PACS numbers: **01.65.+g**, **42.55.−f**, **42.62.−b**
DOI: 10.1070/PU2004v047n10ABEH001911

Development of laser physics in Belarus

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A start on research in the area of quantum electronics[1] in Belarus was made immediately after the advent of the first laser in 1960. As early as in 1961 B I Stepanov et al. published papers on the theory of lasing [1 – 3]. In 1963 V A Pilipovich put into service the first ruby laser in Belarus and this marked the beginning of experimental investigations in this field. Within two or three years, the problems of laser physics and nonlinear optics came to the forefront on the agenda of the Institute of Physics of the Belorussian Academy of Sciences.

From their very inception these investigations were pursued along an extended frontier. In this case, the emphasis was on the problems of achieving lasing under various conditions, the search for new laser media and ways of improving the efficiency of lasing, and the investigation of nonlinear optical effects such as stimulated Raman scattering, harmonic generation, frequency summation, etc.

It is pertinent to note that the fast entry of the Institute of Physics into the laser research area was largely facilitated by the fact that even in the prelaser period B I Stepanov and his disciples had developed methods and approaches which proved to be perfectly suited for calculating the energy and time characteristics of many laser types. In particular, Stepanov and V P Gribkovskiĭ [4 – 6] in their works on the theory of light absorption and luminescence derived relationships which describe these processes with an account for stimulated emission and their nonlinear dependence on the power of incident radiation. In 1958 A P Ivanov [7] showed that the coefficient of light absorption by complex molecules may become negative in some frequency range under strong irradiance, i.e., an absorbing medium may turn into an amplifying one.

In the 1960s, research and development on laser physics in Belarus was entirely concentrated in the Institute of Physics. More recently, it has also been started in other institutes of the Academy of Sciences and in universities, primarily when groups of staff members of the Institute of Physics have changed their place of employment. In the 1970s, the Belorussian Optico-Mechanical Association (BelOMA) launched the serial production of laser engineering devices developed in the S I Vavilov State Optical Institute. Until that time, lasers had been manufactured only in the Special Design Bureau and Pilot-Scale Production at the Institute of Physics (presently the 'Aksikon' Special Design Bureau) primarily for the needs of the institute. In 1979, an Interagency Design Office (presently the LEMT research and production enterprise) was established at the 'Peleng' Central Design Bureau of BelOMA. The Office's main destination was transferring to BelOMA the results of research and development at the Institute of Physics. The year 1984 saw the commissioning of the big Minsk Experimental-Industrial Enterprise (MEIE) of the USSR Academy of Sciences (presently the 'Optron' Instrument-Making Factory). One of its main functions was the small-lot production of the laser systems and instruments developed in the institutes and design bureaus of the Belorussian Academy of Sciences and other USSR organizations. Before long, this factory launched the production of lasers, components, and laser engineering systems elaborated in the Institutes of Physics and Electronics of the Belorussian Academy of Sciences, as well as in the General Physics Institute of the USSR Academy of Sciences. It is noteworthy that an important part in the organization of laser industry in Belarus was played by N A Borisevich (at that time President of the Belorussian Academy of Sciences) and V S Burakov (as Deputy Director of the Institute of Physics and later as Director of the MEIE of the USSR Academy of Sciences).

During the period preceding the onset of perestroika in the USSR, research and development in the field of laser physics in Belarus advanced rapidly and the research area was progressively broadening. As a rule, the research and development work was integrated in major All-Union Programs and was pursued in close cooperation with scientific and production organizations outside of Belarus. Before long, a substantial scientific and technical potential was accumulated in Belarus in the area of laser physics, much scientific brainpower was trained (and not only for Belorussian organizations), and well-known scientific schools were formed. Belorussian scientists and engineers made a large contribution to the solution of numerous problems in laser physics, the development and practical application of laser devices, and the formulation of some foundations of this rapidly developing area of knowledge. Their achievements were marked with many scientific prizes and state awards.

The organizing of the many All-Union and international conferences either in Belarus or with the participation of Belorussian organizations, as well as the hosting of away sessions of the Council on Coherent and Nonlinear Optics of the USSR Academy of Sciences in Belarus, attests to the high level of work and energetic involvement of Belorussian scientists in the areas of laser physics and nonlinear optics. It has been generally recognized that the All-Union Conferences on Coherent and Nonlinear Optics (CNO) have played an important role in the development and coordination of research on laser physics and nonlinear optics in the USSR. These conferences have their origin in the Symposium on Nonlinear Optics organized by the Institute of Physics of the Belorussian Academy of Sciences on the picturesque bank of Naroch' Lake in 1965. The Symposium listened to the first review of the current state of laser physics and nonlinear optics in the USSR and, what is very important, a standing committee was formed for the organization of subsequent conferences and the coordination of research in the field of laser physics in the USSR. The committee was headed by R V Khokhlov, at that time Head of a Chair at Moscow State University. A short time later, the committee established on Naroch' Lake was officialized as the Scientific Council on Coherent and Nonlinear Optics at the USSR Academy of Sciences. It regularly organized International Conferences on Coherent and Nonlinear Optics (the ICONO conferences) in the USSR, which became a major and highly prestigious international forum in the area of laser physics. These conferences continued after the disintegration of the USSR. Three of them, the 6th, the 13th, and the latest, the 17th, which was held in 2001, were organized in Minsk. Also held in Belarus at different times were three All-Union Conferences on Dye Lasers, six Conferences-Schools on Dynamic Holo-

[1] The term 'laser physics' came into wide use in the 1970s. Until that time, laser physics had not been recognized as a scientific area in its own right and a laser was, as a rule, referred to as an optical quantum oscillator (or simply an OQO).

graphy, International Conferences on Ultrafast Process Spectroscopy (UPS-1983) and on Laser Applications in Life Sciences (LALS-1994), 10 Conferences (the last three in 2000, 2002, and 2004 being international) on Quantum Optics.

In the Soviet period of laser physics research, scientific and technical innovative projects and the production of laser instruments in Belarus were financed primarily from All-Union sources. That is why, with the disintegration of the Soviet Union and the disruption of the common scientific-technical field of the USSR, the Belorussian organizations involved in laser research and development found themselves in a very difficult position. In the early 1990s, the manufacture of lasers, laser systems, and components sharply decreased or completely terminated, and business connections between Belorussian and Russian organizations deteriorated substantially. Nevertheless, owing to measures taken by the leaders of the Republic of Belarus, the previously accumulated potential in the area of laser physics was largely retained and gradually accommodated to work under the new conditions. Here, an important part was played by the organization of scientific and scientific-technical programs in Belarus, wide use of grants from international foundations (INTAS, ISTC, and so forth), widening of scientific ties with remote foreign countries, and the emergence of small enterprises for the manufacture of laser instrumentation. A partial reestablishment and revival of the creative cooperation between Belorussian and Russian organizations in the field of laser physics has undoubtedly been fostered by the execution of the 1998 – 2000 Russian – Belorussian Program 'Laser Technologies of the 21st Century', which was financed from the Russia – Belarus Union budget and grants from the Russian and Belorussian Foundations for Basic Research.

At present, research and development in the area of laser physics and practical applications of laser devices is carried out at the B I Stepanov Institute of Physics (IP), the Institute of Molecular and Atomic Physics (IMAP), the Institute of Electronics (IE), the Institute of Solid-State and Semiconductor Physics (ISSP), the Institute of Applied Optics (IAO), and the Physicotechnical Institute (PTI) of the National Academy of Sciences of Belarus; the Belorussian, Grodno, and Gomel' State Universities (BSU, GrSU, and GSU), the Institute of Advanced Training (IAT), the International Laser Center at the Belorussian National Technical University, and the Research Institutes for Applied Physical Problems (IAPP) and Nuclear Problems (INP) at BSU. Lasers and laser-based instruments are designed and manufactured by the state enterprises LEMP BelOMA, KBTM-OMO, and the 'Optron' Instrument-Making Factory; the 'Aksikon' Special Design Bureau of the National Academy of Sciences of Belarus; the 'Peleng' corporation and the scientific-production companies LOTIS-TII, SOLAR-TII, SOLAR-LS, 'Lyuzar', 'Golograficheskaya Industriya' ('Holographic Industry'), and others.

For completeness of the picture we give a brief list of the most significant and outstanding results obtained by Belorussian scientists and engineers in the field of laser physics.

Historically, the first such result is the development of techniques for engineering calculations of the energy and time characteristics of spike-mode and single-pulse lasers. The results of the work in 1965 – 1968 were summarized in the two-volume edition *Metody Rascheta Opticheskikh Kvantovykh Generatorov* (Methods of Calculating Optical Quantum Oscillators) [8], which before long became a handbook for laser design engineers.

In the mid-1960s, the search for new laser media was crowned with the discovery of lasing of organic dye solutions [9] in the Institute of Physics. A short time later, a variety of lasers with a continuously tunable frequency were realized, including lasers with pump-induced distributed feedback (DF), a holographic DF laser which makes it possible to obtain narrow-band coherent radiation for broadband pumping, and a traveling-wave DF laser, which transforms nanosecond pump pulses to picosecond-long pulses tunable in frequency. Although continuous frequency tuning of laser radiation at the present time is easily realized with solid-state lasers, dye lasers have retained their significance.

Lasing was obtained with the vapors of complex molecules [10].

Predicted and practically implemented in the same institute was the oe–e phase matching [11] in harmonic generation (as well as in frequency summation and subtraction), and efficient nonlinear-optical frequency converters were made, based on harmonic generation and stimulated Raman scattering (SRS). In the 1970s it was experimentally shown that these transformations, in combination with dye lasers, make it possible to produce rather intense and high-coherence radiation at any wavelength in the 0.2 – 8 μm range. In recent years, an all-solid-state laser system tunable in the 0.188 – 1.800 μm range was proposed, substantiated, and made; mini- and microchip lasers with intracavity SRS frequency conversion were proposed and realized; and a study was made of the generation as well as conversion of the frequency and other parameters of Bessel light beams.

The physical foundations of dynamic holography were elaborated and holographic methods were proposed for controlling the spatial structure of laser radiation and measuring the physical parameters of different media. The effect of phase conjugation of light beams in four-wave interaction was discovered [12]. This phenomenon is presently widely used to eliminate the phase distortion of a laser beam and concentrate its energy at a specified point. A high-sensitivity holographic thermal conductivity gauge was made (IP).

Laws were established for the propagation of light fluxes through anisotropic waveguides, at the boundaries with amplifying and optically nonlinear media, and in bistable and other nonlinear-optical systems. Technologies were elaborated for the fabrication of elements of integral optics and optoelectronics (IE, IAO, ISSP, IP).

Many laws on the nonlinear interaction between laser radiation and resonance media (gases, solutions, semiconductors, quantum-dimensional structures, etc.) were revealed and new nonlinear spectroscopy techniques were developed on this basis. These techniques enabled us to obtain information on the structure and processes in the microenvironment of resonance centers and measuring the parameters of laser and nonlinear-optical media (IP, IMAP, BSU, IAPP, ILC).

Unique spectrometers (pico- and femtosecond, spectrometers of coherent anti-Stokes scattering, intracavity spectrometers, etc.) were developed and implemented, making it possible to carry out high-sensitivity measurements with a high spectral and temporal resolution. They were employed to study many energy exchange and interaction processes in complex molecular structures, including biologically significant ones, in plasmas, activated crystals, etc. (IP, IMAP, BSU, IAPP, ILC).

Methods were elaborated for laser probing of atmospheric aerosol pollution. In the 1980s, the Institute of

Physics participated as directing agency in the establishment and organization of the work of a system of lidar stations for the monitoring of stratospheric aerosol, comprising stations in Minsk, in Obninsk, at Issyk-Kul' Lake, in Poland, and in Cuba. At present, the lidar station of the Institute of Physics, which is equipped with different-type lidars, is part of the system for monitoring the atmosphere of the European region. Planned together with Russian organizations is the development of a lidar network in the Commonwealth of Independent States, which is additionally intended to unite the networks of Europe and South-East Asia, including Japan.

The problems of various applications of laser radiation have always been a major preoccupation of Belorussian scientists and experts. This is primarily the development and introduction of methods, devices, and facilities that employ lasers in research, industry, construction, defense technology, and other areas.

The staff members of the Institute of Physics and several republican medical institutions performed a vast complex of investigations to elucidate the properties of the therapeutic and biostimulating action of laser radiation of different wavelengths and intensity. On this basis, the 'Aksikon' Special Design Bureau and the 'Lyuzar' Co. developed and manufactured a series of therapeutic laser facilities for the treatment of jaundice in newborns and of dermic, intracavitary, and other diseases in virtually all republican clinics and hospitals.

Belorussian physicists and physicians conducted, together with their Russian and Ukrainian colleagues, thorough investigations into the mechanisms and characteristics of the action of laser radiation on eye tissues. The resultant data underlay the development of several treatments for eye diseases and were used to frame safety limits in laser handling, which were established in the USSR shortly before its disintegration. At the present time, the LEMT state enterprise, with the participation of the Institute of Physics, has developed and certified production prototypes of a laser transscleral and other ophthalmocoagulators for clinical use.

Furthermore, LEMT developed and launched the production of several other laser devices and facilities for different medical purposes, as well as laser range finders, levels, triangulation displacement meters, sights, etc.

At KBTM-OMO of the 'Planar' trust and the 'Peleng' corporation, lasers are used to advantage in production which is much in demand abroad. At 'Planar', lasers are extensively used in the complexes elaborated and produced for the fabrication of integrated circuits; at 'Peleng', lasers are used successfully in defense technology (laser target designators and sights, guidance devices, etc.).

Several republican organizations develop and employ laser technologies for processing different materials. At PTI, IMAP, and the 'Aksikon' Special Design Bureau in collaboration with IP, automated laser facilities were made for the programmable cutting of different materials, drilling, and component strengthening; at IP, the 'Aksikon' Special Design Bureau, and GSU, technologies and instrumentation are elaborated for welding dissimilar materials and tooth replacement; at IAO for the metallization of ferrite articles; and at IAPP and the 'Planar' trust for the processing of superhard materials, including diamonds. At LOTIS-TII, pilot facilities were made for laser volume engraving and the laser marking of teflon-insulated wires.

At the Institute of Physics, technologies were developed and a facility was made for laser cleansing of the surfaces of art works of metal, stone, wood, and parchment. In the framework of an ISTC project, this facility was exported to Greece for the cleansing of antique sculptures and other monuments of antique culture.

A range of lasers have been developed and are manufactured on demand from different organizations in Belarus, Russia, Japan, Germany, and other countries. Among these products are a range of Nd : YAG lasers which generate radiation at different frequencies, including the fifth harmonic; continuously tunable forsterite and titanium:sapphire lasers; erbium and holmium lasers, various nonlinear-optical frequency converters; two-pulse lasers with an adjustable interpulse time; as well as different laser components. It is significant that the majority of output laser sources can be fed from the single-phase alternating-current mains, include a self-contained unit for cooling the working element, possess relatively small dimensions, are simple to control with the aid of a remote panel and (or) a computer, and exhibit a high stability of the generated radiation parameter. At the same time, they are capable of providing output pulses with a relatively high energy (hundreds and dozens of millijoules) throughout wide ranges of other parameters (LOTIS-TII, SOLAR-TII, SOLAR-LS, LEMT, 'Aksikon' Special Design Bureau).

In summary, let us hope that the cooperation between Belorussian and Russian organizations in the field of laser physics in the future develops and strengthens more substantially than at present. I am certain that this would be mutually beneficial.

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