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International Conference on Lasers, Applications, and Technologies 2007

High-Power Lasers and Applications

Vladislav Panchenko
Vladimir Golubev
Andrey Ionin
Alexander Chumakov
Editors

28 May–1 June 2007
Minsk, Belarus

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Introduction

The International Conference on Lasers, Applications, and Technologies (LAT 2007) was held 28 May – 1 June 2007 in Minsk, Belarus.

The LAT 2007 technical program covered a wide range of laser technologies and applications, including advanced lasers and systems, laser-assisted micro- and nanotechnologies, laser technologies for environmental monitoring and ecological applications, laser technologies for medicine, high-power lasers and applications, optical sensors in bio-, chemical, and engineering technologies, and femtosecond laser pulse filamentation.

The LAT 2007 was organized by the Russian Academy of Sciences, M.V. Lomonosov Moscow State University in cooperation with the National Academy of Sciences, Belarus, B.I. Stepanov Institute of Physics, the National Academy of Sciences, Belarus, and the International Science and Technologies Center.

LAT 2007 was held concurrently with the International Conference on Coherent and Nonlinear Optics (ICONO 2007), featuring the nonlinear space-time dynamics, optics and optical diagnostics of nanostructures, physics of intense and superintense laser fields, quantum and atomic optics, physics of quantum information, nonlinear laser spectroscopy and high-precision measurements, fundamentals of laser chemistry and photobiology, novel photonics materials, and attosecond pulses.

More than 400 presentations (plenary and keynote lectures; invited, oral, and poster presentations) were given at the LAT 2007 Conference.

Volume 6735 contains about 40 papers selected by the symposium and conference chairs, and previewed by independent experts. The volume starts with a keynote lecture of Prof. Zarubin who was responsible for coordinating high-power and high-energy laser programs in the former USSR. High-power chemical oxygen-iodine lasers (COIL), chemical HF lasers, electric discharge lasers including electric discharge oxygen-iodine laser (DOIL), high-peak power laser systems using both solid state and gas active medium radiating ultrashort femto- and picosecond pulses are discussed in the first sessions of the volume. The following sessions are devoted to applications of high-power lasers in industry, for laser ablation and interaction of laser radiation with matter. The final session deals with post-deadline lectures.

We are most grateful to all institutions and persons who have contributed to organizing, supporting, and holding the conference. Special thanks are owed to Professor Vladimir Kabanov, the Chairman of ICONO/LAT 2007 Organizing Committee, for impeccable management of the conference.

We are also indebted to Doctor Mikhail Khodasevich and Ms. Tatiana Lukovnikova, Scientific Secretaries of the LAT 2007 Conference, for their honest work with the authors and participants.

Vladislav Panchenko
Vladimir Golubev
Andrey Ionin
Alexander Chumakov

"Terra" and "Omega" - Large-scale Pioneer Soviet High Energy Laser Programs (1965-1977)"

Peter V Zarubin, V.K.Orlov High energy lasers design bureau “Granat”, Moscow
Nicolay V.Cheburkin, V.K.Orlov High energy lasers design bureau “Granat”, Moscow
Eugeniy M. Sukharev, “Almaz” Scientific Industrial Corporation, Moscow

ABSTRACT

Main results of the large-scale pioneer high energy laser research and design programs “Omega” and ‘Terra-3”, accomplished in the USSR during the first decade of the laser era, are reviewed and presented.

These programs, initiated correspondingly by Nobel laureates Alexander Prokhorov and Nicolay Basov, and fulfilled under their general scientific leadership, resulted in tremendous advance of laser science and technology in the USSR, particularly in the high energy laser (HEL) domain. “Omega” and “Terra” were primarily directed at studies of feasibility of HEL lasers applications for anti-aircraft and anti-missile defense, and provided great extension of knowledge in HEL physics and in laser technology and understanding laser beam interaction with matter phenomena.

The R&D efforts culminated in early development and testing of several different Megajoule-class pulse lasers and of a number of different Megawatt-class high average power laser devices. Literally hundreds of scientific institutes and laboratories, industrial design bureaus, representing almost the entire Soviet physical, chemical, optical and electronics scientific and engineering community, took part in these programs.

Different types and some quite uncommon versions of high-energy lasers have been studied, developed and tested, including varieties of solid state, iodine, carbon dioxide, chemical, and Raman lasers. Interaction of high energy laser radiation with different materials, laser radiation propagation in the atmosphere, optical laser glass and crystal physics, chemistry and production techniques, nonlinear optical phenomena physics and many other aspects of HEL-related science and technology were studied and drastically advanced in the course of the “Omega” and “Terra-3” programs. The problems of achieving high laser power and energy and nearly diffraction-limited laser radiation divergence were understood and dealt with. High-energy laser systems beam pointing and laser radar technologies were also developed, studied and improved.

Numerous new academic and industrial laser-oriented scientific, design, production and test facilities, laboratories and teams sprung up or were expanded all over the USSR in the course these programs.

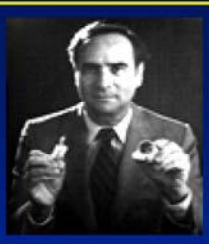
Scientific results of this extensive R&D effort were published in 10000 + (estimated) papers and reports.

"Terra" and "Omega"- Large-scale Pioneer Soviet High Energy Laser Programs (1965-1977)

Now it can be told…

P.V.Zarubin
N.V.Cheburkin
E.M.Sukharev

LAT 2007 Minsk



As soon as the first laser built by Theodore Maiman shined in 1960, it has occurred to many scientists and military that **it may be possible to create a weapon able to burn a target to ashes by a high energy laser beam**.

The first 10-15 years of the "laser era" (1960 – 1975) were to the utmost satiated with laser discoveries and inventions. A spirit of enthusiasm reigned.

Belief that laser science and technology will succeed in solving incredibly difficult and even fantastic tasks was prevalent. During this "initial" period most high energy lasers (HEL) known now have been invented and many big laser testbeds and prototypes have been built.

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The P.N.Lebedev Physical Institute was leading soviet quantum electronics and laser research center since the 50-es . The effort of the scientists resulted in independent creation of first masers in USA and the USSR.

Charles Townes, Alexander Prokhorov and Nicolay Basov became recipients of the 1964 Nobel prize in physics for "fundamental work in the field of quantum electronics, which has lead to the construction of oscillators and amplifiers based on the maser-laser principle".

Charles Townes

Alexander Prokhorov

Nicolay Basov

No wonder that in the USSR just A.Prokhorov and N.Basov became at the head of large-scale High Energy Laser R&D programs , both general and military-oriented.

Charles Townes - Vice-president of the Institute of Defense Analysis (mid – 60-es) , supported USA HEL R&D programs

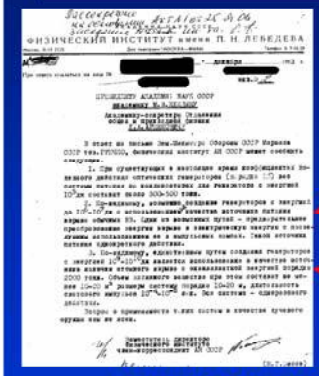
A.M. Prokhorov – scientific leader of the the «Omega» program («Ω»)

N.G. Basov- scientific leader pf the the « Terra-3 » program («T-3»)

The Laser Race

«It would be more than terrible, I would even say criminal, if we would lag behind our neighbors in this matter as in many other cases …»

Talk of prince Boris Golitsin "On development of aeronautics and aviation" at the session of the Russian Academy of Science, December 13, 1909



ФИЗИЧЕСКИЙ ИНСТИТУТ имени П. Н. ЛЕБЕДЕВА

ПРЕЗИДИУМУ АКАДЕМИИ НАУК СССР

АКАДЕМИКУ М.В.КЕЛДЫШУ

First scientific and engineering design ideas aimed at creating multimegawatt CW lasers and multimegajoule pulsed lasers were formulated by Soviet scientists and engineers in as early as in 1963

"Probably, it is possible to make generators with energy up to 10^6-10^7 j using an explosion of conventional HE as a power source..." (Basov meant laser generators)

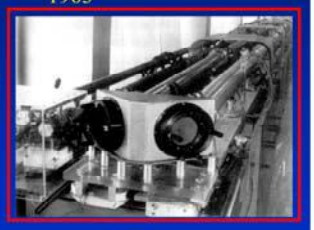
Probably, the only way to create generators with energy 10^9 -10^{10} j is to use an atomic explosion … as the pumping energy source…

A declassified **letter of Lebedev Institute deputy director N.G.Basov to the President of the Soviet Academy of science M.V.Keldysh dated December 1, 1963. An answer to the request of the Soviet deputy Minister of defense A.Grechko**

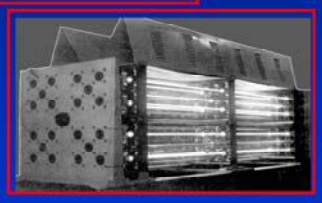
The first USSR "HEL" attempts

1961-1962 - reproduction and advancement of foreign laser development ideas and results

Peter Krukov and Vitaly Zuev aligning a high power ruby laser at Lebedev (FIAN) 1963



One of first Soviet ruby lasers used for Moon ranging experiments (September 1963) GOI (Leningrad), Design Bureau № 16



"Very high average power" multichannel He-Ne laser device – 600 mw CW (0,63 mkm) (1963) Research Institute № 801

High power carbon dioxide laser - 1 Kw , July 1966 Research Institute № 801

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(to mention only a few…)

In 1965-1967 the efforts of scientists and engineers to make high energy (power) pulsed and CW lasers, supported by the military, resulted in commencing of both general and military oriented HEL R&D programs in the USSR, USA and some other countries…

The big Soviet versatile HEL laser R&D programs "Omega" and "Terra-3" included:

Basic laser physics research

- Laser technology development
- "Big" experimental laser machines design and test
- Studies of HEL radiation interaction with materials and hardware
- HEL radiation propagation studies
- Laser optics research and laser optical materials technology development
- Laser radar research and development
- Laser beam pointing technology development
- Construction of new scientific, design, production and test facilities
- Students and post-graduate training in laser-related physics and technology

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The HEL development problems (as seen in 1964-1967)

1. High volume crystal lasing media with good homogeneity - **NOT** available
2. It seemed technologically possible to produce large volume **Neodymium glass** solid state active media
3. Gas as possible HEL lasing media - **YES** (big volumes, good optical homogeneity)
4. Possible high energy optical pumping radiation sources:
   - -flashtubes (limited flux density and spectra due to quartz flashtubes wall)
   - -Radiation of open electrical discharges in gases (high energy and current pulse sources necessary, no quartz wall)
   - -explosion generated optical pumping radiation (HE explosion shock wave front radiation, nuclear explosion radiation– not convenient)
5. First objective – attain high laser radiation power and energy (hence big active media volumes)
6. Second objective – understand and reach low (diffraction limited) beam divergence (high brightness) at high power (energy) level

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The «OMEGA» program

The idea to build a ground based laser for anti-aircraft (AA) defense purposes was conceived in **summer 1966**. It was initiated by B.V.Bunkin (then deputy chief designer in the "Strela", later on – "Almaz" AA systems design bureau chief designer) and was soon finalized at a meeting of A.M.Prokhorov (Lebedev), A.A.Raspletin (head of "Strela"), B.V.Bunkin, E.P.Velikhov (Kurchatov Atomic Energy Institute branch head), academician M.D.Millionschikov (head of MGD generator program in the USSR), F.V.Bunkin (laser scientist from Prokhorov's lab, brother of B.V.Bunkin).

The initiators


A.M.Prokhorov


B.V.Bunkin


E.P.Velikhov


M.D.Millionshikov


F.V.Bunkin

Laser energy required for aerial target damage was estimated on the basis of typical total kinetic energy of splinter warhead fragments used in SA missiles .

10 MJ total beam energy was chosen for the Ω laser .

The system layout chosen was a **96 separate 100 kJ 1-10 ms ND-glass** modules multichannel design.

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Experimental neodymium glass laser system Ω

B.V.Bunkin chief designer

96-channel X-1 Ω Laser -1972

4 x 24 - 100 Kj pulse
2-element "flat" ND-glass
1000x240x40 mm
laser modules

Laser radar and precision beam guidance subsystem

Pulse energy source –
5OO Mw magnetohydrodynamic generator with inductive energy storage coil (not shown)

V.D.Seleznev -design

N.N.Poliashev -design

L.N.Zakhar'ev system

I.M.Bujinsky ND-glass

E.P.Velikhov energy source

M.P.Van'ukov -laser optics

E.M.Sukharev -system

The «Terra-3» program

- The idea to study the possibility to use HEL for anti-ballistic missile (ABM) terminal defense mission was conceived in 1964 by N.G.Basov and O.N.Krokhin.
- From the very beginning it was clear to them that BM warheads are efficiently thermally protected for reentry. Hence the mechanical recoil pulse produced by high flux density pulsed laser irradiation and resulting fast target surface evaporation was suggested (by O.N. Krokhin) as a possible mechanism for damaging the target.
-In 1966 The "Vympel" design bureau (head organization for Soviet ABM system program) leader G.V.Kisyn'ko supported the proposal to study the possibility of using lasers for ABM – first for high precision laser radar and subsequently as a weapon.
- The photodissociation iodine laser pumped by explosion shock-wave radiation (EPDL) was proposed (by Basov and Krokhin) as the leading contender HEL for "T-3"
-The idea was also endorsed by Y.B.Khariton – scientific leader of the Soviet nuclear weapon program at the All-Union Experimental Physics Institute in Sarov (VNIIEF) and E.N.Tsarevsky - Vavilov State Optical Institute – (GOI) in Leningrad

N.G.Basov

O.N.Krokhin

Y.B.Khariton

G.V.Kisyn'ko

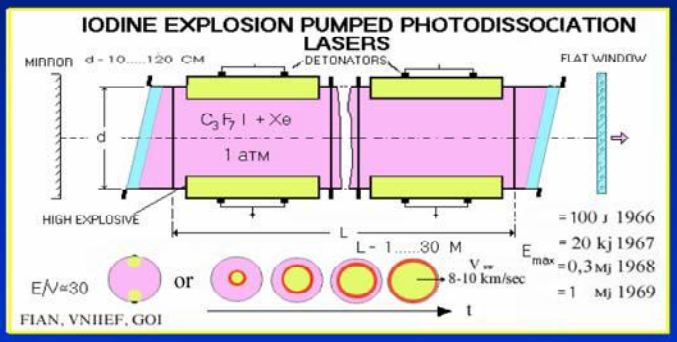
E.N.Tsarevsky

Photodissociation Iodine Laser pumped by explosion shock wave front radiation (EPDL)

In 1964 J.V.V.Kasper, G.C.Pimentel reported the first PDL. In 1965 N.G. Basov and O.N.Krokhin suggested to start a very high energy PDL program in the USSR (T-3) , based on the idea of using explosion shock wave front radiation in Xe as a very high power and energy optical pumping source. The shock wave radiation pumped PDL R&D program was started in cooperation of FIAN (V.Zuev et al), VNIIEF (S.Kormer, G.Kirillov et al, Sarov) teams with participation of GOI and GIPKh (Leningrad) teams. "Luch" (V.K. Orlov's team) designed several industrially produced EPDL models.

V.S.Zuev (Lebedev)
EPDL theory

G.A.Kirillov (VNIIEF)
HE EPDL
experiments



EPDL's had modular design and the pulse energy was determined by number of modules

Scalability!

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T-3 HE EPDL

VNIIEF
Laser Team
Leader
S.B.Kormer

FO-32 module

"Luch"
Laser Team
Leader
V.K.Orlov

VNIIEF
PDL test site

Laser model	Φ0 - 32	Φ0-21
D_{CB} light diameter meters	0,5	1,3
ℓ_{AK} active length meters	20	20
E (pulse energy J)	$6 \cdot 10^4$	$4 \cdot 10^5$
τ pulse, sec	$3 \cdot 10^{-5}$	$12 \cdot 10^{-5}$
Θ (divcrg_rad)	$1 \cdot 10^{-4}$	$(2 \div 3) \cdot 10^{-4}$

Some "Luch" EPDL specifications

EPDL Φ-1200
assembly at VNIIEF
1969

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Raman "summator" lasers

The early EPDL lasers demonstrated poor beam divergence ~ 100 times diffraction limit (later the problem was solved). In 1966 N.G.Basov, I .I .Sobelman et al proposed to use a two-stage system: a HEL Raman laser ("summator") pumped by "poor" quality Iodine EPDL radiation as a solution. High Raman laser efficiency and good media homogeneity allowed to achieve good properties of a two-stage laser system. A HEL Raman laser program was started aimed at building a multimegajoule Raman laser "pumped" by several HE EPD lasers .

E.M.Zemskov - program leader

80 Kj pulsed liquid oxygen **AG-5T Raman Laser**. -400 mm aperture quartz window -70% efficiency

Multimirror optical system used for pumping of the AG-5T laser by several iodine EPDL,s located outside behind the big optical window

400 mm Raman laser glass optics damaged by laser radiation . Fused quartz was used later

E.M.Zemskov team, "Luch" 1975

A 10-Mj Raman summator was designed, but not built

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CO_2 –lasers (the 70- s)

G.G. Dolgov - Saveliev- team leader

The 3D01 laser – initiated by N.G.Basov in 1974, designed by "Luch" (V.K.Orlov, G.G.Dolgov-Saveliev team) (built at "Raduga" test facility)

E-beam sustained closed cycle PRF mode, 0,5 + Mw (average) class laser - 1976

High energy gas dynamic laser nozzle array. Laser built by "Almaz"team in 1973 under scientific leadership of A.M.Prokhorov

Vulnerability test of a drone target hit in flight by CO_2 laser beam "Almaz"

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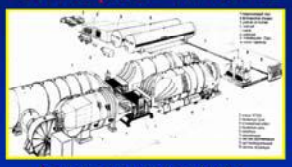
CO2 – Lasers-2

An advanced model of a e-beam sustained CO_2 high PRF pulsed laser KS-10, designed by "Astrofizika" team

5-10 kJ pulse – 100-150 Hz



Laser gas system train sketch

Team leader N.V.Cheburkin

KS-10 laser building and site at "Raduga" test center

A mobile industrial 50-kW CO2 – laser MLTK-50 built by "TRINITI", "Almaz" and VNIIEFA

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The LE-1 laser radar

The potential ability of laser radar to provide extremely high precision measurements of target position for ABM systems was first studied in the "Vympel" design bureau in 1963. Design of an experimental laser radar for ABM research was started by "Vympel" in 1964. The only available high power short pulse laser was a ruby laser. A multi-channel laser system had to be used to provide for the necessary field of view – totally 196 1-Joule 30 nsec 10 Hz pps q-switched ruby lasers (2 kw average total power). After 1969 the LE-1 radar project was moved to "Luch" (later "Astrophysica") design bureau established under the "Terra-3" program. N.D.Ustinov was appointed LE-1 chief designer. Laser and LE-1 optical train design was made by Vavilov (GOI) optical institute (P.P. Zakharov) and "Geophysica" design bureau (Moscow) under D.M.Khorol leadership. The 1,3 meter high dynamic TG-1 telescope was designed and produced by Leningrad Optic-Mechanical Association – LOMO.

TG-1 1,3 m laser telescope and beam director

LE-1 chief designer N.D. Ustinov 1974

Part of LE-1 196 – laser optical train (scanners, telescopic lenses, image rotators, etc)

LE-1 Laser radar at the Saryshagan BMD test range

LE-1 laser radar building

The HEL project leaders at Sary-Shagan ABM test range near Balkhash lake (Kazakhstan)

Missile warheads and satellite tracking and high-precision trajectory measurements were achieved in 1976-77

N.G.Basov

1974 - USSR defense industry leaders and top brass visiting the LE-1 site

The experimental "Terra-3" 1,5 m beam director at Saryshagan

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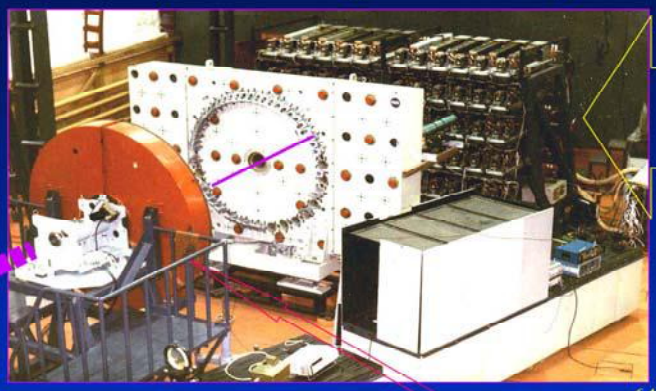
"T-3" - High PRF experimental ND-glass laser facility "TANDEM"

Y.I.Kryjilin



Beam out

64 ND-laser modules

- Each channel rated pulse energy – 2 kJ
- All lasers shoot in turn along the same axis by means of a synchronized rotating optical switch.
- Total PRF – 100 Hz
- Average power - ~ 150 Kw for 2-3 sec.
- Power supply – 6 KV 10 Mw 50 Hz mains, no capacitor bank , thyristor control
- Designed by "Astrophysica" - 1976-1978 , built at "Raduga" laser test center

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Some of numerous new laser laboratories, design offices and test facilities established for "Ω" and "T-3" programs

"Luch" ("Astrophysica") buildings -Moscow

Institute of General Physics "Omega" building

"Granat" high energy lasers design bureau

"Raduga" laser test range facility

"Raduga" laser-town

The "Raduga" laser test facility

As "big" lasers began to emerge, it soon became obvious that many tests could not be performed in the existing labs and special test and evaluation facilities are "a must" .

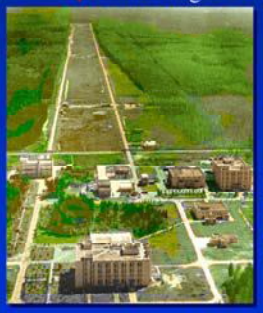
A deserted military shooting-ground was found in Central Russia, 15 miles away from Vladimir. Swampy and wooded uninhabited country prevailed. In 1972 construction was started.

That's how it looked then

General I.S. Kos'minov head and builder of "Raduga"

Laser test laboratories

Laser range 20 km



The only laser town in the world

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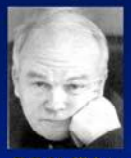
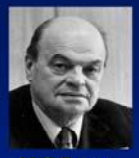
The Soviet HEL programs scientific and technical advisory councils


S.B.Kormer


E.P.Velikhov


N.G.Basov


A.M.Prokhorov


B.V.Bunkin


Yu.B.Khariton


A.I.Pavlovsky


N.D.Ustinov


V.K.Orlov


M.M.Miroshnikov and others…


A.A.Mak


E.N.Tsarevsky


A.M.Bonch-Bruevich

Soviet Defense minister and industry leader D.F. Ustinov discussing HEL lasers with top scientists

Scientific council session

The late great Russian laser leaders


A.M.Prokhorov
-1941-1944
Red army scout officer
Two years at frontline.
Twice wounded


2001


N.G.Basov
-1941-1945
Red army
frontline
paramedic

When asked in 1994 about the final results of the "Terra-3" program, N.G.Basov said: "Well, we made sure that nobody can shoot down a ballistic missile warhead by a laser beam, and we awfully pushed ahead lasers… "

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References

- Many thousands of scientists and engineers contributed to the work reviewed here. There are several thousands publications in scientific literature and conferences.

-We could mention only some names of the program leaders here.

-The leading institutions, design bureaus and and plants were: Lebedev Physical Institute (Moscow), All-union institute of experimental physics (Sarov), Vavilov State optical Institute (Leningrad), Kurchatov Atomic Energy Institute branch (Now – TRINITI - Troitsk), Design bureau "Strela" ("Almaz") (Moscow), Design bureau "Luch" ("Astrophysica") (Moscow), State Institute of Applied Chemistry (GIPH, Leningrad), Institute of Chemical Physics (Moscow), Efremov Institute of electro-physical apparatus (Leningrad), Gorky Machine-building plant (Gor'ky), Raduga Laser Test Center (Vladimir), Leningrad Optic-Mechanical Association – LOMO (Leningrad), Institute of Atmosphere Optics (Tomsk), Lytkarino optical glass plant (Lytkarino), Central Design Bureau "Geophysica" (Moscow), Zverev Krasnogorsk machine-building plant (Krasnogorsk) and about 100 more actively participating institutes and plants .

Also see: P.V.Zarubin "Academician Basov, high power lasers and the antimissile Defense problem", Quantum Electronics, vol.32, No 12, 2002
E.M.Sukharev , "The role of academician Prokhorov and his followers in creation of special laser systems" In "Alexander Mikhailovich Prokhorov" (a collection of reminiscences) , Moscow, Fizmatlit, 2006 (in Russian)

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Technical Director, Director of HEL programs department in the USSR defense Industry Ministry - 1969-1990
Scientific Adviser to Director of V.R.Orlov "High Energy Lasers Design Bureau"
Professor (HEL systems chair) – Moscow Electronics and Automatics Technical University
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Winner of Russian Government prize for science and technology –2002

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