ENGINEERING SUPPORT OF FUNDAMENTAL RESEARCH IN ATMOSPHERIC OPTICS: RESULTS OF 25-YEAR ACTIVITY OF THE DESIGN AND TECHNOLOGY INSTITUTE "OPTIKA"

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This paper is a historical review of the 25-year activity of the Design and Technology Institute "Optika," Siberian Branch of the Russian Academy of Sciences. Presented are brief descriptions and specifications of equipment designed at the Institute for research in atmospheric optics that have been implemented in practice and even produced in small series: laser navigation systems; ground based, airborne and spaceborne lidars; devices and systems for ecological and meteorological monitoring of the atmosphere; optical devices and parts. Specification of the devices developed at the Institute are compared with that of similar devices produced in the world.

INTRODUCTION

In recent decades the atmospheric optics more and more rapidly transforms from the traditional section of Earth sciences into one of powerful section of physico-technical science. This new positions of atmospheric optics research are not only the result of successful fundamental investigations having covered the way from phenomenological description to rigorous physico-mathematical description of optical properties, processes, and phenomena in the Earth's atmosphere.[1] These new positions result equally from a wide practical use of optoelectronic and laser systems, in which the interaction of optical radiation with the atmosphere causes the appearance of both high informative signals in optical sensing of the atmosphere[2] or atmospheric optical noise accompanying optical signal transfer through the atmosphere.[3]

Some problems in the atmospheric-optics research are considered in Ref. 4 as well as in reviews published in this issue. They mainly deal with research foundations (what should be observed) and techniques and technology (in what way it should be observed). Very important is also instrumentation (with which devices it should be observed). Pilot experimental setups for observing atmospheric optical phenomena constructed in the process of fundamental scientific research play a twofold part: on the one hand, they are instruments for perceiving and, on the other hand, they are prototypes of new devices.

Instrumental observations of atmospheric phenomena are conducted for more than three centuries, and by the present century main measuring devices were thermometer invented by Galilei and Torricellian mercury barometer.[5] At present, instrumentation for meteorology and environmental monitoring is dramatically updated, and most promising is new instrumentation based on effects of interaction between the atmosphere and electromagnetic fields of an optical range, as well as acoustic waves.[4]

The main goal of the Design and Technology Institute "Optika" SB RAS is the development and construction of new remote and contact methods, devices, and complexes for both fundamental research in atmospheric optics and meteorological and ecological monitoring of the environment. Below we present the results of 25-year Institute's activity in this field.

1. HISTORICAL BACKGROUND

In January of 1997 there was 25th anniversary of the Design and Technology Institute "Optika" SB RAS (DTI "Optika"), for 20 years it was called Special Design Bureau of Scientific Instrument Engineering "Optika" (SDB SIE "Optika"). By the initiative and due to great persistence of Academician V.E. Zuev, Permission of the Soviet of Ministers of the Russian Federation No. 8898–070 July, 14, 1971, and then Resolution of the Presidium of Siberian the Branch of the USSR Academy of Sciences No. 341 of October 15, 1971, were prepared and issued. It was noted in these documents that "for further development of works in designing instrumental complexes for fast and remote of acquisition of the atmospheric parameters using laser sources and in order to enhance the efficiency and implementation, into national industry, of the results obtained at Institutes of SB AS of the USSR and other research institutions it was decided to organize the Special Design Bureau for Scientific Instrument Engineering "Optika" beginning from January 1, 1972. The Bureau was planned to be self-funded under the scientific supervision of the Institute of Atmospheric

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Optics. On March 1, 1992, according to the Resolution of Presidium of SB AS of the USSR No. 60 from 02.25.92 SDB SIE "Optika" was transformed into Design and Technology Institute "Optika" being a part of the Joined Institute of Atmospheric Optics SB RAS.

In its early period (1972–1973) the Bureau was headed by Vladimir D'yakov, and the next two years by Boris Savel'ev. Along with hiring the staff and developing the leased production areas this period was devoted to design and construction of the first pilot setups as well as the first experimental instrumentation complexes for fast measuring of atmospheric parameters under field conditions. Among the first pilot devices there were nephelometers for studying artificial smog and mists in the chamber and parts of complexes for research in laser spectroscopy.

In 1975 the Bureau started to design and then to build its own production facility of optoelectronic instrument making on the territory of Tomsk Akademgorodok. The forming collective of the Bureau was forced not only to provide equipment for experiments conducted mainly at the Institute of Atmospheric Optics SB RAS, but also to help in building its own specialized production lines and assembling technological sections. In this period Aleksandr Kutelev headed the Bureau (1976–1992).

Only by 1989 the main building-assembling works were completed and simultaneously the production-technological base was developed. By that time in the Institute (the former Bureau) with the staff of 900, the branched infrastructure for conducting experimental and design works has been formed. Organizational structure of the Institute in 1989 included 18 developing subdivisions (300 people), design subdivision (145), experimental production shop (110), departments of experimental pilot device making and optical production (85), department of quality and reliability (15), department of standardization (10) and other departments and supplementary subdivisions. Main directions of work in this period were: automated instrumentation complexes for studying atmospheric effects accompanying laser radiation propagation; lidar systems; laser navigation devices; devices and systems for ecological monitoring; systems for automation of scientific research, data processing, and experiment; microelectronics; metal-vapor and excimer lasers; technology of nonlinear crystal growth; production of optical devices and parts, including large-size optics; technology of optical production control.

In 1990 governmental orders in all branches of experimental and design work at the Institute were dramatically cut. During next two years State funding of governmental orders has entirely stopped, and a lot of employers were dismissed. Only several developing subdivision, becoming independent in wider frame, have passed into related fields, among them development and production of goods.

Under such conditions in 1992 the Siberian Branch of RAS decided to transform the Bureau "Optika" into the Institute "Optika" with a low State funding. Practically at the same time A. Kutelev, the head of the Bureau "Optika", suggested to invite a new director in order to strengthen the Bureau. In November of 1992 Professor Mikhail Kabanov, doctor of Physical Mathematical, corresponding member of the Russian Academy of Sciences, became the director of the Institute. At that time new period had started of searching for new ways in research and production activity of the Institute "Optika".

A search for new forms and contents in the Institute's activity was unavoidable under new economical conditions causing the drop in industrial production and demand for new high-technology instrumentation. The obvious reaction to the demand drop and the following dismissing of employees from the Institute was every-year adaptation of its organizational structure to existing human resources. Most complicated problem the Institute faced with was the necessity of its independent survival, because other institutes faced the same problems and their orders became insolvent. To solve this problem the Institute "Optika" have had

– to expand the independence of subdivisions up to creation of their own bank accounts,

– to organize the small-series production of some devices and technical units having a good demand on market,

– to start conservation small-promising technological sections and attract small enterprises to use at the Institute machinery shop.

At present the search in this direction is continuing. For a more effective use of the Institute scientific potential, priority directions of scientific research have been selected, most important among them is making instruments for ecology and meteorology based on optoelectronic technology. Now the Institute works in close cooperation with enterprises of different ownership. In order to more effectively cooperate with small enterprises, working in the sphere of science and technology and using the industrial and technology base of the Institute, in 1995 the Association "Technotsentr–Akademiya" was registered. This Association, including about 20 small enterprises, as well as the Institute "Optika" and some other academic institutes, is aimed at development of technological park of the Tomsk Akademgorodok.

2. MAIN SCIENTIFIC AND TECHNICAL DEVELOPMENTS OF THE INSTITUTE

2.1. Optical and Meteorological Complexes and Systems

Automated Optical and Meteorological Complexes. In 70ths and 80ths more than adoren of pilot and experimental systems have been designed and manufactured in the DTI "Optika" by orders from IAO and other organization. All these systems both ground based and shipborne were intended for operative monitoring of the atmosphere. These complexes were made in both mobile and stationary versions and were intended for evaluation of optical weather at the place of field tests of new optoelectronic special-purpose systems. One of the first pilot versions of the complex is described in Ref. 6.

Combination of the devices comprising the complex and degree of their automation were determined by the purpose of this complex and the problems it must help to solve. The measurements, necessary for the determination of the profiles of different atmospheric parameters, in most cases required lidar to be included into the complex. To provide additional information such complexes used long path transmissometers for measuring extinction coefficient of the atmosphere and a system for acquiring data on meteorological quantities. In order to determine turbulent characteristics of the atmosphere, the complex included devices for measuring structure characteristics of the atmospheric air refractive index, angles of optical radiation incidence, devices for measuring intensity fluctuations and laser beam spot geometry.

Important part of an automated complex is the device for data processing and control over the work of its parts. The degree of automation of the measurement process and control over independent work of separate devices was determined by the potentialities of then available computers and purposes of the complex. To increase the reliability of determining atmospheric parameters sought, several devices were used that conduct measurements using different physical principles. Specifications of some complexes are also shown in Ref. 7. Optical and meteorological complexes were developed in the department headed by P.P. Vaulin.

Laser Navigation Systems. Along with the optical and meteorological complexes intended for providing tests and use of specialized optoelectronic and laser systems, independent development of industrial laser systems were done at the Institute "Optika" and the Institute of Atmospheric Optics. Among such systems there are laser navigation systems for aeroplane landing and ship navigation through channels and narrow places under severe meteorological conditions.[8,9]

For 25-year period several generations of navigation devices were constructed, including both visual navigation, when the laser beacon beams are detected visually, and the instrumental navigation, when the beams are detected with a photodetector. Most developed are sea and river navigation systems. A great number of different modifications of laser navigation beacons and were created. At the Institute "Optika" these works are conducted in CB–31 headed by V.V. Tatur.

The most recent navigation system developed at the Institute "Optika" is the pilot small-size transit flash bicolor beacon "Raduga M."[10] It uses lasers with the wavelength of 532 (second harmonics of YAG laser) and 633 nm (He-Ne laser). The beacon forms three zones of orientation within channel (waterway): left zone – red flashes; central (transmit) zone –alternation of red and green flashes; right zone – green flashes. By watching these marks, a pilot drives a ship so that both green and red flashes are seen. If flashes take one and the same color, this means that a ship came from the course line into the corresponding side.

In this beacon, in contrast to previous ones, laser beam sweeping in vertical plane is done with cylindrical mirrors, that provides the possibility of creating sweep angle within the limits of 0.5 to 3°. The mirrors are fixed at an axis of scanning devices. With the help of the drives about these axes the sweep in horizontal plane is made in the sector from 0.1 to 3.5° with an error of sustaining horizontal scanning with beams within a channel axis no more than 1 min. of arc. The advantages of laser beam sweep in vertical plane with the help of cylindric mirrors are the following: 1) no need in the second mirror providing vertical sweep and therefore decrease in power losses of optical radiation; 2) no need in the second scanning device that enhances the beacon reliability; 3) better distribution of laser beam power density in the vertical plane. Beacon has the size 400×468×1064 mm and mass of 52 kg.

Laser beacons of the type "Raduga" have been tested in field conditions and have demonstrated their high efficiency under conditions of low visibility, under which usual beacons become invisible. One of the modifications of the laser beacons named "Mars"[9] with autonomous power source for several years was successfully used at the northern sea way (in the ports Igarka, Dudinka, Providenie) at late 80ths. At early 90ths experimental use of a laser bicolor beacon was conducted also at the sea ports of Ventspils and Kerch.

2.2. Lidar Systems

Ground-based lidars. Great attention was paid in the Institute "Optika" to construction of lidars of different purpose, based on different effects of laser radiation interaction with atmospheric constituents (aerosols and gases). In 70ths were developed aerosol lidars based on effects of laser radiation scattering by atmospheric aerosol. This effect is the strongest and, correspondingly, gives the most intense backscattered signal. These lidars are used for determining spatiotemporal variations of aerosol in the near-ground atmosphere, characteristics of clouds and smogs. Their modified versions allow one to measure polarization characteristics of atmospheric scatterers.[11]

The "LOZA" type lidars designed and constructed for scientific research are described in literature in detail.[11–15] In their specifications "LOZA" lidars are well competitive with MARK research lidars from Stanford Research Institute (USA), lidars designed at research centers DFVLR

(Germany), CNR–IROE (Italy) and some Japan Institutes, as well as lidars produced in small series in later 70ths by Impuls Physics GmbH company (Germany).

Using the documentation developed for the of lidar “LOZA–2” a small series of 5 sets were produced. These sets were then delivered to the Institute of Electronics of the Bulgarian Academy of Sciences, Research Institute of Fire Safety, Kemerovo State University, Scientific Production Association “Zenit” of the USSR Ministry of Electronic Industry. The transceiver of “LOZA–3” lidar, similar to the previous version, was assembled a van of radar station SON–9 built around electromechanic drive instead of parabolic antenna. This lidar is described in detail in Ref. 11.

In IAO the modified and improved lidar complex “LOZA”[15] is still operated and provides remote atmospheric measurements in different research programs.

In addition to lidars of “LOZA” series, at the same period several modifications of specialized aerosol lidars have been created, being a part of automated optical and meteorological complexes.[16–18] Requirements to operation conditions of these lidars were determined by corresponding State standards and other standards. All the above-enumerated lidars were developed in the laboratory headed by A.A. Tikhomirov, Candidate of Technical Sciences.

Design documentation for lidars “LOZA–2” and “LOZA–3” in later 70ths was delivered to the Scientific Production Association “Zenith”, where it was used as a base for creation and production, in small series, of aerosol lidars “Elektronika–01,” “Elektronika–03,”[19] and then versatile small-size lidar “Elektronika–06” for measuring profiles of extinction coefficients, atmospheric transmittance and slant visibility range in airports.[20] These lidars used scientific principles of atmospheric sensing developed at the Institute of Atmospheric Optics.

In 80ths specialists from the Institute took part in designing and constructing the transceiving device for high-altitude lidar (mirror diameter of 1.0 m).[21] Their contribution includes calculation of parameters, construction and coating of the mirror itself and the receiving system of the Siberian Lidar Station (diameter of the receiving mirror is 2.2 m).[22]

The most important and complete project of the Institute among lidar systems in early 90ths was design and construction of the receiving system of meteorological lidar.[23] To apply the correlation technique of wind velocity measurement along three directions of sensing separated by 6.5°, the lidar receiving system with the total wide field-of-view of 6.5° receives the backscattered radiation in an instantaneous narrow field-of-view, being several minutes of arc, in the direction of a laser beam, that provides an increase in signal-to-noise ratio for the operation in day-time.

Airborne lidars. Lidar system placed on mobile carriers enable remote sensing of the environment over vast territories, as well the study of local formations in the atmosphere and hydrosphere from short distances. Most attractive are airborne platforms for lidars that have precise navigation instruments and meteorological devices, which provide conducting of accompanying measurements. Detailed review of airborne lidars created in different countries by middle 80ths and intended for sensing the atmosphere and ground covers is presented in Ref. 24.

In the Design and Technology Institute “Optika” in cooperation with the Institute of Atmospheric Optics, several modifications of airborne lidars for remote monitoring of the atmosphere and hydrosphere were constructed in 80ths, among them there are multipurpose lidar “Svetozar–3” developed in early 80ths, lidar “Makrel’–2” for studying cloud fields and the hydrosphere, and lidar M2M.[25,26] Brief descriptions of these lidars are given in Table I. As is seen from the table, in the process of lidar creation, they were permanently improved and their energy potential increased.

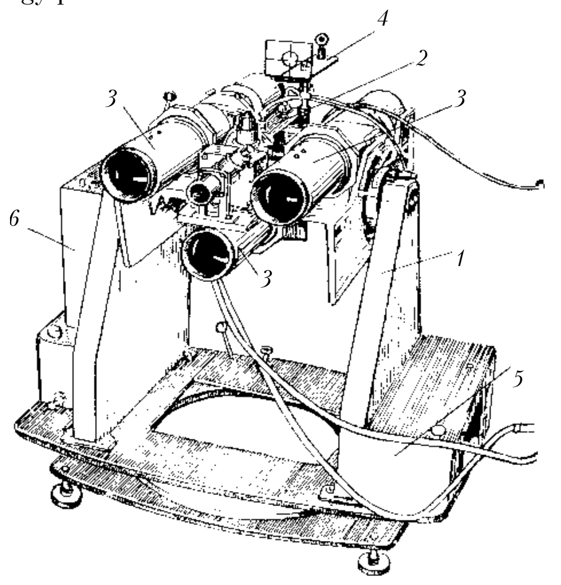

FIG. 1. General view of the transmitter-receiver of a lidar “Svetozar – 3”: console with the zenith drive (1), transmitter (2), receiving optics (3), aiming tube (4), cooling liquid circulator (5), and power supply of the laser (6).

Versatile lidar “Svetozar-3” (Fig. 1) has one transmitter and three identical receiving systems arranged symmetrically around it.[25] The transmitter can emit radiation with different polarization. A wide set of field diaphragms allows studying multiply scattered radiation, it is also possible to set changeable PMT blocks for 532 and 1064 nm. In addition, receiver’s construction provides for simultaneous rotation of analyzer plane and both photodetectors within ±90° depending on the position of the polarization plane of sensing radiation, as well as an additional λ/4 plate can be set in front of the analyzer in one of the receivers. Lidar is multifunctional, i.e. it provides the following measurement modes: 1) determination of Stokes parameters of lidar return at the wavelength of 532 nm at linear and circular polarization of sensing radiation; 2) determination of the degree of linear depolarization of backscattered radiation at the wavelengths of 532 and 1064 nm simultaneously at linear polarization of sensing radiation; 3) determination of the degree of linear depolarization at one of the sensing wavelength and three different field-of-view angles simultaneously.

TABLE I. Specifications of airborne polarization lidars.

Parameter	Measurement unit	Name (date of issue)			
		Svetozar-3 (1981)		Makrel'-2 (1987)	M2M (1989)
Transmitter					
Radiation wavelength,	nm	1064	532	532	532
Output power,	mJ	30	10	70	30
Pulse length,	ns	13	13	13	15
Beam divergence,	mrad	0.8	0.8	1.5	1.0 – 65.0
Polarization of sensing radiation	–	linear (horizontal or vertical)	linear (at any angle) right-handed or left-handed	linear	linear
Receiver		Lens objective (three receiving systems)		Lens objective	Lens objective
Polarization channel					
Diameter,	mm	100		150	200
Focal length,	m	0.5		0.5	0.75
Field-of-view,	mrad	2; 3.16; 5.02; 16.0; 20.0; 31.16		2; 3.16; 5.02; 16.0; 20.0; 31.2	70
Analyzer		Wollaston prism		Wollaston prism	Polaroid filter
Photodetector		FEU-83	FEU-84	FEU-144	FEU-84-3
Luminescent channel,		No		Yes	No
Field-of-view,	mrad	–		5.0	–
Filter passband center	nm	–		680	–
Photodetector		–		FEU-83	–
Recording system					
Analog-to-digital convertor, number of bits		6		7	7
Frequency band width	MHz	40		130	130
Microcomputer		15VM16		IBM PC	IBM PC
Device for electromechanic scanning		absent		present	absent
Max deflection angle	degrees	–		15	–
Scanning rate	R.P.M.	–		1	–

The specialized lidar "Makrel'–2" was designed for sensing cloudy fields, underlying surface and hydrosphere from an aeroplane. The lidar transceiver construction was simplified in comparison with the previous version. The transmitter has only linear polarization of radiation. To increase the lidar potentialities, receiving system diameter was 1.5 times increased. In addition to the polarization channel, the luminescence channel was introduced. PMTs with higher time resolution were used. In order to enhance the sensing area covered during a flight, the electromechanic scanning device comprising two rotating optical wedges, whose aperture covers the whole lidar transceiver is used.[25] The lidar "Makrel'–2" has demonstrated its good performance as a detector of bioproductive zones in sea waters, as well as for detecting fish shoals under conditions of polar night. Due to its sufficient versatility and small size, the lidar "Makrel'–2" is widely used both in scientific research conducted at the Institute of Atmospheric Optics, and in fish seeking flights (two lidars were delivered to the USSR Ministry of Fishevy). Using the documentation developed, a small series (8 copies) of lidars has been manufactured.

The lidar M2M[26] was specially designed for providing studies of clouds and underlying surface under satellite during the operation of space based lidar "Balkan,"[27] as well as for imitation of the conditions of its operation. For this purpose the possibility of creating wider angular width of sounding radiation from a transmitter and wide receiver's field of view were provided in order to provide the same experiment geometry in an aeroplane flight at 4.5 km height over cloud top (diameter of laser beam at a cloud and its coverage by receiver's field of view) as it is for lidar "Balkan" from 400 km altitude.

Airborne polarization lidars were designed in the laboratory headed by A.A. Tikhomirov, Candidate of Technical Sciences, leading designer – A.I. Abramochkin, senior research worker. It should also be noted that lidars "Makrel'–2" and M2M are now parts of instrumented aircraft "Optik–E"[28] and provide conducting experiments in national and international expeditions of the Institute of Atmospheric Optics.

Spaceborne lidar "Balkan". Most outstanding achievement is the design and construction of a spaceborne lidar "Balkan."[27] This work was done at the Design and Technology Institute "Optika" in collaboration with the Institute of Atmospheric Optics SB RAS and Scientific and Production Association of the USSR Ministry of General Machine Making (now Russian Research Institute of Space Instrument Making of the Russian Space Agency). The lidar design started in 1986 by the technical order of the Scientific and Production Association "Energiya." For this purpose a specialized set of control and check instrumentation[29] was created a full-size and technological bread board models of the lidar for testing, as well as a simulator for astronaut training. Lidar prototype was delivered to the customer in 1990 for mounting in the third orbital module of the station "Mir". In 1991 as a part of this module the lidar passed all complex and joint tests, and then works with the module were frozen for 2.5 years. The lidar was launched to space on module "Spektr" in May 1995, already after the American lidar operated within the frame of LITE program[30,31] in 1994. The works on design of the lidar "Balkan" were supervised by Yu.S. Balin, Candidate of Physical and Mathematical Sciences (1986–1988) and then by A.A. Tikhomirov, Candidate of Technical Sciences.

Since August 1995 the lidar "Balkan" has been operated at the orbital station "Mir" as a first stationary long-term spaceborne lidar. In summer of 1996 the Russian-French lidar "ALISSA"[32,33] installed on the module "Priroda" started to operate too.

TABLE II. Parameters of spaceborne lidars.

Parameter	Measurement unit	LITE Refs. 30, 31			Balkan Ref. 27	ALISSA Refs. 32, 33
Sensing wavelength	nm	355	532	1064	532	542
Output power	mJ	150	460	500	150	40 (4 lasers)
Pulse length	ns	31	27	27	12	15
Beam divergence	mrad	0.6	0.6	1.0	0.15	0.5
Pulse repetition rate	Hz	10	10	10	0.18	50
Receiving telescope diameter	mm		985		275	400
Field-of-view	mrad		1.1		0.44	0.5
Photoreceiver mode			Analog		Analog	Photon-counting
Spatial resolution	m		15		3	150
Power supply	W		2000		200	3000
Space platform			Discovery		Orbital station "Mir" "Spektr" Module	"Priroda" Module
Average height of orbit	km		240		400	400
Orbit slant angle	degs.		57		51.7	51.7
Distance between measurement point	km		0.7		42.6	0.9
Period of functioning			9 days in September of 1994		1995–1997	1996–1997

For a comparison, Table II presents the main specifications of the first three spaceborne lidars. As is seen from the table, the lidar "Balkan", being 150 times lower in power potential then the lidar LITE (due to lower output power, smaller area of receiving antenna and higher orbit), has higher potential than the lidar "ALISSA", which can operate only at a shadow side of the Earth, because it detects backscattered radiation only in the photon-counting mode. In addition, high power consumption of the lidar "ALISSA" operating only on a shadow side, when the station's solar batteries do not function, markedly shortens the duration of measurement sessions. It should be noted that many of the results obtained during the development, construction, ground and fly tests of the lidar "Balkan" were taken into account in designing the lidar "ALISSA" whose prototype was set at the orbital module "Priroda" in fall of 1995.

Among the disadvantages of the lidar "Balkan" are low repetition rate of sounding pulses, what is caused by the natural air cooling of the laser active element. This does not allow continuous monitoring of cloud fields and Earth's underlying surface, because the distance between the neighbor measurement points is 42.6 km. Nevertheless, our lidar has higher vertical spatial resolution, smallest size and lowest power consumption characteristics, that is rather important for onboard research devices.

TABLE III. Comparative characteristics of mercury analyzers.

Parameter	Measurement units	Model / Company / Country				
		ZEEMAN-6000 HITACHI Japan	JEROME-411 USA	AGP-01 OEZSGO Russia	RTUT'-102 Analitpribor Ukraine	RGA-11 DTI "Optika" Russia
Purpose	–	Analysis of a wide range of objects	Analysis of mercury content in air and liquids	Measurement of mercury content in the atmosphere, liquid and solid samples	Liquid samples analysis. Analysis of atmospheric air with the use of liquid sorbent	Analysis of atmospheric air, liquid and solid samples, biological objects under laboratory and field conditions
Minimum detectable concentration	ng/m^3	20	1000	100	100	30 (in air) 0,02 ng/ml (in liquid) 10^{-7} % (in solid samples)
Measurement range	ng/m^3	1000–1.99·10^5	1000–1.99·10^5	100–99999	100–16700	30–10000
Size	mm		32.5×150×100	336×221×144	100 dm^3	700×365×90
Mass	kg		2.7	10	24.5	10
Notes	-	Stationary laboratory complex, multielement analysis, Zeeman background correction.	Small-size mercury analyzer, measurement of gold sorbent conductance.	Field analyzer of atmospheric air with a set of additional tools for analyzing solid and liquid samples. Gold sorbent with burning and following atom-absorption analysis.	Atom-absorption analyzer of liquid samples by the method of cold vapor, air analysis at a liquid sorbent	Versatile atom-absorption analyzer with Zeeman background correction. Continuous monitoring in atmospheric air. Aerosol and molecular absorption do not affect the measurement results.

For the time elapsed astronauts of three orbital expeditions worked with the lidar "Balkan". Total of more than 30 sessions of laser sensing of cloud fields and the Earth's underlying surface, in different areas of land and ocean were performed.[34] Lidar performance characteristics were obtained experimentally and they proved to be close to the calculated ones. Vertical resolution of data obtained is 3 m, the length of the monitored section of surface can reach 3400 km in one sensing session. In the ranging mode, the error of range estimation is ±1.5 m that is more than one order of magnitude better than an error given by existing radar systems used for estimating the height of "Mir" station orbit.

2.3. Devices and Systems for Ecological Monitoring of the Atmosphere

Mercury analyzer "RGA–11". Since 1990 the Design and Technology Institute has produced, in small series, "RGA–11" mercury analyzer developed in the laboratory headed by A.B. Antipov, Candidate of physical and mathematical sciences. The device described in detail in Ref. 35 is based on differential technique of atom-absorption spectroscopy with Zeeman background correction in the UV range. The use of fine spectroscopic effects in combination with specially developed techniques provides higher sensitivity and selectivity in comparison known analogs (Table III). In its sensitivity, RGA–11 is much better than analogous devices and allows mercury concentration to be measured at a level of 0.1 MPC for populated areas. The device and the technique have been metrologically certified at the Scientific and Production Association "D.I. Mendeleev VNIIM" in St. Petersburg, certified by Rosstandart, and included into the State register of measuring tools.

RGA–11 allows the analysis of atmospheric air for mercury concentration ranging from 30 to 10000 ng/m^3 without concentrating samples. Using additional tools it is possible to analyze liquid samples by the method of cool vapor, solid samples by firing at a temperature of 700°C, and biological objects by the method of cold vapor.

Several dozens of the device copies were produced and then delivered in regional services of nature protection and State sanitary inspections of a number of regional centers. Small size and independence of the analyzer allow continuous monitoring with the use of different carriers (man, car, motor hang glider, helicopter, etc.). That is why this device was also bougth by geological exploration expeditions.

Laser densitometer. In early 90ths in the laboratory headed by I.Ya. Shapiro, Candidate of Technical Sciences, the pilot laser densitometer has been created for measuring dust mass concentration.[36] The device is based on the phenomenon of laser radiation extinction at aerosols. Measurements are done in a local volume using a dual beam measurement scheme and a multipass cell. The cell provides up to 200 passes that corresponds to pathlength up to 100 m at a cell length of 0.5 m. The pilot device has passed state metrological attestation at the Scientific and Production Association " D.I. Mendeleev VNIIM".

It has been allowed for use with the following characteristics: parameters of the dust analyzed: average particle radius (1.2 ± 0.1) μm, density 2.16 g/cm^3; at the number of paths in the cell of 64, measurable dust concentration ranges from 3 to 18 mg/m^3 at a 25% main relative measurement error. The device became a part of mobile automated station "Ekolid" intended for ecological monitoring.

Automated mobile station "Ekolid". The system for monitoring of air pollution of industrial centers includes a mobile station-laboratory as one of its parts. This station is used in route and under-plume measurements. For these purposes, in later 80ths the Scientific and Production Association "Khimavtomatika" started to produce prototypes of mobile stations. However, the degree of automation of data collection, processing, and storing from measuring sensors in that stations was too low. In 1993 the Design and Technology Institute completed the creation of the "Ekolid" automated mobile station for atmospheric monitoring designed by the order from East-Kazakhstan Administration on Ecology and Bioresources (Ust'-Kamenogorsk).[37]

The "Ekolid" station is intended for operative detection of air pollution and for measurement of concentrations of gaseous and aerosol pollution in atmospheric air of populated areas and industrial zones, as well as for mapping the air basin state on the scale of a large city and for short-term forecasting of evolution and transport of dangerous gas and aerosol emissions. The measuring devices, comprising the station, and measured parameters are listed in Table IV. All the devices were produced at the Design and Technology Institute "Optika" (some of them were produced in cooperation with the Kiev Research Institute of Analytical Instrument Making). Gas analyzers, being the parts of the station, have passed the State attestation in the Scientific Production Association "D.I. Mendeleev VNIIM" and have corresponding certificates. The station also included the computer complex based on IBM PC, the system of sampling and sample preparation for atmospheric air under analysis, and the system of air thermostabilization (air cooling or heating) in the van.

The control of the station performance in the measuring mode and in the mode of collecting of information from gas analyzers and the measuring devices are done by the computer complex based on an IBM PC with an interface block following the given algorithm. Measurement results are entered in the data base and used for compiling the map of pollution and for forecasting the transport of dangerous gas pollutions. Before the station was delivered to customer, it was tested in field experiments.[38]

TABLE IV. Measurement devices comprising the station "Ekolid" and measured parameters.

Device name and type	Measured parameter	Measurement unit	Measurement range	Measurement error	MPC in air of a populated zone
Fluorescent gas analyzer 667FF–03	SO_2	mg/m^3	0–0.2	±0.012	0.05
			0.2–1.0	±(0.05+0.15X)	
			1.0–5.0	±(0.05+0.15X)	
Chemiluminescent gas analyzer 645HL–04	NO	mg/m^3	0.0026–10	±0.0013	0.06
	NO_2	mg/m^3	0.0026–10	±0.0013	0.04
Mercury analyzer RGA–11	Hg	ng/m^3	30–4000	20	300
Flame-ionization analyzer 623KPI–03	CH_4	mg/m^3	0–50	5%	–
	ΣC_xH_y	mg/m^3	0–50	5%	1.0
	$\Sigma C_xH_y - CH_4$	mg/m^3	0–50	5%	-
Laser densitometer LD-10	Dust	mg/m^3	3–18	25%	0.05
Ultrasound thermoanemorhumbo -meter TARM	Wind speed	m/s	0.4–30	0.1	–
	Wind direction	degrees	0–360	0.5	–
	Temperature	°C	–40 – +40	0.5	–
Acoustic radar AL–10	Height of inversion layer	m	30–500	–	–

2.4. Devices and Systems for Meteorological Monitoring of the Atmosphere

As was noted above, at present the instruments at Rosgidromet (Russian Hydrological Meteorological Center) posts need in significant updating one of the fields of Istitute's activity, which is elaborated since 1972, is the creation of new equipment for measuring meteorological elements of the atmosphere. Below we present the data on some devices based on new physical principles. These devices are parts of the mobile meteorological station that is under construction in the Design and Technology Institute "Optika".

Acoustic thermoanemometer TAU–1. During last several years the ultrasonic thermoanemometer was developed at the Institute. This anemometer would allow one to measure, in a local volume, simultaneously air flow speed, direction, and temperature which affect the velocity of sound propagation between an acoustic transmitter and a receiver.[39] The prototype of the thermoanemorhumbometer TARM was created by V.I. Galkin, senior research worker.[40] The prototype of thermoanemometer was designed and constructed by the group from Design Bureau–32 under supervision of A.A. Azbukin when constructing the mobile meteorological complex.[41] The prototype of similar device was also constructed earlier at the Institute of Atmospheric Optics SB RAS.[42] Table V presents, for a comparison, the characteristics of foreign devices being in mass production and the pilot TAU–1 device. (The characteristics of foreign devices are taken from advertising booklets). As is seen from the table, our device is highly competitive with the best foreign devices, while the English model does not provide simultaneous measurement of temperature.

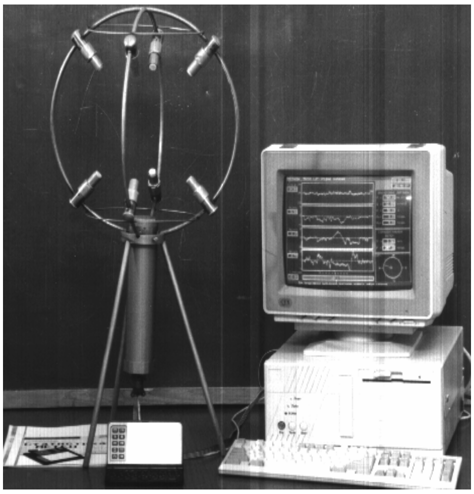

FIG. 2. External view of the measuring head of the thermoanemometer.

To measure the $X-Y-Z$ wind velocity vector, ultrasonic transmitters and receivers, as in most foreign devices, are placed at some angle to the measured volume about the vertical (Fig. 2). However, in TAU–1 device, the measuring head has more rigid structure. Electronic block is placed in a cylinder on which the measuring head is mounted. The software developed displays, on a computer monitor, measurement results on temperature and wind velocity components in the volume between transmitters and receivers with averaging period ranging from fractions of a second to several minutes. To complete the work on TAU–1 preparation for small-series production, it should be metrologically certified in the corresponding services of Rosgidromet.

TABLE V. Characteristics of ultrasonic anemometers.

Measured parameter	Measurement unit	Model / Company / Country			
		USAT-3 METEK Germany Ref. 43	DA-600-3T KAIJO Japan Ref. 44	1012S BIRAL Great Britain Ref. 45	TAU-1 DTI "Optika" Russia Ref. 41
Wind speed	m/s	0 – 30	0 – 60	0 ÷ 60	0 – 30
Error	m/s	± 0.05	± 0.005	± 0.01	± (0.1+0.02V)
Wind direction	degrees	0 – 360	0 – 360	0 – 360	0 – 360
Error	degrees	± 0.4		± 2	± 1
Temperature	°C	–30 – +50	–10 – +40	–	–50 – +50
Error	°C	± 0.01	± 0.025	–	± 0,1
Rolling rate	Hz	until 48	20	80	100
Averaging interval	s	min 1	30 – 600	4	3 – 600
Digital output		RS232	RS232S	RS442	RS232
Power supply	V	40÷60 cc	220 ac	220 ac	27 cc
Power requirements	W	25		24	6
Measuring head mass	kg	4	3	2.5	3
Measuring head size	mm	∅420×930	∅508×580	∅240×545	∅390×680
Year of production		1989	1990	1991	1996

Optical hygrometer. The hygrometers being used now at posts of Gidrometeoset' do not provide sufficient accuracy of air humidity measurements already at temperature below minus 10°C. When creating the mobile meteorological complex described above, at the Design and Technology Institute "Optika," in the same subdivision, the prototype of an optical hygrometer was constructed (the leading developer – V.V. Burkov, senior researcher). Brief information about the operation principles and characteristics of it is presented in Ref. 46. The hygrometer has no foreign analogs. It uses the differential absorption technique, is performed using radiation from two photodiodes in the near IR range. The air sample analyzed is blown through the optical cell in which the radiation from two photodiodes propagates. The radiation is emitted at 0.94 nm (on the H_2O absorption band) and 0.86 nm (out of the absorption band). The difference signal from photodetectors which record the radiation at the reference wavelengths and the radiation passed through the cell is digitized and then it is used for obtaining the parameter sought.

The prototype of optical hygrometer was tested in the climatic chamber at temperature ranging from –50 to +50°C and absolute humidity from 0.5 to 100 g/m^3. In addition, it was tested in comparison with the stock hygrometer "Volna" and the psychrometer. As a result of tests, good performance of the device at low temperature and humidity was proved, and its comparison with stock devices demonstrated good agreement between the results under stable meteorological situations. The experimental unit tested in the saturated water vapor medium at absolute humidity from 1 to 100 g/m^3, the hygrometer gave the records deviating from linear by no more than 1%.

2.5. Optical Devices, Units, and Parts

The production of optical components started to develop at the Institute from the very beginning. It was organized and headed by M.M. Nolle during first decades (before this time Tomsk had no its own optical production). First optical parts for pilot setups of IAO were produced as early as late in 1972. Starting from 1973, all optoelectronic devices constructed at the Institute "Optika" had optical parts of their own at production.

TABLE VI. List of optical systems and elements.

Name	Size	Measurement range	Notes
Telescopic systems (Cassegrain, Richi-Kretien, Shmidt, etc.).	∅ 25–800	1/6 – 1/3	RMS deviation of wave front from sphere no more than 0.05 μm
Monochromatic single-lens objectives	∅ 25–500	1/6 – 1/3	Raleigh resolution (at axis) no more 50 lines/mm
Spherical lenses	∅ 25–500	–	Planoconvex, planoconcave double convex, double concave
Spherical mirrors	∅ 25–1000	1/4 – 1/1.15	RMS deviation of surface no more than 0.05 μm
Plates and plane mirrors	∅ 5–1000	–	RMS deviation of surface no more than 0.05 μm
Polarization prizms (Roshon, Senarmont, Vollaston)	14×14×14 20×20×20	–	–
Interference light filters	∅ 14–70	–	Spectral range 300–1300 nm Bandwidth ≥1 nm
Metallodielectric light filters	∅ 14–100	–	Spectral range 200–400 nm
Attenuating neutral light filters	∅ 10–70	–	Transmission 0.01–50%

The list of optical parts was rather long (Table VI). Flexible production and technological base of the Institute provided the development and production of individual and small-series optical systems and high-quality elements. Items were metrologically certified. They were made from different types of glass quartz, glass ceramic and crystals for operation in the wavelength range from the UV to near IR range (13 μm). The technology of production of complex aspheric surfaces of any order was brought to high level. High quality of optical parts produced was reached owing to complex control at all stadies from the design (using the packages of applied programs) to production-technological processes (using wide set of unique methods and technical means).

For conducting control and technological certification of spherical wave fronts and quality of spherical surfaces production and measuring the curvature radii, in KB–54 headed first by L.A. Pushnoi and then by I.G. Polovtsev the interferometer "FAVN–35" was developed and constructed.[47,48] This device allows one to measure the curvature radii of convex surfaces in the range from 3 to 30 mm, concave surfaces in the range from 3 to 640 mm at D/E ratios of the parts under control of no more than 1/1.15 with error of surface shape control no worse than 1/20 wavelength. The error of curvature radii measurements is no more than 5 μm. In its parameters, the interferometer is highly competetive with the analogous device MARK–2 manufactured by ZYGO company. In addition, the device was created for processing interferograms. For this purpose the software for IBM PC is used. At early 90ths 10 prototypes of such devices were produced, and these devices were delivered to a number of optical-mechanical plants in Russia for technological and certification control of the parts produced.

Further development of the methods of optical technological control allowed the creation of contactless optical sensors for control of the geometry of solid bodies. The automated system for control of the ripple factor of rails during their transport in a rolling shop[49] was developed. (The system is built around four such sensors). The system providing the measurement accuracy within 35 μm was certified at the Research Institute of Metrology and implemented in 1995 at the Kuznetsk Metallurgical Integrated Plant (Novokuznetsk). This work was done in collaboration with "Optikon" Ltd.

The other independent field of the development of optical instrument making was the design of the setup for laboratory practical works on physical optics.[50] Based on the single small-size set of equipment, 26 optical phenomena can be demonstrated, including diffraction, polarization, interference experiments, recording of reflection holograms, interferograms, experiments with Fourier optics, etc. The small series of these setups named UMOG was produced at the Institute.

CONCLUSION

Opto-electronic technologies and physical effects associated with the optical radiation interaction with different components of the Earth's atmosphere comprise the scientific and engineering base of the up-to-date technical means for experimental studies of the atmosphere and other components of the environment. Wide use of these technical means in fundamental and applied research brings the problems of their instrumentation to the level of independent scientific and technological research field. Further development of the ecological and meteorological instrument making together with the scientific research in atmospheric optics at the IAO SB RAS and other research institutes, on the one hand, and practical application of new optoelectronic devices for environmental monitoring on the other hand, are now the scientific and technical activities of primary importance in the Institute "Optika".

Main projects of the Institute "Optika", the majority of which were made in cooperation with IAO SB RAS, are briefly described above. More detailed description, as well as scientific and technical foundations of the atmospheric monitoring are now published in a series of monographs with the common name "Regional monitoring of the atmosphere".[51,52] In general this series of monographs is issued within the project "Climatic and Ecological Monitoring of Siberia" (within the frame of the Scientific and Technical Project "Siberia") with the participation of leading, in this field, institutes of the Siberian Branch of RAS and Siberian high education institutes, as well as within the framework of a number of projects of the Russian Foundation for Fundamental Research.

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