Achievements in physics in Azerbaĭdzhan

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The roots of scientific thinking in Azerbaĭdzhan extend into the distant past. Research shows that during the period of the first state of Manny in the territory of Azerbaĭdzhan in the IX–XIIth centuries before our era, the Manneens had their own written language. In northern Azerbaĭdzhan, a script based on the Albanian alphabet was created in the fifth century. Later, the Arabic script was adopted. This made possible broad contact with the achievements of science, literature, and culture of that time. Thus, in the XIth century, Khabib Tebrizi, the philospher Bakhmanyar, the astronomer Fazil' Fariêddin Shirvani, the architect Adzhemi and others worked in Azerbaĭdzhan.

In the XIIIth century, Muhammed Nasireddin Tusi, who founded spherical trigonometry and in 1259 created the world-renowned Maragin Observatory, worked in Azerbaĭdzhan.

Science progressed further in Azerbaĭdzhan through the work of scholarly philosphers and thinkers, such as A. Bakikhanov, M. F. Akhundov, and G. Zardabi.

The Azerbaĭdzhan State University was opened in 1919 and later the Polytechnical Institute was opened.

Work on electrolysis in solids, magnetism, and the study of the thermal properties of petroleum products began in the 1920s under the direction of K. D. Sinel'ni-

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After the creation of the Azerbaĭdzhan Branch of the Trans-Caucasian Affiliate of the USSR Academy of Sciences (1932) and the Azerbaĭdzhan Affiliate of the USSR Academy of Sciences (1935), investigations started on the physical properties of petroleum, molecular physics, spectroscopy, and the thermal and electrical properties of semiconductors. During this period, Academician A. F. Ioffe undertook a number of measures to provide the physics division of the Azerbaidzhan Branch of the Trans-Caucasian Affiliate of the USSR Academy of Sciences with scientific equipment and to determine the direction of research in the republic.

The Academy of Sciences of the Azerbaĭdzhan SSR and the Institute of Physics and Mathematics, whose creation predetermined further development of fundamental and applied research, were organized in 1945.

Four scientific paths determined the development of physics research in Azerbaĭdzhan: solid-state physics, radio physics, nuclear physics, and the physicotechnical problems of power engineering.

Considerable progress has been achieved in the physics of semiconductors, progress in which has an appreciable effect on the development of new nontraditional sectors of engineering in Azerbaĭdzhan: microelectronics, computer technology, construction of instruments for space medicine, biology and geophysics, etc.

One of the first semiconducting materials used in technology is selenium, whose physical properties were studied by scientists in Azerbaĭdzhan.

Working on obtaining selenium, new binary, ternary, and more complicated chalcogenides and the complex study of their physical properties is being conducted on a broad front in the republic.

Fundamental research on selenium established that the physical processes occurring in selenium and instruments based on it are related to the structural characteristics of selenium, and the purity and specific aspects of its crystallization. The scientists at the Institute of Physics of the Academy of Sciences of the Azerbaĭdzhan SSR showed that when the real polymer structure of the smearing of the zone boundaries, caused by the disorder in the structure, as well as the interaction of impurities with one another and with atoms of the main lattice are taken into account, it is possible to explain practically all physical and physicochemical processes observed in different modifications of selenium.

Among a large class of materials obtained and investigated by scientists in the republic, semiconducting compounds with a strongly anisotropic crystal lattice structure occupy a special place: layered ($\varepsilon = $GaSe, GaS, InSe, GaTe) and chain-like (TlSe, TlS, InTe, $TlInSe_2$, $TlGaTe_2$, $TlInTe_2$) crystals of the group A^3B^6 and layered chalcogenides based on them (compounds of the group $A^3B^3C_2^6$–$TlGaS_2$, $TlGaSe_2$, $TlInS_2$).

Interest in the physical properties of these compounds is due to the characteristics of their crystalline structure.

A strong chemical bond of the covalent, ionic, or mixed type predominates in the lattices of such compounds within each layer, while the weak van der Waal's bond is most significant between neighboring layers.

Layered semiconductors have attracted our attention in connection with the search for two-dimensional states in real crystals. The presence of weak interlayer bonds makes it possible to regard the layers as isolated gigantic two-dimensional quasimolecules and to examine the physical properties of the crystal describing it by the layer symmetry. This permits regarding the crystals as typically molecular ones, and viewing the interlayer bond as some perturbation leading to splitting of intralayer states (for example, phonon states) into a number of components which are a multiple of the number of layers in the unit cell (Davydov doublets).

The first layered material whose properties were studied in the republic was gallium selenide, whose unit cell consists of four sublayers of atoms, alternating in the sequence anion-cation-cation-anion.

Investigations of the electronic spectrum of ε-GaSe were begun with measurements of the Faraday effect in the region of excitonic absorption in weak fields in the orientation $E \perp C$. The relaxation times, corresponding to the exciton level, were determined and the values of the effective g-factors as well as the values of the g-factors of the valence and conduction bands were obtained. The dispersion of the index of refraction near the first exciton absorption line was studied (using Rozhdestvenskiĭ's method of "hooks") and it was established that anomalous dispersion occurs near this line.

Research concerned with establishing the relation between the structure of layered and chain-like semiconductors and their optical and nonlinear properties was also successful.

Features related to the excited states of straight free excitons were discovered in the luminescence and photoconductivity spectra of ε-GaSe. It was shown for the first time that the hot luminescence, observed at 2 K and optical excitation densities $p < 1$ kW/cm^2, is due to scattering of free excitons by lattice defects. The experimental data on exciton states of layered crystals of the group A^3B^6 were analyzed on the basis of the theory of anisotropic (in the limiting case "two-dimensional") Wannier excitons. It was shown that the spectrum of exciton states with $K = 0$ is completely described by the "three-dimensional" serial dependence. The splitting of exciton absorption and luminescence spectra in ε-GaSe crystals was observed and investigated for the first time. This work established that the doublet nature of excitonic spectra is a spectral manifestation of the weak interaction between layers.

Complex theoretical and experimental investigations of gallium selenide showed that in spite of the strong anisotropy of the crystalline structure (layered structure) and of the mechanical properties, two-dimensional states are not realized in this compound.

The continuation of the search for two-dimensional states in real crystals led to the prediction and manufacture of new layered crystals, an isolated layer of which, with thicknesses smaller than those in GaSe, contains a larger number of atomic planes with an ionic bond between layers.

Investigations of electron spectra of complex chalcogenides of the group $A^3B^3C_2^6$ with an ionic bond between the layers led to the experimental observation of two-dimensional electronic states in them at the band edge,

The characteristics of the optical properties and vibrational spectra, due to the strong anisotropy of the crystalline structure of layered and chain-like crystals, were brought out. Work is being performed on the influence of hydrostatic pressure on the Raman light scattering spectra (RLS) and on the fundamental absorption spectra. It has been established that the spectrum of optical phonons in layered and chain-like crystals of the groups A^3B^6 and $A^3B^3C_2^6$ is characterized by the presence of low-energy interlayer (interchain) phonons, whose Gruneisen mode parameters are one to two orders of magnitude greater than the values of the Gruneisen mode parameters for intralayer (intrachain) vibrations. It was shown that the hydrostatic pressure increases the anisotropy of the elastic interaction constants in layered crystals belonging to the group A^3B^6.

A series of experiments was performed on IR spectroscopy of layered and chain-like crystals of the group A^3B^6. The effect in these compounds of oblique incidence of the exciting light on the surface was observed investigated, and explained in experiments on IR reflection in the band of residual rays. It was shown that the fine structure of the reflection spectra is not related to the Davydov splitting of IR active phonons, but arises as a result of the not strictly normal incidence of light on the crystal.

Phase transitions under hydrostatic pressure were discovered in ternary chalcogenides belonging to the group $A^3B^3C_2^6$. The nature of the transitions was established.

Investigations of the vibrational spectra using the methods of optical spectroscopy and the methods of optical spectroscopy under pressure made possible a unique identification of the different polytypes of layered compounds, whose results agree with data from x-ray structural analysis. As an example, it was established that gallium selenide crystals, grown by Bridgman's method, belong to the noncentrosymmetrical space group D_{3h}^1.

The electrical and photoelectrical properties of layered semiconductors of the group A^3B^6 in strong electric fields (up to 10^6 V/cm) were studied. The effect of switching along and across layers was observed and explained. As a result, switching devices, operating over a wide range of temperatures, were created.

The electret and photoelectret effects were first discovered in these compounds. These effects permit forming the potential relief of an image and creating apparatus for obtaining a video signal.

Ultrathin single-crystalline films of layered compounds with a thickness less than 100 Å have been obtained. It has been shown experimentally that the exciton binding energy increases in thin gallium selenide films with thicknesses less than 50 Å. This is explained within the framework of the model of increased Coulomb interaction in thin films.

The physical properties of layered compounds are also being studied by methods of Mössbauer spectroscopy. The anisotropy of the chemical bonds in crystals of ε-GaSe and GaS was studied by measuring the magnitude of the mean-square displacement of Mössbauer atoms, introduced into the crystal in the form of an impurity, as a function of the angle formed by the direction of the γ quanta relative to the crystallographic axes. Investigations in the temperature range 4.2–300 K established that the Mössbauer spectra of $Ga_{0.98}Fe_{0.02}S$ represent a doublet, for which the ratio of the component intensities changes with temperature. As the temperature decreases, the asymmetry decreases, which is characteristic of the Gol'danskii-Koryagin effect, arising due to the anisotropy of chemical bonds.

Interesting results have been obtained in studying the phase formation and kinetics of phase transformations in thin semiconducting films. The method of kinematic electron-diffraction analysis was first assimilated in our country at the Institute of Physics of the Academy of Sciences of the Azerbaĭdzhan SSR.

A multi-user computer system is successfully being used at the Institute of Physics by scientists in the republic for calculating energy spectra of layered and other crystals with the help of an ES computer.

A series of theoretical and experimental works was performed on narrow-band semiconductors (HgCdTe, PbSnTe, Ag_2Te and others). These investigations were stimulated primarily by the application of the materials indicated above in IR technology.

The successful development of fundamental investigations in the area of solid-state physics stimulated the development of work in the republic on semiconductor and quantum electronics, using layered crystals as the active media.

The generation regime with "longitudinal" (relative to the C-axis) and "transverse" pumping by an electron beam was obtained for the first time in ε-GaSe. These results showed the fundamental possibility of creating a quantum generator in the "emitting mirror" geometry. The maximum of the stimulated radiation spectrum was observed to shift toward longer wavelengths with an increase in the pumping current density. This is related to exciton-exciton collisions.

In 1972, a group of staff members at the P. N. Lebedev Physics Institute of the USSR Academy of Sciences and at the Institute of Physics of the Academy of Sciences of the Azerbaĭdzhan SSR were the first to demonstrate the possibility of using ε-GaSe crystals as an efficient nonlinear optical material. CO and CO_2 laser radiation was experimentally converted in ε-GaSe into the range of sensitivity of the photocathode of an electrooptical converter when mixed with radiation from the YAG: Nd^{3+} laser and the lasing spectrum of the CO_2 laser was recorded on photographic film.

An apparatus for rapid extraction of 16 digit alphanumerical information on ordinary dry paper, using standard dyes and having a printing rate of 100 lines per second, was developed at the Institute of Physics. Software for controlling the operation of the developed apparatus was also produced.

The possibilities of practical application of layered crystals belonging to the group $A^3B^3C_2^6$ were also demonstrated. A piezophotoresistive effect, i.e., an increase in the sensitivity of conductivity to deformation under laser excitation, was observed in these compounds. X-ray radiation detectors, distinguished by their high sensitivity (up to 1 μA/R · min) and low inertia (10^{-2} s) were also developed.

Together with compounds with strong anisotropy of the crystal structure, strongly degenerate semiconductors belonging to group A^IB^{VI} with a certain amount of ionic conductivity are also being studied. In MIS tunnel structures based on these compounds, a polarity dependent multistable switching with memory, due to reversible modulation of the tunnel barrier by mobile ions, was discovered. A reprogrammable permanent memory with a capacity of 4 K was created based on this effect.

Scientists in the republic are also obtaining and studying magnetic semiconductors (analogs of $CdSr_2Se_4$), defective gallium and indium sesquisulfides and selenides, semimetals (As, Sb, and their solid solutions), Ge, Si, Se, Te, thermoelectric materials, semiconductor-metal composite materials (of the type InSb-NiSb), and others materials. Various thermoelectric devices and apparatus, based on these compounds, are being made in experimental production at the Institute of Physics.

Research in the area of gas radiospectroscopy of molecules has grown. The existence of previously unknown infraweak intramolecular hydrogen bonds was predicted and demonstrated experimentally; a complex of computer programs for ES class computers has been created and put into use for the purpose of automating the interpretation of MV rotational spectra, determination of spectroscopic, electric, and structural parameters, and configurational characteristics of polyatomic molecules.

In the area of nuclear physics, research on the interaction of hadrons and antineutrinos with nuclei is being conducted together with the Joint Institute of Nuclear Research (Dubna) and the Institute of High-Energy Physics (Serpukhov). The mechanism responsible for the creation of cumulative protons has been established and their contribution to different kinematic regions has been identified.

The resolutions adopted at the XXVI Congress of the Communist Party of the Soviet Union devote a great deal of attention to the development of powder metallurgy in our country. The program on powder metallurgy is among 41 goal-oriented complex scientific-technical programs of the XIth Five-year Plan, encompassing the solution of urgent problems of paramount importance to the state.

Powder metallurgy is also given a prominent place in the resolutions adopted at the XXXth Congress of the Communist Party of Azerbaĭdzhan.

The scientists of our republic, working together with the Institute of Problems in Materials Science of the Academy of Sciences of the Ukrainian SSR, are investigating the technology for atomizing metals in order to obtain powders with a definite composition. The methods of self-propagating high-temperature synthesis are used to prepare powders of refractory compounds Nb, Si_3N_4, AlN, B_4C, TiC, and others. Abrasive pastes, replacing extremely scarce diamond pastes, are obtained from titanium carbide powders. Boron nitride (wurtzite) is being produced. Instruments made from this material are replacing diamond instruments. A batch of crucibles based on silicon nitride for melting noble and refractory metals has been produced.

All these achievements are a vivid expression of the great collaboration between the physicists of Azerbaĭdzhan and the scientists of our multinational country.

Translated by M. E. Alferieff