

PROCEEDINGS OF SPIE

*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

Organized by

National Academy of Sciences (Belarus) • Russian Academy of Sciences • M.V. Lomonosov
Moscow State University (Russia) • B.I. Stepanov Institute of Physics (Belarus) • International
Science and Technologies Center

Sponsored by

National Academy of Sciences (Belarus) • Russian Academy of Sciences • M.V. Lomonosov
Moscow State University (Russia) • Belarus Foundation for Basic Research • Belarus Physical
Society • Russian Physical Society • International Science and Technologies Center • SPIE Russia
Chapter

Published by
SPIE

Volume 6735

Proceedings of SPIE, 0277-786X, v. 6735

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

The papers included in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. The papers published in these proceedings reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from this book:

Author(s), "Title of Paper," in *International Conference on Lasers, Applications, and Technologies 2007: High-Power Lasers and Applications*, edited by Vladislav Panchenko, Vladimir Golubev, Andrey Ionin, Alexander Chumakov, Proceedings of SPIE Vol. 6735 (SPIE, Bellingham, WA, 2007) Article CID Number.

ISSN 0277-786X
ISBN 9780819468932

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Copyright © 2007, Society of Photo-Optical Instrumentation Engineers

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/07/\$18.00.

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

SPIE 
Digital Library

SPIDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc.

The CID number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

Contents

- ix Conference Committee
xi Symposium Committee
xiii Introduction
xv *Terra and Omega: large-scale pioneer Soviet energy laser programs (1965–1977) (Keynote Lecture)*
P. V. Zarubin, N. V. Cheburkin, V.K. Orlov High Energy Lasers Design Bureau, Granat (Russia); E. M. Sukharev, Almaz Scientific Industrial Corp. (Russia)

SESSION 1 CHEMICAL LASERS

- 6735 03 **Contribution to development of chemical and discharge oxygen-iodine lasers (Invited Paper) [6735-03]**
J. Kodymová, O. Špalek, V. Jirásek, M. Čenský, J. Hrubý, J. Schmiedberger, Institute of Physics (Czech Republic)
- 6735 04 **Dissociation of I₂ in chemical oxygen-iodine lasers: experiment, modeling, and pre-dissociation by electrical discharge (Invited Paper) [6735-05]**
A. Katz, K. Waichman, Z. Dahan, V. Rybalkin, B. D. Barmashenko, S. Rosenwaks, Ben-Gurion Univ. of the Negev (Israel)
- 6735 05 **Advanced singlet oxygen generator and nozzle bank in traditional COIL technology (Invited Paper) [6735-06]**
M. V. Zagidullin, V. D. Nikolaev, N. A. Khvatov, M. I. Svistun, P.N. Lebedev Physical Institute (Russia)
- 6735 06 **Chemical oxygen-iodine laser with atomic iodine generated via fluorine atoms [6735-08]**
O. Špalek, V. Jirásek, M. Čenský, J. Kodymová, I. Picková, Institute of Physics (Czech Republic); I. Jakubec, Institute of Inorganic Chemistry (Czech Republic)
- 6735 07 **I₂ dissociation pathways in the coil medium [6735-29]**
M. V. Zagidullin, V. N. Azyazov, S. Yu. Pichugin, P.N. Lebedev Physical Institute (Russia)
- 6735 08 **Possibilities of simultaneous lasing in two different spectral bands on HF and DF molecules in autonomous cw HF/DF laser [6735-09]**
A. S. Bashkin, S. N. Petrova, NPO Energomash (Russia); D. V. Polinovsky, Moscow Aviation Institute (Russia)
- 6735 09 **Numerical simulation of double-band cw HF-HBr chemical laser [6735-33]**
B. P. Aleksandrov, A. A. Stepanov, NPO Energomash (Russia)
- 6735 0A **Comparison of well-known kinetic models by the cw HF and DF chemical lasers numerical simulation [6735-34]**
B. P. Aleksandrov, A. A. Stepanov, NPO Energomash (Russia)

SESSION 2 ELECTRIC DISCHARGE LASERS

- 6735 0B **Achievement of 30% conversion from O₂ to O₂($\alpha^1\Delta$) at 50 torr using an integrally cooled, controlled avalanche ionized electric O₂($\alpha^1\Delta$) generator [6735-28]**
A. E. Hill, Texas A&M Univ. (USA) and Plasmatronics, Inc. (USA)
- 6735 0C **Gas discharge lasers pumped by generators with semiconductor opening switch (Invited Paper) [6735-11]**
A. N. Panchenko, V. F. Tarasenko, A. E. Tel'minov, High Current Electronics Institute (Russia)
- 6735 0D **Microwave excited planar CO₂-laser [6735-22]**
A. P. Mineev, S. M. Nefedov, P. P. Pashinin, A.M. Prokhorov General Physics Institute (Russia)
- 6735 0E **Cryogenic sealed-off slab CO laser excited by repetitively pulsed RF discharge [6735-23]**
A. A. Ionin, L. V. Seleznev, A. V. Shelestovich, D. V. Sinitsyn, P.N. Lebedev Physical Institute (Russia)
- 6735 0F **High-efficient discharge-pumped ArF (193 nm) excimer laser with a TPI thyratron as a high-voltage switch [6735-26]**
A. M. Razhev, A. A. Zhupikov, D. S. Churkin, Institute of Laser Physics (Russia)
- 6735 0G **Long-pulse discharge nitrogen lasers [6735-30]**
A. N. Panchenko, I. N. Konovalov, A. I. Suslov, V. F. Tarasenko, A. E. Tel'minov, High Current Electronics Institute (Russia)
- 6735 0H **Pulsed CO laser operating on gas mixtures with high oxygen content [6735-32]**
Yu. M. Klimachev, A. A. Ionin, A. A. Kotkov, A. Yu. Kozlov, L. V. Seleznev, R. P. Andrusenko, P.N. Lebedev Physical Institute (Russia)
- 6735 0I **Generation of a high quality short pulse in excimer laser at use of SBS mirror [6735-39]**
V. F. Losev, Yu. N. Panchenko, Institute of High Current Electronics (Russia)

SESSION 3 HIGH-PEAK POWER LASER SYSTEMS

- 6735 0J **Development of petawatt laser amplification systems at the Central Laser Facility [6735-17]**
O. Chekhlov, E. J. Divall, K. Ertel, S. J. Hawkes, C. J. Hooker, I. N. Ross, P. Matousek, C. Hernandez-Gomez, I. Musgrave, Y. Tang, T. Winstone, D. Neely, R. Clarke, P. Foster, S. J. Hancock, B. E. Wyborn, J. L. Collier, STFC Rutherford Appleton Lab. (United Kingdom)
- 6735 0K **High power optical sources of femtosecond pulses on the base of hybrid laser systems with wide-aperture gas laser amplifiers [6735-18]**
A. A. Ionin, A. V. Konyashchenko, Lebedev Physical Institute (Russia); B. M. Koval'chuk, Institute of High-Current Electronics (Russia); O. N. Krokhin, Lebedev Physical Institute (Russia); V. F. Losev, Institute of High-Current Electronics (Russia); G. A. Mesyats, L. D. Mikheev, A. G. Molchanov, Yu. N. Novoselov, L. V. Seleznev, D. V. Sinitsyn, A. N. Starodub, Lebedev Physical Institute (Russia); V. F. Tarasenko, Institute of High-Current Electronics (Russia); S. I. Yakovlenko, General Physics Institute (Russia); V. D. Zvorykin, Lebedev Physical Institute (Russia)

- 6735 0L **Sub-picosecond petawatt class N₂O laser system: mid-IR non-linear optics and new possibilities for high-energy physics (Invited Paper)** [6735-19]
B. G. Bravy, Institute of Problems of Chemical Physics (Russia); V. M. Gordienko, V. T. Platonenko, S. G. Rykovanov, M.V. Lomonosov Moscow State Univ. (Russia); G. K. Vasiliev, Institute of Problems of Chemical Physics (Russia)
- 6735 0M **Formation of short high-power laser radiation pulses in excimer mediums (Invited Paper)** [6735-20]
V. F. Losev, N. G. Ivanov, Yu. N. Panchenko, Institute of High Current Electronics (Russia)
- 6735 0N **Suppression of gain narrowing with a combination of negative and positive CPA** [6735-21]
M. P. Kalashnikov, K. Osvay, Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Germany)
- 6735 0O **Design and construction of a PW ultrashort laser facility with ns, ps, and fs outputting pulses** [6735-42]
Q. Zhu, X. Huang, X. Wang, X. Zeng, X. Xie, F. Wang, F. Wang, D. Lin, D. Jiang, X. Wang, K. Zhou, Y. Zuo, Y. Zhang, Y. Deng, X. Wei, D. Fan, Research Ctr. of Laser Fusion (China)

SESSION 4 LASER DESIGN AND LASER BEAM CONTROL

- 6735 0P **Laser systems for pulsed volumetric laser beams generation** [6735-35]
Yu. Chivel, Institute of Molecular and Atomic Physics (Belarus)
- 6735 0Q **Short-pulse disk laser** [6735-36]
Yu. Chivel, I. Niconchuk, D. Zatiagin, Institute of Molecular and Atomic Physics (Belarus)
- 6735 0R **High-energy diffractive variable attenuator** [6735-43]
A. G. Poleshchuk, D. E. Denk, A. I. Malyshev, Institute of Automation and Electrometry (Russia)
- 6735 0S **Optical experimental fiber for transmission of high power laser radiation** [6735-44]
Y. V. Sorokin, SPA Astrophysika (Russia)

SESSION 5 APPLICATIONS IN INDUSTRY

- 6735 0T **High power laser sources for industry and their applications (Invited Paper)** [6735-12]
F. Bachmann, ROFIN-SINAR Laser GmbH (Germany)
- 6735 0U **Dieless wire drawing with lasers (Invited Paper)** [6735-13]
G. Liedl, D. Schuöcker, Institute for Forming and High Power Laser Technology (Austria)
- 6735 0V **Optimization of the quality of laser cutting and power consumption (Invited Paper)** [6735-14]
Ch. Sipavichius, A. Amulevichius, K. Mazheika, Institute of Physics (Lithuania)
- 6735 0W **Development of resonators for high-power CO₂ lasers** [6735-24]
A. M. Orishich, V. B. Shulyat'ev, Khristianovich's Institute of Theoretical and Applied Mechanics (Russia); G. N. Grachev, S. I. Trashkeyev, P. A. Statsenko, Institute of Laser Physics (Russia)

- 6735 0X **Pulse laser welding of aluminum alloy by combined radiation** [6735-54]
A. V. Fedin, Y. A. Chaschin, I. V. Shilov, S. A. Solokhin, M. N. Ershkov, Kovrov State Technological Academy (Russia)
- 6735 0Y **Application of Mössbauer spectroscopy in the studies of oxidation of steel** [6735-56]
A. Amulevichius, K. Mazheika, Ch. Sipavichius, A. Daugvila, R. Davidonis, Institute of Physics (Lithuania)
- 6735 0Z **Mechanism of plasma generation under focused beam effect on metallic surface in laser welding** [6735-57]
V. S. Golubev, M. G. Galushkin, R. V. Grishaev, Yu. N. Zavalov, Institute on Laser and Information Technologies (Russia)

SESSION 6 LASER-MATTER INTERACTION

- 6735 10 **Pulsed plasma thruster based on solid-state lasers** [6735-27]
A. N. Chumakov, N. A. Bosak, A. M. Petrenko, Institute of Molecular and Atomic Physics (Belarus); M. V. Bogdanovich, A. I. Yenzhyieuski, A. V. Pozhidaev, M. A. Shemelev, A. G. Ryabtsev, G. I. Ryabtsev, B.I. Stepanov Institute of Physics (Belarus); Yu. A. Stankevich, Heat and Mass Transfer Institute (Belarus)
- 6735 11 **Deflection of sub-100-fs electrons by femtosecond light** [6735-38]
S. A. Aseyev, B. N. Mironov, S. V. Chekalin, Institute of Spectroscopy (Russia)
- 6735 12 **High-power and ultrashort laser pulse ablation of metals: threshold characteristics** [6735-49]
I. N. Zvestovskaya, O. A. Glazov, N. A. Menkova, P.N. Lebedev Physical Institute (Russia)
- 6735 13 **Laser ablation in liquids: an efficient sample preparation technique in ICP elemental analysis of art materials** [6735-50]
E. V. Klyachkovskaya, Institute of Molecular and Atomic Physics (Belarus); N. M. Kozhukh, National Art Museum of Belarus (Belarus); E. V. Muravitskaya, V. A. Rosantsev, M. V. Belkov, E. A. Ershov-Pavlov, Institute of Molecular and Atomic Physics (Belarus)
- 6735 14 **Time-resolved measurements of laser plasmas interaction during breakdown in normal atmosphere by various wavelengths** [6735-51]
A. A. Il'in, A. V. Bulanov, V.I. Il'ichev Pacific Oceanological Institute (Russia); S. S. Golik, Institute for Automation and Control Processes (Russia)

SESSION 7 POST-DEADLINE PAPERS

- 6735 15 **Surface-enhanced Raman scattering substrate and microfluidic waveguide fabricated by fs laser microprocessing** [6735-63]
Z. Zhou, H. Sun, Y. Cheng, Z. Xu, Shanghai Institute of Optics and Fine Mechanics (China)
- 6735 16 **LANTCET: laser nanotechnology for screening and treating tumor ex vivo and in vivo** [6735-67]
D. O. Lapotko, E. Y. Lukianova-Hleb, S. A. Zhdanok, Lykov Heat and Mass Transfer Institute (Belarus); J. H. Hafner, B. C. Rostro, P. Scully, Rice Univ. (USA); M. Konopleva, M. Andreeff, C. Li, E. Y. Hanna, J. N. Myers, The Univ. of Texas M.D. Anderson Cancer Ctr. (USA); A. A. Oraevsky, Fairway Medical Technologies, Inc. (USA)

6735 17 **Influence of laser beam focusing on LIBS efficiency at the elemental analysis of metals**
[6735-68]
V. I. Zhuravleva, V. A. Rozantsev, E. A. Ershov-Pavlov, Institute of Molecular and Atomic
Physics (Belarus)

6735 1X **Optical, structural, and lasing properties of a composite material nanoporous glass filled
with an organic dye-activated polymer** [6735-65]
S. S. Anufrik, M. I. Ihnatouski, Yanka Kupala State Univ. of Grodno (Belarus); M. F. Koldunov,
A.M. Prokhorov General Physics Institute (Russia); A. M. Lyalikov, Yanka Kupala State Univ.
of Grodno (Belarus); A. A. Manenkov, A.M. Prokhorov General Physics Institute (Russia);
V. V. Tarkovsky, Yanka Kupala State Univ. of Grodno (Belarus)

Author Index

Conference Committee

LAT 2007 Program Chairs

Vladislav Panchenko, Institute on Laser and Information Technologies
(Russia)
Valentin Orlovich, B.I. Stepanov Institute of Physics (Belarus)

LAT 2007 Scientific Secretaries

Mikhail Khodasevich, B.I. Stepanov Institute of Physics (Belarus)
Tatiana Lukovnikova, Institute on Laser and Information Technologies
(Russia)

Conference Chairs

Andrey Ionin, Lebedev Physical Institute (Russia)
Alexander Chumakov, Institute of Molecular and Atomic Physics
(Belarus)
Vladimir Golubev, Institute on Laser and Information Technologies
(Russia)
William J. Rich, Ohio State University (USA)

Program Committee

Friedrich Bachmann, ROFIN-SINAR Laser GmbH (Germany)
Boris Barmashenko, Ben-Gurion University of the Negev (Israel)
Joung Cook, Boeing Corporation (USA)
Vyacheslav Dlugunovich, B.I. Stepanov Institute of Physics (Belarus)
Miltcha Danailov, Laser Lab Sincrotrone-Trieste (Italy)
Hans Eichler, Technische Universität Berlin (Germany)
Salman Rosenwaks, Ben-Gurion University of the Negev (Israel)
Victor Vasiltssov, Institute on Laser and Information Technologies
(Russia)

Symposium Committees

ICONO/LAT 2007 General Chairs

Sergey Bagayev, Institute of Laser Physics (Russia)
Anatoly Rubinov, B.I. Stepanov Institute of Physics (Belarus)

ICONO/LAT 2007 General Vice-Chairs

Nikolai Kazak, B.I. Stepanov Institute of Physics (Belarus)
Vladimir Makarov, M.V. Lomonosov Moscow State University
(Russia)

ICONO/LAT 2007 Organizing Committee

Committee Chair

Vladimir Kabanov, B.I. Stepanov Institute of Physics (Belarus)

Committee Vice-Chairs

Vitaly Plavski, B.I. Stepanov Institute of Physics (Belarus)
Pavel Mikheev, M.V. Lomonosov Moscow State University (Russia)

Committee Members

Maria Drabovich, M.V. Lomonosov Moscow State University (Russia)
Alexander Grabchikov, B.I. Stepanov Institute of Physics (Belarus)
Valeri Gudelev, B.I. Stepanov Institute of Physics (Belarus)
Vyacheslav Dlugunovich, B.I. Stepanov Institute of Physics (Belarus)
Eugene Ivakin, B.I. Stepanov Institute of Physics (Belarus)
Maria Kulagina, B.I. Stepanov Institute of Physics (Belarus)
Boris Kuntsevich, B.I. Stepanov Institute of Physics (Belarus)
Svetlana Kurilkina, B.I. Stepanov Institute of Physics (Belarus)
Galina Ledneva, B.I. Stepanov Institute of Physics (Belarus)
Eugene Lutsenko, B.I. Stepanov Institute of Physics (Belarus)
Nikolai Malevich, B.I. Stepanov Institute of Physics (Belarus)
Andrey Olenin, M.V. Lomonosov Moscow State University (Russia)
Valeri Pavlenko, B.I. Stepanov Institute of Physics (Belarus)
Vyacheslav Pavlovskii, B.I. Stepanov Institute of Physics (Belarus)
Gennadi Ryabtsev, B.I. Stepanov Institute of Physics (Belarus)
Andrei Sobchuk, B.I. Stepanov Institute of Physics (Belarus)
Antonina Tretyakova, B.I. Stepanov Institute of Physics (Belarus)
Vyachedslav Chizhevskii, B.I. Stepanov Institute of Physics (Belarus)
Roman Shulyakovski, B.I. Stepanov Institute of Physics (Belarus)

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...

LAT 2007 Minsk

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



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.

2

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»)

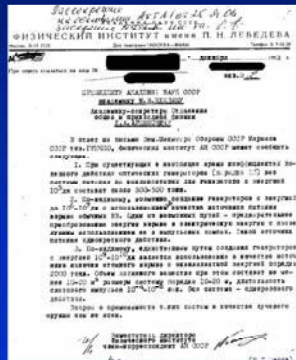
N.G. Basov- scientific leader pf the the « Terra-3 » program («T-3») ³

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**

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



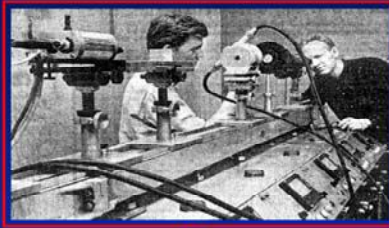
“Probably, it is possible to make generators with energy up to 10^6 - 10^7 j using an explosion of conventional HE as a power source...” (Basov meant laser generators)

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

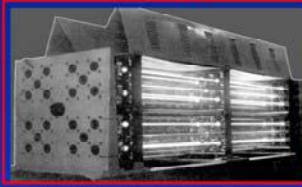
1961-1962 - reproduction and advancement of foreign laser development ideas and results



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

(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



6

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

7

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.Millionshikov** (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 .

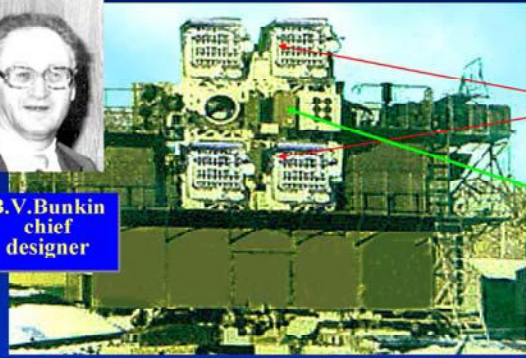
The system layout chosen was a **96 separate 100 kJ 1-10 ms ND-glass** modules multichannel design.

8

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 –
500 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)

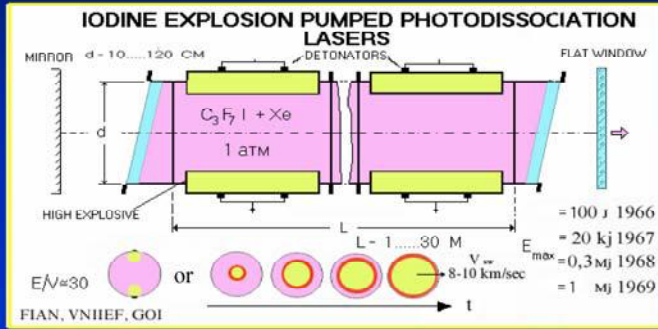
In 1964 J.V.V.Kasper, G.C.Pimentel reported the first PDL. In 1965 N.G. Basov and O.N.Krokhin suggested to start a very high energy PDL program in the USSR (T-3), based on the idea of using explosion shock wave front radiation in Xe as a very high power and energy optical pumping source. The shock wave 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!
11

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



EPDL Φ-1200₁₂
assembly at VNIIEF
1969

Laser model	Φ0 - 32	Φ0 - 21
D_{light} diameter meters	0,5	1,3
L_{active} 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 (diverg. rad)	$1 \cdot 10^{-4}$	$(2+3) \cdot 10^{-4}$

Some "Luch" EPDL specifications

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

13

CO₂ –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



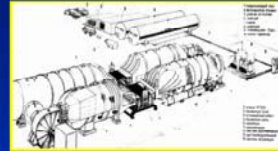
Vulnerability test of a drone target hit in flight by CO₂ laser beam “Almaz”

14

CO₂ – Lasers-2



An advanced model of a e-beam sustained CO₂ 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 15

The LE-1 laser radar

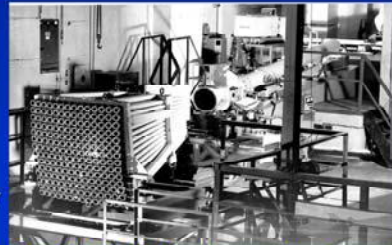
The potential ability of laser radar to provide extremely high precision measurements of target position for ABM systems was first studied in the “Vympel” design bureau in 1963. Design of an experimental laser radar for ABM research was started by “Vympel” in 1964. The only available high power short pulse laser was a ruby laser. A multi-channel laser system had to be used to provide 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)

N.G.Basov



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



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

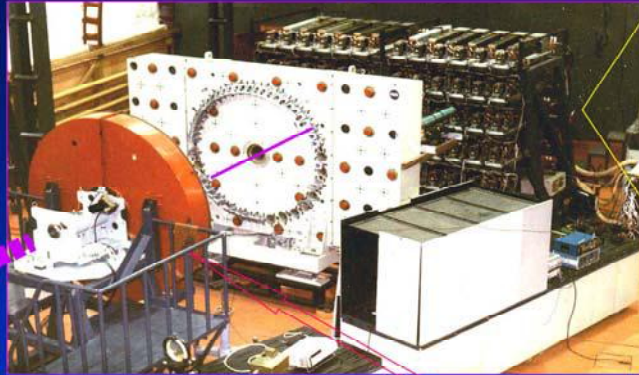


The experimental "Terra-3" 1,5 m beam director at Saryshagan

"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

Some of numerous new laser laboratories, design offices and test facilities established for “Ω” and “I-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

The Soviet HEL programs scientific and technical advisory councils



S.B.Korner



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-
Bruевич



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... “

22

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 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)

23

The authors:



Peter V. Zarubin (b.1932) -
Graduate of Moscow Physical-Technical Institute 1957 , PhD –1967, Prof - 1990
Head of laser physics laboratory in Moscow Institute of Applied Physics 1965
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
Winner of USSR state prize for science and Technology –1980
Winner of Russian Government prize for science and technology –2002



Nicolay V. Cheburkin (b.1941)-
Graduate of Moscow Energy Institute, 1964, Dr.sci – 1979, Prof-1990
Head of laser lab, laser department in “Granat” (“Astrophysica”)-196x-198x
Deputy chief designer, “Granat” Chief designer - 1981
“Granat” Director and chief designer since 1992 –
Professor, Chair of High Energy Lasers systems Department -Moscow Electronics and Automatics Technical University
Winner of USSR state prize for science and Technology –1978
Winner of USSR government prize for science and technology - 1990
Winner of Russian Government prize for science and technology –2002
Full member of the A.M.Prokhorov Academy of Engineering Sciences



Eugeny M. Sukharev (b.1933) –
Graduate of Moscow Physical-Technical Institute 1957 - Dr. Sci
Head of “Almaz” design bureau first laser systems laboratory - 1966
Deputy Chief designer of Laser systems – “Almaz” –since 1966 –
Professor (Radioelectronics) – Moscow Physical-Technical Institute
Winner of USSR state prize for science and Technology -
Full member of the A.M.Prokhorov Academy of Engineering Sciences

24

