essential feature of the Svechnikov's scientific activity was the formation of a strong scientific school. His numerous disciples and collaborators continued and expanded the research directions initiated under his leadership, applying them to new semiconductor materials, device architectures, fabrication technologies, and information-processing systems. The evolution from A^2B^6 semiconductor compounds and photosensitive films toward silicon, silicon carbide, nanocrystalline materials, organic semiconductors, and other non-traditional materials reflects the Svechnikov's ability to recognize emerging scientific and technological trends and incorporate them into development of optoelectronics.

Svechnikov also understood the importance of international scientific cooperation and dissemination of scientific results. His participation in international research projects and organizations, as well as his activity as the first Editor-in-Chief of *Semiconductor Physics, Quantum Electronics and Optoelectronics* (SPQEO) during 1998–2004, contributed to international development and visibility of the Ukrainian school of optoelectronics.

The centenary of the birth of S.V. Svechnikov therefore provides an appropriate opportunity to recognize his enduring contribution to semiconductor physics and optoelectronics and to the scientific community that continues the research traditions he established.

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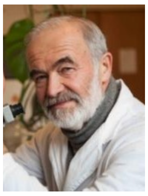

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Maksimenko Z.: verification, writing – review & editing.
Belyaev A.: resources, methodology, writing – review & editing.

Школа оптоелектроніки Інституту фізики напівпровідників ім. В. Лашкарьова та журнал «SPQEO»: до сторіччя з дня народження першого головного редактора «SPQEO» Сергія Свечникова (21 липня 1926 р. – 13 квітня 2017 р.)

П.С. Смертенко, З.В. Максименко, А.Є. Бєляєв

Анотація. Наукова спадщина академіка Сергія В. Свечникова демонструє важливу роль, яку відіграли фундаментальні дослідження напівпровідників, матеріалознавство, розробка приладів та міжнародне наукове співробітництво у становленні оптоелектроніки в Україні. Його наукова діяльність згодом охоплювала надзвичайно широкий спектр проблем, включаючи оптоелектронні прилади та схеми, перенесення та рекомбінацію заряду, фоточутливі та світловипромінюючі матеріали, напівпровідникові гетероструктури, лазерні технології та взаємодію електромагнітного випромінювання з напівпровідниковими матеріалами. Істотною особливістю наукової діяльності Свечникова було формування сильної наукової школи. Його численні учні та співробітники продовжили та розширили напрямки досліджень, започатковані під його керівництвом, застосовуючи їх до нових напівпровідникових матеріалів, архітектур приладів, технологій виготовлення та систем обробки інформації. Еволюція від напівпровідникових сполук A^2B^6 та фоточутливих плівок до кремнію, карбіду кремнію, нанокристалічних матеріалів, органічних напівпровідників та інших нетрадиційних матеріалів відображає його здатність розпізнавати нові науково-технологічні тенденції та включати їх у розвиток оптоелектроніки. Свечников також розумів важливість міжнародного наукового співробітництва та поширення наукових результатів. Його участь у міжнародних дослідницьких проектах та організаціях, а також його діяльність на посаді першого головного редактора журналу «Фізика напівпровідників, квантова електроніка та оптоелектроніка» (SPQEO) протягом 1998–2009 років сприяли міжнародному розвитку та визнанню української школи оптоелектроніки. Тому сторіччя з дня його народження надає слушну нагоду відзначити його незмінний внесок у фізику напівпровідників та оптоелектроніку, а також у наукову спільноту, яка продовжує дослідницькі традиції, що він започаткував.

Ключові слова: журнал SPQEO, оптоелектроніка, школа оптоелектроніки, 100-річчя, С.В. Свечников, Інститут фізики напівпровідників ім. В.Лашкарьова.