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THE CENTENNIAL OF SEMICONDUCTOR SCIENCE: ORIGINS AND UKRAINIAN CONTRIBUTION

A review of experimental facts and theoretical hypotheses, which resulted in the appearance of a new branch in our knowledge, semiconductor science, at the beginning of the 20th century, has been made. Johann Königsberger is shown to be the first who put forward the idea of semiconductors as a separate class of substances in 1914 on the basis of the original hypothesis about the "dissociation mechanism" of conductivity. The priority of the Ukrainian scientist Vadym Lashkaryov in the discovery of a p–n-junction, which forms the basis of modern electronic devices, has been demonstrated.

K e y w o r d s: metals, insulators, semiconductors, conductivity, band theory, electronics.

1. Introduction

How old is the semiconductor science? This simple question cannot be answered at once even by those who have been working in this branch during all their life. This is of no surprise, because people have dealt with some semiconductors (e.g., silicon) since long ago, although not in the role of "electric conductors". Since the 18th century, scientists have actively been studying the electric properties of various materials, which we call semiconductors today. However, where is the boundary between separated empirical observations, on the one hand, and the semiconductor science with its own and well-distinguished scope of researches, on the other hand? When did physicists begin to discern semiconductors as a separate class of materials? We will try to answer those questions by reviewing the experimental facts and theoretical hypotheses that had been accumulated for a long time and, at the beginning of the 20the century, brought about the appearance of a new field in our knowledge, semiconductor science.

2. Conductors and Insulators

In 1729, the Englishman Stephen Gray (1666–1736) discovered the phenomenon of electric conductivity [1]. He took a glass bottle and sealed it with a cork, into which a metallic stick with an ivory ball at the end was plunged. Then, he electrified the bottle with the help of a piece of cloth. It turned out that "the electricity" passed from the bottle on the ball; it was so, because the ball started to attract small dust particles, small pieces of paper, and so on.

While continuing his experiments, S. Gray found that not only metallic wires conduct the electricity, but also coal rods and muscles of humans and animals. Proceeding from short metallic sticks, the scientist proved that the conductivity is retained in wires up to 250 m in length. He came to a conclusion that the electricity can easily flow in both horizontally and vertically arranged conductors (at that time, the electricity was imagined as a special fluid, so that the fact studied by S. Gray had to be experimentally verified).

At the same time, S. Gray found that rubber, wax, silk threads, and porcelain did not conduct, and, hence, they could be used as insulators to prevent the electricity from flowing out. The scientist informed about his experiments in his letter to the Royal society dated by February 8, 1731. However, the scientist could not explain, of course, such a difference in the behavior of various materials.

In his informative investigation concerning the early history of semiconductors, G. Busch claimed [2] that the very term "semiconductor" was used for the first time by the famous Italian scientist Alessandro Volta (1745–1827) in his report to the London Royal society on March 14, 1782. By touching an electrometer with various materials, he found that putting it in contact with metal resulted in the immediate discharge of an electrometer, whereas the contact with insulators left the charge to be constant. At the same time, there were some materials, through which the electrometer also discharged, but for a finite time interval. Just those materials were called by A. Volta as "semiconductors".

In 1800, A. Volta stacked one hundred of alternating zinc and silver discs separated by paper soaked in the brine and obtained a rather powerful source of electricity, the "voltaic pile". In contrast to the previous electric sources that were based on the electrization by friction, the "voltaic pile" was not an instant, but permanent discharge source, which discovered the huge opportunities before physicists and engineers. With the use of a thermocouple invented not long before (it produced a more stable voltage than the "voltaic pile" did), the German scientist Georg Simon Ohm (1787–1854) ultimately succeeded (1826) in establishing the main law of electric circuits, which was called after him.

3. Semiconductors: First Experimental Facts

In 1821, the English physical chemist Humphry Davy (1778–1829), using a "voltaic pile", established that the electric conductivity depended on the temperature; in particular, as the temperature grew, the conductivity of metals (at that time, the term "conducting power" was applied) decreased. In 1833, the great disciple of H. Davy, Michael Faraday (1791–1867), revealed a surprising property of silver sulfide Ag_2S: its conductivity was very low at room temperatures, but considerably grew to "metallic" values at 175 °C. Hence, a discovery that the conductivity in some substances can grow with the temperature was made. Unfortunately, M. Faraday, who preferred qualitative experiments, has not left any data, tables, or plots.

Later, it turned out that not only the temperature but also light can affect the conductivity in solids. In 1839, the young French physicist Alexandre-Edmond Becquerel (1820–1891), having embedded a plate of silver chloride with platinum contacts into an electrolyte solution, observed, for the first time, the photoeffect phenomenon, i.e. the appearance of voltage under illumination. In 1873, the English engineer Willoughby Smith (1828–1891) established the fact of a drastic reduction in the selenium resistance at the illumination. For almost one and a half centuries, this effect has been governing the work of various exposure meters. However, the physical nature of this effect remained obscured for almost 60 years.

In the next 1874 year, the German physicist and inventor Karl Ferdinand Braun (1850–1918) revealed that a point-contact between the metal and the metal sulfide can operate as a rectifier, by allowing the current to flow in one direction and not in the other. This discovery was widely applied in the first "detector" receivers that did not require an electric supply (for this reason, they were used in Ukrainian villages up to the 1950s). Later, K.F. Braun actively cooperated with the inventor of radio Guglielmo Marconi, and they both were awarded the Nobel Prize in physics in 1909.

4. Classical Theory of Electroconductivity

A new powerful method to study solids became the Hall effect discovered by the American physicist Edwin Herbert Hall (1855–1938) in 1879. However, the physical nature of charge carriers in conductors deviated at their motion by the magnetic field was still obscured (this issue remained open for a long time; in the 18th century and later, scientists believed that there existed a special "electric fluid" capable of flowing between objects). In 1897, the English scientist Joseph John Thomson (1856–1940) demonstrated that cathode rays consisted of negatively charged particles, electrons. So the issue on the material carriers of the electric current has been ultimately resolved.

On the basis of those discoveries, the German scientist Paul Drude (1863–1906) constructed the classical electron theory of electric conductivity in metals (1900). According to it, the current in a metal is transferred by electrons, which behave as a classical ideal gas. Between collisions (τ is the mean free time between two collisions), the electrons move freely to pass a certain distance l. Electrons mainly collide with the lattice ions, which gives rise to the thermal equilibrium between the electron gas and the crystal lattice (the difference between the electron gas and the ordinary one consists in that the gas molecules in the latter are scattered from one another). The average velocity of thermal motion for electrons can be evaluated as $\langle u \rangle \sim \sqrt{\frac{kT}{m}}$, where T is the temperature, k the Boltzmann constant, and m the electron mass. At room temperature, this velocity equals 10^7 cm/s by the order of magnitude. If an electric field with strength E is applied, electrons start to move with the acceleration

$$a = \frac{e}{m}E. \quad (1)$$

The average velocity of electrons – charge carriers – in the field approximately equals half the velocity acquired by electrons before the next collision,

$$v = \frac{a\tau}{2}. \quad (2)$$

According to the "electrostatic definition" of current as a charge that crosses a unit area per unit time, the current density can be easily written as

$$j = env. \quad (3)$$

Here, n is the electron concentration (the number of electrons in a unit volume; it can be determined experimentally from the Hall effect), and e the electron charge. Substituting the average velocity of an electron (2) into this expression, we obtain

$$j = \frac{e^2 n\tau}{2m}E. \quad (4)$$

This formula coincides with Ohm's law for a circuit section written in the differential form,

$$j = \sigma E. \quad (5)$$

Hence, together with the explanation of Ohm's law, the theory provided an expression for the specific conductance (the quantity reciprocal to the specific resistance),

$$\sigma = \frac{e^2 n\tau}{2m}. \quad (6)$$

Since the electron concentrations in all metals are approximately identical, the dependence of the specific conductance on the temperature and metal parameters should be determined by the mean free time τ. Moreover, since electrons are scattered more intensively at higher temperatures, the mean free time and the specific conductance have to decrease as the temperature grows. The Drude theory qualitatively explained the increase in the specific resistance of metals, $\rho = 1/\sigma$, which was experimentally revealed at high temperatures as long ago as by H. Davy (this is valid for not too low temperatures),

$$\rho(t) = \rho_0(1 + \alpha t), \quad (7)$$

where t is the temperature in centigrade degrees, and α is the proportionality coefficient. (Analytically, formula (7) was derived by Felix Bloch only in 1930 for the range of rather high temperatures with regard for the electron scattering by lattice vibrations–phonons.)

At last, the qualitative difference between metals and insulators became clear. The former have a large number of conduction electrons; this fact is responsible, in particular, for their characteristic "metallic" luster, because the surface charge reflects light. The latter have no conduction electrons for some reasons.

A number of experiments were carried out to confirm the Drude theory. In 1901, the German physicist Eduard Riecke took two copper and one aluminum cylinders with well ground end faces, weighed them, and combined one by one into a circuit copper–aluminum–copper. A direct current had been run permanently through such a combined conductor for a year. Within a year, an enormous charge of about 3.43×10^6 C passed through the conductor. Nevertheless, the further research of cylinders showed that the current did not affect their weight. Moreover, no penetration of one metal into the other at the end faces of the cylinders was revealed. Hence, the described experiment testified that the charge in metals is transferred by electrons rather than atoms.

5. Königsberger Introduced the Concept of a New Class of Substances

However, the Drude theory failed in explaining the presence of materials, the resistance of which decreased as the temperature increased. The next attempt to explain this "anomaly" was made by Johann Georg Königsberger (Fig. 1), Professor at the University of Freiburg (Germany). Professor Königsberger was a versatile scientist. His works concerned the electric, optical, and thermal properties of many natural minerals and synthetic compounds. In addition, the scientist was interested in spectroscopy, thermal radiation, and geophysical phenomena. In work [3], J. Königsberger together with K. Schilling showed that the temperature dependence of a specific resistance for some substances, e.g., titanium and zirconium, had a minimum, whereas the resistance of silicon decreased in the whole examined temperature interval.

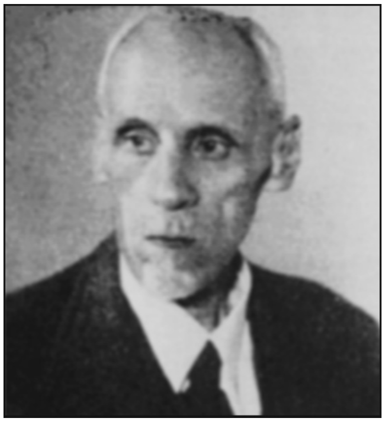

Fig. 1. Johann Georg Königsberger

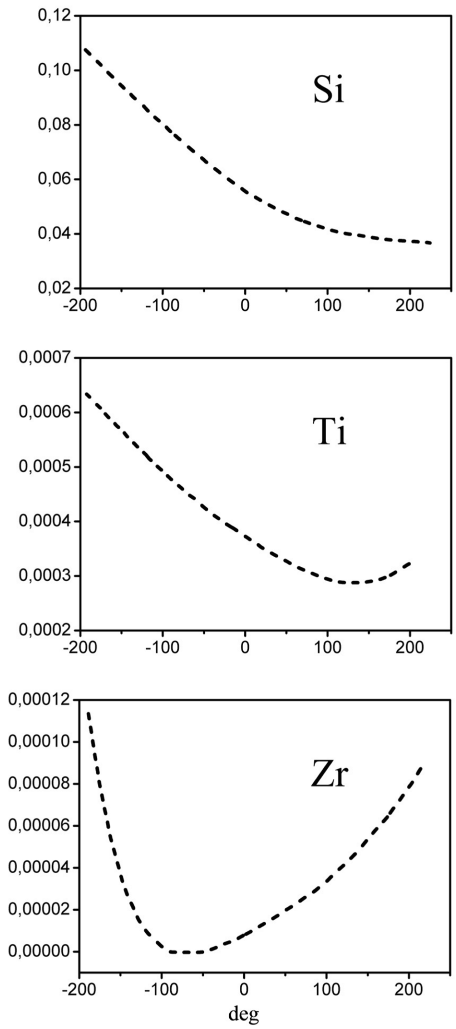

Fig. 2. Temperature dependences of the specific resistance in Si, Ti, and Zr (taken from work [3])

Trying to explain the obtained dependences, J. Königsberger postulated that, actually, the charge carriers appear in any substance as a result of the atomic dissociation into free electrons and positive ions, the number of which equals

$$N = N_0 \exp\left(-\frac{Q}{t+273}\right), \tag{8}$$

where the parameter Q is proportional to the dissociation energy. This assumption allows expression (7) to be modified as

$$\rho(t) = \rho_0(1+\alpha t)\exp\left(\frac{Q}{t+273}\right), \tag{9}$$

which evidently allows one to explain the curves with minima in Fig. 2! J. Königsberger himself proposed no model for the determination of the dissociation energy. However, in his further work [4], he used just the Q-value to class all substances as metals, insulators, and "variable conductors" (in German, die variable Leiter). In particular, Q goes to infinity for insulators (hence, there are no free conduction electrons in them), and, at high temperatures, to zero for metals (therefore, the number of conduction electrons in metals equals the number of ions – P. Drude proceeded just from this assumption). For "variable conductors", the value of parameter Q is finite, which results in an exponential decrease of their specific resistance as the temperature grows!

It should be noted that J. Königsberger also experimentally showed that the value of Q for "variable conductors" substantially depends on their purity degree and the presence of structural imperfections in examined specimens. This fact enables us to date the beginning of semiconductor science to 1914, when work [4] was published. Since then, the experimental facts were associated with the new class of substances with completely definite properties rather than unclassified "anomalous" materials.

It is of interest that J. Königsberger himself did not use the term "semiconductor" (in German, Halbleiter). For the first time, it was used by P. Weiss, the post-graduate student under J. Königsberger, in his thesis for the doctoral degree defended in 1910. However, even this terminological inconsistency does not prevent J. Königsberger from being declared the "father" of modern concept of semiconductors.

6. New Experimental Facts

Simultaneously with J. Königsberger and his disciples, semiconductor materials were also actively studied by Professor of physics at the University of Jena Karl Bädekker (1877–1914) (Fig. 3). A talented physicist, a son of the publisher of world-wide known tourist guidebooks Fritz Bädekker, he was killed at the front in the first week of World War I at the age of 37. Therefore, the list of his works is short, but his main works are distinguished by a high carefulness and a pioneer approach. Karl Bädekker's book "Electrical Phenomena in Metal Conductors" (1911) served as a textbook for two decades.

A very bad reproducibility of results was almost the largest "scourge" of experiments dealing with conductivity at that time. In 1907, K. Bädekker proposed a new method of specimen preparation. He sputtered thin films of copper, silver, cadmium, thallium, and lead on a glass or mica substrate. The thicknesses of the films obtained were determined by the precise weighing. Then, the films were kept in oxygen or in sulfur, selenium, arsenic, or iodine vapors to obtain the required compounds.

The most interesting results were obtained for copper iodide CuI. The as-prepared films had a very high conductivity typical of metals; but, being left in air at room temperature, they became almost insulators. However, the sequential holding of the film in iodine vapor restored the metallic conductivity and reduced the film resistance by several orders of magnitude. This cycle could be repeated several times. Whence the evident conclusion followed that the specific conductance crucially depended on the iodine content in the specimen.

K. Bädekker was the first who measured the Hall effect in a semiconductor film CuI. The first surprise was the fact that the Hall voltage polarity was opposite to that observed for bismuth at a similar geometry of experiment. Hence, it had to be recognized that positive charge carriers are responsible for the current in CuI! In such a way, the hole conductivity in the semiconductor was revealed for the first time, although the words "hole" and "semiconductor" had not been used yet. While measuring the magnitude of Hall constant and admitting that the charge is transferred by carriers of the same kind, K. Bädekker confirmed the validity of formula (8) postulated by J. Königsberger: the number of charge carriers really exponentially grew with the temperature!

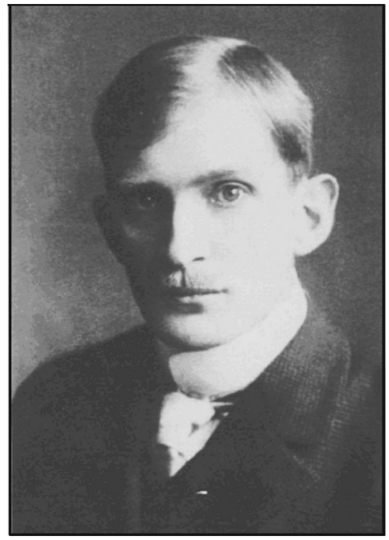

Fig. 3. Karl Bädekker

In the years to come, various researchers discovered plenty of compounds with semiconductor properties, with cuprous oxide Cu_2O being among the most "popular" of them. As was demonstrated by Professor at the University of Göttingen Bernard Gudden (1892–1945), the author of, probably, the first review devoted to the conductivity in semiconductor compounds [5], the resistances of various Cu_2O specimens at room temperature could differ from one another by 6 to 7 orders of magnitude, with the specific conductance of cuprous oxide grew as the oxygen pressure increased.

7. Birth of the Theory of Semiconductors

Semiconductors became a considerable puzzle for theorists, and classical physics could not solve it in principle. In 1927, just after the creation of the fundamentals of quantum mechanics, Wolfgang Pauli and Enrico Fermi developed the theory of strongly degenerate electron gas in metals. In 1928, the Swiss physicist Felix Bloch (1905–1983)–at that time, the postgraduate student under W. Heisenberg at Leipzig–obtained the general expression for the wave functions in a periodic potential. Two years later, he developed the theory of the temperature dependence of a metal resistance ρ with regard for the charge carrier scattering by vibrations of lattice ions. F. Bloch obtained

Fig. 4. Alan Wilson

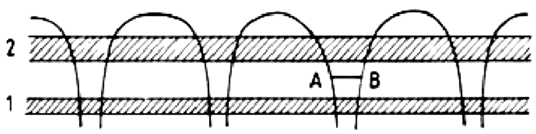

Fig. 5. The very first band diagram of a semiconductor from Wilson's work

the well-known "classical" limiting case for high temperatures ($\rho \sim T$) and showed that, at low temperatures, the so-called "Bloch–Grüneisen regime" ($\rho \sim \sim T^5$) can be realized. However, F. Bloch did not try to explain the existence of metals, semiconductors, and insulators.

As the "father" of the band theory of solids, we can rightly consider the British scientist Alan Wilson (1906–1995) (Fig. 4). After studying in Cambridge under R. Fowler, he trained at the beginning of the 1930s in Leipzig under W. Heisenberg, where he got acquainted with Bloch's works. Two classical articles by A. Wilson [6, 7] appeared during 1931. The scientist introduced there, for the first time, a scenario, usual for us, with the bands of allowed energies and the energy gaps between them. He introduced the concepts of "donors" and "acceptors". He also suggested to distinguish between "intrinsic" and "extrinsic" semiconductors (the conductivity in the former case is associated with the electron transitions between two allowed bands; in the latter case, these are transitions from the impurity level into the allowed band. Hence, the concept of "dissociation energy" intuitively introduced by J. Königsberger obtained the physical sense of the energy gap width (according to the state of technologies at that time, the thermal activation energy of the impurity level), and the classification into metals, insulators, and semiconductors, which was proposed in 1914, obtained its explanation and confirmation. It is worth noting that the concept of "holes" as charge carriers with a positive charge was ultimately introduced the same year (1931) by Werner von Heisenberg [8], who interpreted, in such a manner, empty levels in the almost filled valence band.

In the same years, J. Frenkel [9], C. Wagner and W. Schottky [10], and W. Jost [11] independently developed their own models of point defects in crystal lattices, which not only made it possible to describe the electron conductivity in ionic crystals, but also played a large role in the further development of semiconductor science. Simultaneously, in 1930, the Russian scientist Igor Tamm developed the quantum-mechanical theory of light scattering in crystals and introduced the concept of elastic vibrations in solids, i.e. phonons. The idea of a phonon was already contained in the early works by A. Einstein (1907) and P. Debye (1912) devoted to the theory of heat capacity of solids. However, the term "phonon" belongs to I. Tamm. Hence, at the beginning of the 1930s, the basis of the theory of semiconductors was laid.

8. Materials that Changed Mankind's Life

However, a totally undeveloped state of technologies for the production of "pure" substances till the end of the 1940s called into question the very possibility of studying "intrinsic" semiconductors experimentally. All real semiconductors available at that time were "dirty" and strongly "extrinsic"; and the results obtained for them were badly reproduced. In work [2], the letter of W. Pauli to R. Peierls written in 1931 is quoted: "One shouldn't work on semiconductors, that is a filthy mess; who knows whether they really exist".

As the author of work [2] G. Busch marked that such an attitude to semiconductors continued till the end of the 1930s and changed considerably only after the invention of a p–n transistor by the American scientist W. Shockley (1910–1989) and his colleagues J. Bardeen (1908–1991) and W. Brattain (1902–1987) in 1951. This invention stimulated an unimaginable technological break-through of the mankind in practically all domains and was recognized by the Nobel Prize in 1956. It should be noted that, while working on the invention, W. Shockley solved the differential equations for the diffusive and drift motions of charge carriers and developed the model of recombination through impurity levels (the Shockley–Read model). The result obtained by him formed the basis of the fundamental monograph "Electrons and Holes in Semiconductors with Application to Transistor Electronics " published in 1950.

The first integrated circuit composed of two transistors, a resistance, and a few capacitors was produced – in effect, manually – in 1959 on the basis of a crystal 2 cm in diameter. The application of microcircuits very quickly and considerably expanded the human capabilities in all branches, from calculations and communication to household electronics.

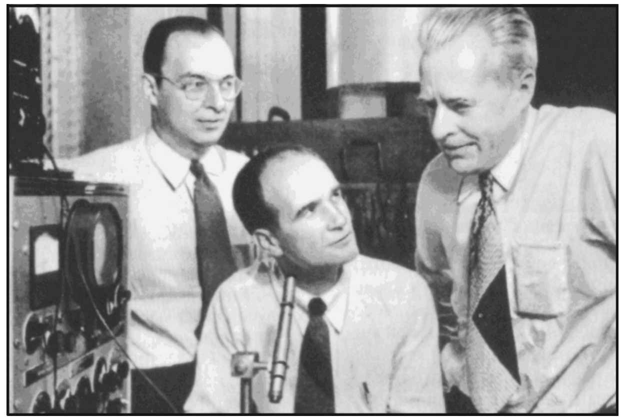

Fig. 6. J. Bardeen, W. Shockley, and W. Brattain

Fig. 7. The first transistor

9. Semiconductors: Ukrainian Contribution

Rapid progress in microelectronics at the beginning of the 1960s stimulated active researches in semiconductor physics throughout the world. To a great extent, it was associated with the race of arms at that time, which had accelerated the development of semiconductor science in the USSR. In particular, in 1954, by the initiative of A. Joffe (1880–1960) (he was born in Ukraine in the city of Romny; was the student of C. Röntgen; in the pre-war years, he was a foreign member of T. Shevchenko Scientific Society in Lviv), the Institute of Semiconductors was established in Leningrad.

However, the development of semiconductor physics in Ukraine started much earlier. Since 1929, the researches of new aspects of the Becquerel (photogalvanic) effect had been carried out under the direction of the founder of the Institute of Physics of the All-Ukrainian Academy of Sciences Oleksandr Goldman (1884–1971), in which O.G. Miselyuk, G.A. Fedorus, M.P. Lukasevych, V.K. Bernadskyi, and other researchers also took part. Unfortunately, in 1938, O. Goldman was arrested on the charge in the "Ukrainian nationalism" (despite his Jewish origin!). He managed to return to a scientific work only in a decade of imprisonment and exile.

It is worth remembering that one of the greatest achievements in the semiconductor science of the 20th century is coupled with Kyiv. Vadym Lashkaryov (1903–1974), a future Academician of the Academy of Sciences of the UkrSSR, have returned to Ukraine after his exile in Arkhangelsk and, occupying the posts of the Head of the Department of Semiconductors at the Institute of Physics and, simultaneously, the Head of the Chair of Physics at the Taras Shevchenko State University of Kyiv, made the main discovery of his life. While studying the barrier layers in cuprous oxide rectifiers the help of a thermoprobe, the scientist discovered a p–n junction (the first band diagram of a p–n junction from V. Lashkaryov's work [12] is shown in Fig. 8). Simultaneously, the scientist elucidated the role of a p–n junction in the emergence of the photovoltaic effect, the generation of a voltage at the illumination of the contact between the semiconductor regions with two types of conductivity.

Work [12] by Lashkaryov did not concede the works by the Nobel Prize winners W. Shockley, J. Bardeen,

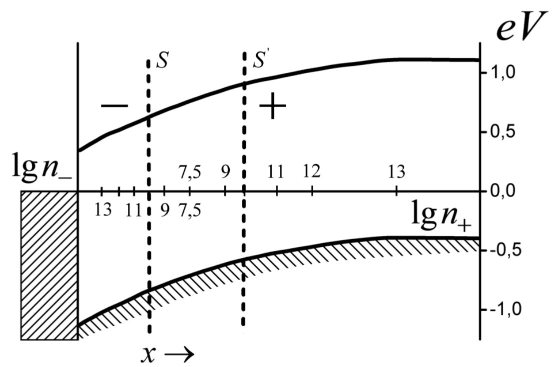

Fig. 8. The very first diagram of a p–n junction (taken from work [12]). The region of p-conductivity is located to the right from the vertical line S', and the region of n-conductivity to the left from the vertical line S. The numbers below and above the abscissa axis indicate the logarithms of the hole (n_+) and electron (n_-) concentrations

Fig. 9. Pioneers – the Chair of Semiconductor Physics at T.G. Shevchenko University of Kyiv (1956). Sitting from left to right: N.Ya. Karkhanina, V.I. Lyashenko, V.E. Lashkaryov, Yu.I. Karkhanin, G.A. Kholodar, and Yu.I. Grytsenko; standing from left to right: I.G. Sambur, E.M. Bereznyakovskyi, V. Zhitkov, V.E. Kozhevin, G.P. Peka, G.P. Zubrin, V.I. Strikha, and R.M. Bondarenko

and W. Brattain by the scientific importance. It is so, because the p–n junction underlies the work of modern semiconductor devices from simple rectifiers to the most complicated integrated circuits. However, owing to a number of adverse circumstances (the work was published in a Russian-language journal before the beginning of the World War II, and its English-language version [13] became accessible only since 2008), the work remained almost unknown in the West, where Russell Shoemaker Ohl (1898–1987) is traditionally considered as the discoverer of a p–n junction [14]. However, the patent application of R. Ohl [15], which is adopted to be the proof of his priority, was filed on May 27, 1941 (after V. Lashkaryov's work had been published!), and the patent itself was issued only on June 25, 1946. It should also be noted that the first papers devoted to p–n junctions in germanium and lead sulfide were published in the Western journals only in 1947 (a review of those papers was made in the classical work by W. Shockley [16]). Therefore, although R. Ohl worked independently in the same direction, the priority of V. Lashkaryov in the discovery of a p–n junction isbeyond doubt.

After the war, Vadym Lashkaryov realized a large program aimed at the study of semiconductors. He did it simultaneously at the Institute of Physics and Taras Shevchenko University of Kyiv. Here, he established and headed (in 1952–1957) a powerful Chair of Semiconductor Physics (later, the Chair was headed for more than 20 years by his disciple Vitalii Strikha (1931–1999), the creator of the general theory of contact metal–semiconductor and one of the pioneers of the development of sensorics in Ukraine). In 1960, on the basis of the Department of Semiconductors of the Institute of Physics, a new Institute of Semiconductors of the Academy of Sciences of the UkrSSR was organized. V. Lashkaryov was the director of this institute over the next decade, and today the institute is named after him. The works of Academician Lashkaryov found a wide practical application in electronics, automatics, telemechanics, and computer facilities.

The development of semiconductor science in Ukraine is associated with the names of experimenters V.I. Lyashenko, P.G. Borzyak, O.V. Snitko, M.P. Lisitsa, B.O. Nesterenko, M.K. Sheinkman, L.I. Datsenko, E.A. Salkova, D.G. Semak, G.A. Shepelskyi, V.V. Ilchenko, P.I. Baranskyi, S.V. Svechnikov, V.F. Machulin, V.G. Litovchenko, O.E. Belyaev, M.Ya. Valakh, V.S. Lysenko, P.F. Oleksenko, S.M. Ryabchenko, F.F. Syzov, M.L. Dmytruk, and V.A. Smyntyna, and theorists S.I. Pekar, K.B. Tolpygo, K.D. Tovstyuk, M.F. Deigen, I.M. Dykman, E.I. Rashba, P.M. Tomchuk, V.O. Kochelap, I.I. Boiko, Z.S. Gribnikova, F.T. Vasko, and many other first-rank scientists. The story of the development of semiconductor physics in Ukraine can be read in more details in book [17].

10. Instead of Conclusion: What's Next?

On the basis of a brief review of experimental facts and theoretical hypotheses, we have demonstrated how a new field of knowledge, the semiconductor science, was formed at the beginning of the 20th century. The concept of semiconductors as a separate class of materials was accurately formulated for the first time in 1914 by J. Königsberger on the basis of his original hypothesis about the "dissociation mechanism" of conductivity. Even for that only, the scientist deserves our grateful memory. In the second half of the 20th century, the development of semiconductor science and technology invoked a true scientific and technical revolution, which considerably expanded human capabilities.

However, sooner or later, every science passes through a stage of "exhaustion". This also concerned the semiconductor physics, where – after the development of the band theory and the theory of impurity states, the profound study of charge carrier transport and optical transitions in basic semiconductor materials, the creation of technologies for fabricating highly pure materials with prescribed properties for semiconductor electronics – the main fundamental problems seemed to have already been solved, and only some important, although unessential in principle, details remained to be specified.

However, the creation of nanosystems, where the motion of charge carriers is quantized in principle, and the appearance, in addition to the traditional "charge electronics", of spintronics, where the spin projection rather than the charge is transferred, gave a powerful impetus to the seemingly "traditional" branch on the verge of the new millenium. An additional stimulus was associated with the requirements in the development of photovoltaics and sensorics. According to the prognosis of experts, the former can make an important contribution to the solution of mankind's energy problems and provide a steady ecologically safe progress [18]. On the other hand, only the sensors can answer, in the real-time mode, thousands and thousands of questions that the life puts to the humanity. A number of interesting fundamental and applied problems were formulated while developing radiators and detectors in a new terahertz wave band. The mainstream of ideas in semiconductor physics also includes a lot of problems set by a new physics of graphene [19]. This branch rapidly develops after the first carbon monolayer was obtained in 2004 and has already resulted in the appearance of a variety of other similar materials, such as molybdenum borate, silicene, germanene, and others.

Unfortunately, a tremendous obstacle for the development of semiconductor science in Ukraine is the ugly state of the resource-consuming national economy based on outdated technologies, the actual death of Ukrainian microelectronics, and the absence of domestic customers for works in many hi-tech directions. This problem has a beyond-science character and can be solved only by the joint efforts of politicians, businessmen, and the whole society.

Therefore, the celebration of the centennial of semiconductors gives us one more opportunity not only to recall the glorious pages of the history (as such, they are important for contemporary and future researchers), but also to resume the public discussion on the role of science and high technologies in the contemporary Ukraine. For this purpose, it is necessary that the unnoticed anniversary will attract attention. This is the aim of this paper and work [20], where Vadym Lashkaryov's priority in the discovery of a p–n junction is revealed for the first time for a wide European physical community.

To summarize, the author wishes to dedicate this paper to the blessed memory of his father, one of the pioneers of semiconductor science in Ukraine, Vitalii Illarionovych Strikha, as well as to all researchers from that excellent heroic generation, who began to study a new mysterious class of materials, semiconductors and managed to appreciably change the face of the mankind.

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СТОРІЧЧЯ
НАУКИ ПРО НАПІВПРОВІДНИКИ:
ВИТОКИ І УКРАЇНСЬКИЙ ВНЕСОК

Р е з ю м е

Дано огляд експериментальних фактів та теоретичних гіпотез, які на початку XX століття привели до появи нової галузі знань – науки про напівпровідники. Показано, що поняття про напівпровідники як окремий клас матеріалів уперше чітко сформулював Йоганн Кенігсбергер (1914 р.) на основі оригінальної гіпотези про "дисоціативний механізм" провідності. Продемонстровано пріоритет українського вченого Вадима Лашкарьова у відкритті p–n-переходу, що лежить в основі приладів сучасної електроніки.