PROCEEDINGS OF SPIE

Laser Technology 2018: Progress and Applications of Lasers

Jan K. Jabczyński
Ryszard S. Romaniuk
Editors

25–27 September 2018
Jastarnia, Poland

Sponsored by
Committee on Electronics and Telecommunication, Polish Academy of Sciences (Poland)
Polish Committee for Optoelectronics, Association of Polish Electrical Engineers (Poland)
Photonics Society of Poland (Poland)
Ministry of Science and Higher Education Warsaw (Poland)

Organized by
Military University of Technology (Poland)
Warsaw University of Technology (Poland)
Warsaw University (Poland)
Wrocław University of Technology (Poland)

Published by
SPIE

Volume 10974

Proceedings of SPIE 0277-786X, V. 10974

Laser Technology 2018: Progress and Applications of Lasers, edited by Jan K. Jabczyński, Ryszard S. Romaniuk,
Proc. of SPIE Vol. 10974, 1097401 · © 2018 SPIE · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2522499

The papers 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. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIEDigitalLibrary.org.

The papers 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 these proceedings:
Author(s), "Title of Paper," in *Laser Technology 2018: Progress and Applications of Lasers*, edited by Jan K. Jabczyński, Ryszard S. Romaniuk, Proceedings of SPIE Vol. 10974 (SPIE, Bellingham, WA, 2018) Seven-digit Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)

ISBN: 9781510626034
ISBN: 9781510626041 (electronic)

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

Printed in the United States of America.

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

SPIE. DIGITAL LIBRARY
SPIEDigitalLibrary.org

Paper Numbering: *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five 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.

Contents

Authors

Numbers in the index correspond to the last two digits of the seven-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first five digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Symposium Committees

Honorary Committee

Alfreda Padzik-Graczyk, Military University of Technology (Poland)
Zdzisław Jankiewicz, Military University of Technology (Poland)
Romuald Jóźwicki, Warsaw University of Technology (Poland)
Bohdan Mroziewicz, Institute of Electron Technology (Poland)
Zbigniew Puzewicz, Military University of Technology (Poland)
Wiesław Woliński, *full member of Polish Academy of Sciences*, Warsaw University of Technology (Poland)

Scientific Committee

Jan K. Jabczyński, (*Chair*), Military University of Technology (Poland)
Krzysztof Abramski, (*Vice-chair*), Wrocław University of Technology (Poland)
Michał Malinowski, (*Vice-chair*), Warsaw University of Technology (Poland)
Czesław Radzewicz, (*Vice-chair*), Warsaw University (Poland)
Bogdan Antoszewski, Kielce University of Technology (Poland)
Jan Badziak, Institute of Plasma Physics and Laser Microfusion (Poland)
Elżbieta Bereś-Pawlik, Wrocław University of Technology (Poland)
Zbigniew Bielecki, Military University of Technology (Poland)
Maciej Bugajski, Institute of Electron Technology (Poland)
Edward Chlebus, Wrocław University of Technology (Poland)
Dominik Dorosz, AGH University of Science and Technology (Poland)
Henryk Fiedorowicz, Military University of Technology (Poland)
Jan Kusiński, AGH University of Science and Technology (Poland)
Daniel Lisak, Mikołaj Kopernik University (Poland)
Bogusław Major, Institute of Metallurgy and Material Engineering (Poland)
Andrzej Maląg, Institute of Electronic Materials Technology (Poland)
Zygmunt Mierczyk, Military University of Technology (Poland)
Jerzy Mizeraczyk, Maritime University (Poland)
Zygmunt Mucha, Kielce University of Technology (Poland)
Włodzimierz Nakwaski, Łódź University of Technology (Poland)
Ryszard Pawlak, Łódź University of Technology (Poland)
Ryszard Piramidowicz, Warsaw University of Technology (Poland)
Antoni Rogalski, Military University of Technology (Poland)
Ryszard S. Romaniuk, Warsaw University of Technology (Poland)
Robert Sarzała, Łódź University of Technology (Poland)
Jarosław Sotor, Wrocław University of Technology (Poland)
Tadeusz Stacewicz, Warsaw University (Poland)
Yurij Stepanenko, Institute of Chemical Physics (Poland)
Lucjan Śnieżek, Military University of Technology (Poland)
Elżbieta Trafny, Military University of Technology (Poland)

Andrzej Zając, Białystok University of Technology (Poland)
Waldemar Żendzian, Military University of Technology (Poland)

Organizing Committee

Krzysztof Kopczyński, (*Chair*) Military University of Technology (Poland)
Kamila Iwańska-Zbojna, Military University of Technology (Poland)
Jadwiga Mierczyk, Military University of Technology (Poland)
Maria Wincenciak, Military University of Technology (Poland)
Przemysław Wachulak, Military University of Technology (Poland)
Mariusz Zbojna, Military University of Technology (Poland)
Arkadiusz Antończak, Wrocław University of Technology (Poland)
Ryszard Piramidowicz, Warsaw University of Technology (Poland)
Tadeusz Stacewicz, Warsaw University (Poland)

Session Chairs

Integrated Photonics
Krzysztof Abramski, Wrocław University of Technology (Poland)

Fibre Lasers
Czesław Radzewicz, Warsaw University (Poland)

NIR Pulse Lasers
Waldemar Żendzian, Military University of Technology (Poland)

Lasers in Research
Ryszard S. Romaniuk, Warsaw University of Technology (Poland)

Active Laser Materials
Zygmunt Mierczyk, Military University of Technology (Poland)

Semiconductor Lasers I
Maciej Bugajski, Institute of Electron Technology, Warsaw (Poland)

Semiconductor Lasers II
Andrzej Maląg, Institute of Electronic materials Technology (Poland)

Laser Applications I
Henryk Fiedorowicz, Military University of Technology (Poland)

Laser Applications II
Zygmunt Mucha, Kielce University of Technology (Poland)

Optoelectronic Measurements I
Zbigniew Bielecki, Military University of Technology (Poland)

Laser Applications III
Jan K. Jabczyński, Military University of Technology (Poland)

Optoelectronic Measurements II
Zbigniew Bielecki, Military University of Technology (Poland)

Introduction

Laser Technology (SLT 2018) was the twelfth symposium in a periodic series that deals with advances in the state-of-the-art of laser technology and applications in Poland. Historically this series of symposia has evolved since 1984, due to the work of the Committee of Electronics and Telecommunication of the Polish Academy of Sciences, the Polish Committee of Optoelectronics of the Association of Polish Electrical Engineers, and the support of relevant universities.

The First Symposium on Laser Technology was organized and hosted by the Nicolaus Copernicus University at Toruń (Poland) and co-organized by Warsaw University of Technology (Poland), the Military University of Technology (Poland), and the Industrial Center of Optics in Warsaw (Poland). Three volumes of Proceedings were published beginning in June 1984.

The Second Symposium Laser Technology was organized in 1987 by Szczecin University of Technology (Poland), Warsaw University of Technology (Poland), and the Military University of Technology (Poland). The host of the symposium was the Institute of Industrial Automation of Szczecin University of Technology (Poland). The SLT 1987 symposium provided material for four volumes of Proceedings. Two of them were published in Polish: a volume of 140 contributed papers and volume of 14 invited papers; and two in English— a volume of abstracts and the first SPIE Proceedings for the SLT series, volume 0859, edited by Ryszard S. Romaniuk, Bohdan K. Wołczak and Wielsaw L. Woliński.

Laser Technology III was organized in 1990 also by Szczecin University of Technology (Poland), Warsaw University of Technology (Poland) and Military University of Technology (Poland). It was hosted by the Institute of Industrial Automation of Szczecin University of Technology (Poland). The symposium provided materials for four volumes of Proceedings. Two published in Polish: a volume of 140 contributed papers and another of invited papers; and two in English— a volume of abstracts and SPIE Proceedings volume 1391.

Laser Technology IV was organized in 1993 by Szczecin University of Technology (Poland), Warsaw University of Technology (Poland) and the Military University of Technology (Poland). The host of the symposium was the Institute of Electronics and Computer Science of Szczecin University of Technology (Poland). The symposium provided material for five volumes of Proceedings. Two of them were published in Polish: a volume of contributed papers and another of invited papers; and three in English— a volume of abstracts and SPIE Proceedings volumes 2202 and 2203.

Laser Technology V was organized in 1996 by Szczecin University of Technology (Poland), Warsaw University of Technology (Poland) and the Military University of

Technology (Poland). The host of the symposium was the Institute of Electronics and Computer Science of Szczecin University of Technology (Poland). The symposium provided material for five volumes of Proceedings. Two of them were published in Polish: a volume of contributed papers and another one of invited papers; and three in English— SPIE Proceedings volumes 3186, 3187, and 3188.

Laser Technology VI was organized in 1999 by Szczecin University of Technology (Poland), Warsaw University of Technology (Poland), and the Military University of Technology (Poland), and by the Committee for Optoelectronics of the Association of Polish Electrical Engineers, under the auspices of the Polish Academy of Sciences Committee of Electronics and Telecommunication. The symposium provided material for four volumes of Proceedings. Two of them were published in Polish: a volume of contributed papers and another one of invited papers; and two in English— SPIE Proceedings volumes 4237 and 4238.

Laser Technology VII was organized in 2002 by Szczecin University of Technology (Poland), Warsaw University of Technology (Poland) and the Military University of Technology (Poland), and by the Committee for Optoelectronics of the Association of Polish Electrical Engineers and SPIE Poland Chapter, under the auspices of the Polish Academy of Sciences Committee of Electronics and Telecommunication. The symposium provided material for four volumes of Proceedings. Two of them were published in Polish: a volume of contributed papers and another one of invited papers; and two in English— SPIE Proceedings volumes 5229 and 5230.

Laser Technology VIII was organized in 2006 by Szczecin University of Technology (Poland), Warsaw University of Technology (Poland), and the Military University of Technology (Poland), and by the Committee for Optoelectronics of the Association of Polish Electrical Engineers and Poland Chapter of SPIE, under the auspices of the Polish Academy of Sciences Committee of Electronics and Telecommunication. The symposium was hosted by Institute of Electronics, Telecommunications and Computer Science of Szczecin University of Technology (Poland), and was held in Świnoujście, Poland, in September. The symposium provided material for four volumes of Proceedings. Two of them were published in Polish: a volume of contributed papers and another one of invited papers; and two in English— SPIE Proceedings volumes 6598 and 6599.

Laser Technology IX was organized in 2009 by Szczecin University of Technology (Poland), Warsaw University of Technology (Poland) and the Military University of Technology (Poland), and by the Committee for Optoelectronics of the Association of Polish Electrical Engineers and by the Photonics Society of Poland (converted from the Poland Chapter of SPIE), under the auspices of the Polish Academy of Sciences Committee of Electronics and Telecommunication. The symposium was hosted by Institute of Electronics, Telecommunications and Computer Science of Szczecin University of Technology (Poland) and was held in

Świnoujście, Poland, in September. The symposium provided material for a volume of abstracts. This time there was no SPIE Proceedings volume published.

The Jubilee Laser Technology X was organized in 2012 by West Pomeranian University of Technology in Szczecin (Poland) which converted from Szczecin University of Technology (Poland) and Szczecin University of Natural Sciences (Poland), Warsaw University of Technology (Poland), and the Military University of Technology (Poland), and by the Committee for Optoelectronics of the Association of Polish Electrical Engineers and Photonics Society of Poland, under the auspices of the Polish Academy of Sciences Committee of Electronics and Telecommunication. The symposium was hosted by Faculty of Electrical Engineering, Chair of Photonics of West Pomeranian University of Technology in Szczecin (Poland) and was held in Świnoujście, Poland, on 24–28 September.

Approximately 120 participants attended this symposium. Professor Wiesław L. Woliński, Chairman of the Polish Committee for Optoelectronics, and the Symposium Scientific Committee presented the welcome address and opened the meeting. The opening lectures were given by professor Zygmunt Mierczyk of the Military University of Technology (Poland) on lasers in the dual application technologies, and professor Krzysztof Abramski of Wrocław University of Technology (Poland) on optical fiber frequency combs.

The topics of Laser Technology X were as follows:

(1) Laser materials, components and assemblies;
(2) gas lasers, solid-state lasers, semiconductor lasers, and other kinds of lasers;
(3) generation, amplification, stabilization, synchronization, multiplication of frequencies, shaping of space and time characteristics of laser radiation;
(4) detection and registration of laser beam parameters;
(5) circuits, devices, apparatus and systems working with lasers; and
(6) applications of lasers in industry, medicine and biology, environment protection, military technology and in research. T

he tenth symposium provided material for three volumes of proceedings. One of them was published in Polish: a volume of abstracts of all symposium presentations; and two in English— SPIE Proceedings, volume 8702 *Progress in Lasers*; and volume 8703 *Applications of Lasers*. The Proceedings volumes contained 60 chosen reviewed papers by authors affiliated primarily with university based laboratories. The editors of these volumes were Wielsaw L. Woliński, Zdizsław Jankiewicz, and Ryszard S. Romaniuk, who would all go on to act as editors for the 2002, 2006, and 2012 Proceedings.

Laser Technology XI was organized in September 2016 by the Military University of Technology (Poland), Institute of Optoelectronics (Poland), in cooperation with Warsaw University of Technology (Poland), Warsaw University (Poland), and Wrocław University of Technology (Poland). The eleventh SLT was originally

scheduled for September 2015, but due to a number of additional conferences and meetings associated with celebrations of the International Year of Light in Poland (IYL2015), it had to be re-scheduled and finally delayed by one year. The Symposium SLT 2016 venue was the Jastarnia Resort situated on the Hel Peninsula at the Polish Baltic seashore. As was traditional the patronage and sponsoring organizations were: Polish Academy of Sciences Committee of Electronics and Telecommunication, Committee for Optoelectronics of the Association of Polish Electrical Engineers, and the Photonics Society of Poland, which evolved several years ago from the SPIE Poland Chapter.

The symposium provided material for two volumes of Proceedings. One of them was published in Polish: a volume of abstracts for contributed and invited papers; and one in English— SPIE Proceedings volume 10159. Approximately 140 participants attended this symposium from all leading research laser technology and laser application research centers in academia, research institutes, and industry. Over 120 papers were presented. The topics of Laser Technology XI were as follows: Lasers: Yesterday, Today and Tomorrow; Optical Fibre Lasers; Laser Applications in Research; New Types of Lasers; Applications of Lasers in Material Engineering and Nanotechnology; Industrial Applications of Lasers; Applications of Lasers in Medicine and Biomedical Engineering; Application of Lasers in Safety and Defense Systems; New Laser Materials, Components and Assemblies; Optical and Laser Measurements; and Laser Spectroscopy.

Laser Technology XII was held on 25–27 September 2018 in Jastarnia, Poland on the Hel Penninsula once more by Military University of Technology (Poland), Institute of Optoelectronics (Poland), in cooperation with Warsaw University of Technology (Poland), Warsaw University (Poland) and Wrocław University of Technology (Poland). The main aim of the meeting was exchange of information and dissemination of research and technical knowledge from the area of laser technology and optoelectronics.

The symposium was attended by representatives of key academic centers, research institutes and a broad community of manufacturers, vendors, and users of laser technology. The thirteenth symposium was opened with a memorial lecture on the research and technical activities of the late professor Zbigniew Puzewicz, who was a leader of the Chair of Fundamentals of Radiotechnics at the Faculty of Radioelectronics at the Military Academy of Technology (Poland) in the 1960's. He worked on the first laser launched in Poland on 20 August 1963.

The thirteenth symposium summarized the research and technical achievements in Poland during the period of 2016–2018. Traditionally the subject area of the STL symposium is divided to two branches: research and development of lasers and laser systems, and laser applications. Development of laser technology included main subjects: laser sources UV-VIS-IR, picosecond and femtosecond lasers, fiber lasers and amplifiers, semiconductor lasers, high power/high energy lasers and their applications, new materials and laser components. Applications of lasers

included: measurement techniques, metrology, research applications, military applications, monitoring and preservation of natural environment, remote sensing of trace substances, industry, material processing, material engineering.

The partners and sponsors of the thirteenth symposium were: PCO SA (Poland), CRW Telesystem Mesko (Poland), and VIGO System SA (Poland).

The Symposium Chairs and Editors would like to thank personally the authors and conference contributors who made this book possible. Special cordial thanks are also due to SPIE for supporting the symposium by undertaking the publication of the Proceedings volumes for the last nearly three decades. The Symposium Committee announces with pleasure that the next meeting on Laser Technology is scheduled to be held in September 2020, and will be organized by Wrocław University of Technology (Poland).

Jan K. Jabczyński
Ryszard S. Romaniuk

In Memory of Professor Zbigniew Puzewicz (1930-2018)

Photo Archive, Institute of Optoelectronics, WAT

Professor Zbigniew Puzewicz was born on 14 February 1930 in Wilno, Poland (now Vilnius, Lithuania). After the war, he and his family were repatriated to Gdańsk, where in 1948 he began his studies at the Faculty of Electrical Engineering at the Gdańsk University of Technology (Poland). He graduated in 1951, obtaining a Bachelor of Electrical Engineering in 1952. In 1951, he was transferred to the Military University of Technology in Warsaw, Poland, where along with continuing his Master's degree, he taught laboratory and accounting classes. Even before the defense of his master's thesis, he began to conduct lectures on the basics of field theory and high-frequency techniques, theoretical foundations of radio technology and electromagnetic field theory, as well as ultra-short wave techniques, quantum electronics, and selected issues of vacuum devices. In December 1960, he successfully defended his doctoral thesis, and in 1961 he took over the chairmanship of the Department of Radio Technology. However, he would turn his focus to quantum electronics. In 1967 he founded the Institute of Quantum Electronics at the Military University of Technology (Poland), which he managed until 1994 before assuming control of the Quantum Electronics Group of the Institute of Optoelectronics (Poland).

Under Professor Zbigniew Puzewicz's direction at the Department of Radio Technology, the first lasers in Poland were created: in August 1963, the He-Ne laser that generated radiation with a wavelength of 1.15 μm, a ruby laser in November of that year, and in 1966 the first high-power molecular CO_2 laser in Poland. After developing these lasers, the professor began working on their various applications. In March 1965, a laser coagulator demonstration took place and, shortly thereafter, in April, the first eye coagulation operation in Europe was conducted. From 1965 to 1978, the lasers developed by the

professor at the Eye Diseases Clinic of the Medical Academy in Warsaw (Poland) were employed in over 6,000 operations. Another medical laser, the Laser Lancet, was made in 1978. In the Otolaryngological Clinic (Poland), approximately 2,300 operations were performed using a laser scalpel from the Quantum Electronics Institute (Poland).

However, the most important sphere of Professor Puzewicz's scientific work involved the research and implementation of military optoelectronic systems. The systems developed by PORTLAND (a laser art rangefinder), SKO MERIDA (a fire control system), BOBRAWA (a laser warning system) and the fire control systems of SKO DRAWA and SKO DRAWA-T for the T-72 tank were all manufactured between 1984 and 1990 at the Industrial Center of Optics in Warsaw for the purposes of the Armed Forces and export. After creating the Quantum Electronics Group, prof. Puzewicz devoted himself entirely to work on rocket technology and precision-guided munitions. Under the direction of the professor, GROM-I (1996) and GROM (2000) portable anti-aircraft rocket systems were created and implemented. Right until the end, he managed work on the latest PIORUN projectile. Professor Puzewicz was the originator of the mobile version of the KUSZA rocket system. He also directed work on the LPC-1 target laser and homing warheads for 120 mm mortar grenades and 155 mm artillery shells, as well as the PIRAT anti-tank rocket system.

Professor Zbigniew Puzewicz believed that the technical and scientific value of a project can only be properly determined after it has been fully implemented and in doing so, the theoretical basis behind the academic endeavour is confirmed.

Krzysztof Kopczyński
Zygmunt Mierczyk