# PROCEEDINGS OF SPIE

# Laser Resonators, Microresonators, and Beam Control XX

Alexis V. Kudryashov Alan H. Paxton Vladimir S. Ilchenko Editors

29 January—1 February 2018 San Francisco, California, United States

Sponsored and Published by SPIE

**Volume 10518** 

Proceedings of SPIE 0277-786X, V. 10518

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

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 Resonators, Microresonators, and Beam Control XX, edited by Alexis V. Kudryashov, Alan H. Paxton, Vladimir S. Ilchenko, Proceedings of SPIE Vol. 10518 (SPIE, Bellingham, WA, 2018) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510615212

ISBN: 9781510615229 (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

Copyright © 2018, 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/18/\$18.00.

Printed in the United States of America.

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



**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**

vii	Authors
ix	Conference Committee
xiii	Introduction
	NOVEL MICRORESONATOR TOPOLOGIES AND SENSORS I
10518 02	Electro-optic tuning of potassium tantalate-niobate whispering gallery resonators [10518-1]
10518 04	Nonlinear behavior in hybrid microcavities (Invited Paper) [10518-3]
10518 05	Hollow whispering gallery resonators (Invited Paper) [10518-4]
	MICRORESONATORS AND OPTICAL FREQUENCY COMBS I: JOINT SESSION WITH CONFERENCES 10516 AND 10518
10518 OB	Integrated Kerr micro-comb sources for photonic microwave applications (Invited Paper) [10518-10]
10518 0D	Temporal cavity solitons in synchronously driven Fabry-Perot microresonators (Invited Paper) [10518-12]
10518 OE	Advances in nonlinear phenomena in whispering gallery mode resonators [10518-13]
	MICRORESONATORS AND OPTICAL FREQUENCY COMBS II: JOINT SESSION WITH CONFERENCES 10516 AND 10518
10518 OH	Saturable absorption by carbon nanotubes on silica microtoroids for stable mode locking [10518-16]
10518 01	Wideband critically coupled resonators [10518-17]
10518 OJ	Agile generation of microresonator-based frequency combs without pump detuning and local temperature controlling [10518-18]

### MICRORESONATOR LASERS AND RF PHOTONICS 10518 ON Ultra-low noise microwave signal generation with an optical frequency comb (Invited Paper) [10518-22] 10518 OP Whispering gallery mode resonators for mid-IR quantum and interband cascade laser analysis and control [10518-24] QUANTUM OPTICS AND OPTOMECHANICS WITH MICRORESONATORS 10518 OS Surface scattering and opto-mechanical effects in droplet microresonators (Invited Paper) [10518-27] 10518 OU Incoherently pumped lasing and self-pumped three-wave mixing in laser-active whisperinggallery resonators [10518-29] **NOVEL MICRORESONATOR TOPOLOGIES AND SENSORS II** 10518 0V Using the lasing threshold in whispering gallery mode resonators for refractive index sensing [10518-30] 10518 0W Environmentally stable integrated ultra-high-Q optical cavities [10518-32] 10518 0X Mid-infrared whispering gallery resonators based on non-oxide nonlinear optical crystals [10518-33] **NOVEL MICRORESONATOR TOPOLOGIES AND SENSORS III** 10518 OY Sensitivity-enhanced intracavity-absorption acetylene sensor based on mode competition [10518-35] 10518 OZ Mode-splitting for refractive index sensing in fluorescent whispering gallery mode resonators with broken symmetry [10518-37] 10518 10 Dual coupler coupled cavities optical gyroscope with enhanced performance [10518-31] LASER MODE CONTROL AND MODELING I 10518 11 Dynamically stable operation of a 100-watt level CW single frequency ring laser at 1064 nm [10518-38] 10518 13 FPGA based laser frequency stabilization using FM spectroscopy [10518-40]

10518 14	Characterization on the effect of group delay in a total reflection prism ring resonator [10518-41]
	LASER MODE CONTROL AND MODELING II
10518 15	Analytic treatment of high power diode pumped lasers with unstable resonator in a flowing medium (Invited Paper) [10518-42]
10518 16	Intracavity diode-side-pumped Raman laser at 1147 nm and 1163 nm [10518-43]
10518 17	Spectrally stabilized high-power high-brightness DBR-tapered lasers in the VIS and NIR range [10518-44]
	ADAPTIVE OPTICS I
10518 18	Comparison of the efficiency of laser beam focusing through the scattering medium using 14-and 31-channel bimorph mirrors (Invited Paper) [10518-45]
10518 19	Development of an adaptive laser beam shaper [10518-46]
10518 1A	Arbitrary control of the polarization state and intensity of non-diffracting beams along their propagation direction [10518-47]
10518 1B	High-energy OPA stability control with adaptive lenses [10518-48]
	ADAPTIVE OPTICS II
10518 1E	Formation of the doughnut and super-Gaussian intensity distribution by means of different types of wavefront correctors [10518-51]
	ULTRASHORT LASER
10518 1H	Femtosecond laser transverse mode conversion by an achromatic volume phase mask [10518-54]
	BEAM CHARACTERIZATION AND SHAPING I
10518 11	Anamorphic beam shaping for efficient laser homogenization: methods and high power applications (Invited Paper) [10518-55]
10518 1J	Analysis of wavefront structures of diode lasers by their spatial and current dependent evolution [10518-56]

10518 1K	M-squared measurement with improved repeatability for CW to single pulse lasers [10518-57]
10518 1L	Solving the logarithmic Monge-Ampère equation with a RK4-algorithm for beam shaping purposes of femtosecond laser beams with spatial light modulators [10518-58]
	BEAM CHARACTERIZATION AND SHAPING II
10518 1N	A novel laser resonator for fractal modes [10518-60]
10518 1P	Manipulation of Airy beams in photonic lattices by means of optical Bloch oscillation [10518-62]
10518 1Q	Non-paraxial diffractive and refractive laser beam shaping [10518-63]
10518 1R	Power handling for LCoS spatial light modulators [10518-64]
10518 1S	Gradient-index beam shapers: fabricated devices and 3D design method (Invited Paper) [10518-65]
10518 1T	Generation and amplification of vector vortex beams [10518-66]
	POSTER SESSION
10518 1U	Dielectric equilateral triangle microresonators: integral equations and semi-classical physics approaches [10518-67]
10518 1V	Investigation of an ultra large mode area power amplifier stage for a pulsed 1550-nm laser system [10518-69]
10518 1X	Efficient octave-spanning frequency comb generation in normal dispersion regime [10518-72]
10518 1Y	Longitudinally excited CO <sub>2</sub> laser with short laser pulse and high quality beam [10518-73]
10518 1Z	High-efficiency coupling to small-core microstructured fibers for broadband dispersion characterization [10518-74]
10518 20	New topologies of femtosecond Er:fibre laser cavities [10518-75]

#### **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.

Adib, George A., 10 Agarwal, Anuradha M., 0J Alexandre, Christophe, ON Antropov, Alexander, 20 Arlotti, C., 01

Armani, Andrea, 04, 0W

Avino, S., OS

Bao, Changjing, 1X Bartosch, Wolfgang, 13 Bauchert, Kipp, 1R Beck, Torsten, 11 Bereczki, Allan, 11 Bittner, Stefan, 1U Blume, Holger, 13 Bonora, Stefano, 1B Borri, Simone, OP Bouchand, Romain, ON Brasch, Victor, 0D Breunig, Ingo, 02, 0U, 0X Buse, Karsten, 02, 0U, 0X

Calvez, S., Ol Carbajo, Sergio, 1R Chembo, Yanne K., 0E Chen, Dongyu, 04, 0W Choi, Hyungwoo, 04 Chu, Sai T., OB Ciriolo, Anna G., 1B

Corato-Zanarella, Mateus, 1A Courtial, Johannes, 1N D'Amato, Francesco, OP D'Ambrosio, Davide, OP Datta, Shubhashish, ON De Natale, Paolo, OP, OS Devetta, Michele, 1B Diallo, Souleymane, 0E Dietz, Barbara, 1U Divliansky, Ivan, 1H Dorer, Stefan, 11 Dorrah, Ahmed H., 1A Douglass, Glen, 1S Duan, Liangcheng, 0Y

Eichentopf, Inga-Maria, 1J Eliyahu, Danny, OP Ertmer, Wolfgang, 13 Fernandez, A., 01 Ferreira, Amauri A., 11 Ferreira, Merilyn S., 16 Flamm, Daniel, 11 Forbes, Andrew, 1N, 1T

François, Alexandre, OV, OZ

Gagliardi, G., 0S Galaktionov, Ilya, 18, 1E Gauthier-Lafaye, O., 01 Gavrielides, Athanasios, 15

Ghorevshi, Ali, 1S Giorgini, A., 0S Giunta, Michele, 0N Glebov, Leonid, 1H Goto, Hayato, 1Y Gross, Simon, 1S Guo, Yuhao, 0J, 1X Gutierrez, N., 01 Haas, Gil, 1K Hale, Evan R., 1H Hanka, Kevin, 0X Hänsel, Wolfgang, 0N Hawks, Michael R., 15 Heimes, Andreas, 11 Hellmann, Christian, 1Q Hellstern, Julian, 11 Henry, Leanne J., 1V Herr, Simon J., 0U Herr, Tobias, 0D Hirota, Naoya, 0H Holzwarth, Ronald, ON Hori, Atsuhiro, 0H Horn, Alexander, 1L Ilchenko, Vladimir, OP Insero, Giacomo, OP

Jitsuno, Takahisa, 1Y Joshi, Abhay, 0N Kang, Yvonne Q., 0Z Kasumie, S., 05 Khalil, Diaa, 10

Jain, Ravinder, 1V

Jia, Yuechen, 0X

Kimerling, Lionel C., 0J Kini Manjeshwar, Sushanth, 02

Klopfer, Michael, 1V Knoth, Roberto, 1Q Kobtsev, Sergey, 20 Koliada, Natalia, 20 Komanec, Matej, 1Z König, Hans-Georg, 19 Kovach, Andre, 04, 0W Kratsch, Alexander, 1L Kudryashov, Alexis, 18, 1E, 21 Kumagai, Tsutaru, OH

Kunkel, W. Minster, 1S Lafargue, Clément, 1U Lange, Felix, 19 Lebental, Mélanie, 1U Lecomte, Steve, 0D Le Coq, Yann, 0N Leger, James R., 1S Lei, F., 05 Lezius, Matthias, 0N Li, Dong, 14 Li, Guifang, 0J, 1X Li, Jianhui, 1Y Liao, Pengcheng, 1X Lingel, Christian, 11 Lisa, Nyameko, 1T Little, Brent E., OB Litvin, laor, 1T Llopis, O., 01 Loosen, Peter, 19 Loper, Robert D., 15 Lopez Garcia, Inaki, 0P Lours, Michel, 0N Lu, Ying, 0Y Madugani, R., 05 Maki, Hideyuki, 0H Malara, P., 0S Maleki, Lute, OP Marschall, Felix, 11 Matsko, Andrey, OP Michel, Jurgen, 0J Mitchell, Arnan, 0B Mocci, Jacopo, 1B Mojahedi, Mo, 1A Monmayrant, A., Ol Monro, Tanya M., 0V, 0Z Morandotti, Roberto, OB Moss, David J., 0B Muradore, Riccardo, 1B Naidoo, Darryl, 1N, 1T Namiki, Koki, 0H Negro, Matteo, 1B Nemecek, Tomas, 1Z Nic Chormaic, S., 05 Nicolodi, Daniele, 0N Nikitin, Alexander, 18, 1E Nyushkov, Boris, 20 Obrzud, Ewelina, 0D Olbrich, Markus, 1L Paschke, Katrin, 17 Pask, Helen M., 16 Perram, Glen P., 15 Pivtsov, Victor, 20 Poust, Sumiko, OW Pshonkin, Danila, 21 Pütsch, Oliver, 19 Quintavalla, Martino, 1B Rasel, Ernst M., 13 Reufer, Martin, 1J

Riesen, Nicolas, 0Z Rukosuev, Alexey, 1E Sabry, Yasser M., 10 Samarkin, Vadim, 18, 1E, 21 Santambrogio, Gabriele, OP Santarelli, Giorgio, 0N Sato, Katsuya, OH Savchenkov, Anatoliy, OP Scagas, Michael, 1K Schlie, L. A. (Vern), 15 Schunemann, Peter G., 0X Schwefel, Harald, 0V Sheldakova, Julia, 18, 1E Shen, Xiaoqin, 04, 0W Shi, Wei, 0Y Siciliani de Cumis, Mario, OP Skvortsov, Arkadiy, 21 Soltani, Soheil, 04 Spindeldreier, Christian, 13 Sroor, Hend, 1N, 1T Stagira, Salvatore, 1B Stollenwerk, Jochen, 19 Sukharevsky, Ilya O., 1U Sumpf, Bernd, 17 Suslov, Dmytro, 1Z Szabados, Jan, 02 Tanabe, Takasumi, 0H Tillkorn, Christoph, 11 Toporovskiy, Vladimir, 21 Tremblin, Pierre-Alain, 0N Uno, Kazuyuki, 1Y Viciani, Silvia, OP Vozzi, Caterina, 1B Wang, Jing, 0J Ward, J. M., 05 Weißmantel, Steffen, 1L Wendrich, Thijs, 13 Wetter, Niklaus U., 11, 16 Willner, Alan E., 1X Withford, Michael J., 1S Wu, Jiayang, 0B Wyrowski, Frank, 1Q Xiao, Fajun, 1P Xie, Xiaopeng, 0N Xu, Lijuan, OJ Xu, Xingyuan, 0B Xue, Lifang, 0Y Yakovlev, Arkadii, 20 Yang, Liangxin, 1Q Yang, Minghui, 1X Yang, Xianchao, 0Y Yang, Y., 05 Yao, Jianquan, 0Y Zamboni-Rached, Michel, 1A Zawilski, Kevin T., 0X Zhang, Haiwei, 0Y Zhana, Lin, OJ, 1X Zhao, Jianlin, 14, 1P

Zvanovec, Stanislav, 1Z

#### **Conference Committee**

Symposium Chairs

Koji Sugioka, RIKEN (Japan)

**Reinhart Poprawe**, Fraunhofer-Institut für Lasertechnik (Germany)

Symposium Co-chairs

**Xianfan Xu**, Purdue University (United States) **Beat Neuenschwander**, Berner Fachhochschule Technik und

Informatik (Switzerland)

**Program Track Chairs** 

Vladimir S. Ilchenko, GM Cruise LLC (United States)

**Paul O. Leisher**, Rose-Hulman Institute of Technology (United States)

Conference Chairs

**Alexis V. Kudryashov**, Institute of Geosphere Dynamics (Russian Federation)

Alan H. Paxton, Air Force Research Laboratory (United States)

Vladimir S. Ilchenko, GM Cruise LLC (United States)

Conference Co-chair

Lutz Aschke, TRUMPF Lasertechnik GmbH (Germany)

Conference Program Committee

**Andrea M. Armani**, The University of Southern California (United States)

Gaurav Bahl, University of Illinois (United States)

Yanne K. Chembo, FEMTO-ST (France)

Jean-Claude M. Diels, The University of New Mexico (United States)

Hans Joachim Eichler, Technische Universität Berlin (Germany)

**Andrew Forbes**, University of the Witwatersrand, Johannesburg (South Africa)

Pierre Galarneau, INO (Canada)

Michael L. Gorodetsky, Russian Quantum Center (Russian Federation)

**Thomas Graf**, Universität Stuttgart (Germany)

**Tobias J. Kippenberg**, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

James R. Leger, University of Minnesota, Twin Cities (United States)

Andrey B. Matsko, OEwaves, Inc. (United States)

Gualtiero Nunzi Conti, Istituto di Fisica Applicata "Nello Carrara" (Italy)

Andrew W. Poon, Hong Kong University of Science and Technology
(Hong Kong, China)

Michael J. Scaggs, Haas Laser Technologies, Inc. (United States)

Haiyin Sun, ChemImage Corporation (United States)
Yun-Feng Xiao, Peking University (China)

**Lei Xu**, Fudan University (China)

Lan Yang, Washington University in St. Louis (United States)

#### Session Chairs

- Novel Microresonator Topologies and Sensors I
   Vladimir S. Ilchenko, GM Cruise LLC (United States)
- Quantum Optics with Microresonators Andrea M. Armani, The University of Southern California (United States)
- 3 Microresonators and Optical Frequency Combs I: Joint Session with Conferences 10516 and 10518 Andrey B. Matsko, OEwaves, Inc. (United States)
- 4 Microresonators and Optical Frequency Combs II: Joint Session with Conferences 10516 and 10518
  - **Konstantin L. Vodopyanov**, CREOL, The College of Optics and Photonics, University of Central Florida (United States)
- Microresonator Lasers and RF Photonics
   Yanne K. Chembo, FEMTO-ST (France)
   Vladimir S. Ilchenko, GM Cruise LLC (United States)
- 6 Quantum Optics and Optomechanics with Microresonators
  Alan H. Paxton, Air Force Research Laboratory (United States)
- 7 Novel Microresonator Topologies and Sensors II Gaurav Bahl, University of Illinois (United States)
- 8 Novel Microresonator Topologies and Sensors III Vladimir S. Ilchenko, GM Cruise LLC (United States)
- 9 Laser Mode Control and Modeling I Alexis V. Kudryashov, Institute of Geosphere Dynamics (Russian Federation)
- 10 Laser Mode Control and Modeling II Jean-Claude M. Diels, The University of New Mexico (United States)

- 11 Adaptive Optics IAlan H. Paxton, Air Force Research Laboratory (United States)
- 12 Adaptive Optics II

  Jean-Claude M. Diels, The University of New Mexico (United States)
- 13 Ultrashort Laser
  James R. Leger, University of Minnesota, Twin Cities (United States)
- 14 Beam Characterization and Shaping I Lutz Aschke, TRUMPF Lasertechnik GmbH (Germany)
- Beam Characterization and Shaping II
  Michael J. Scaggs, Haas Laser Technologies, Inc. (United States)

#### Introduction

This volume includes the proceedings of the 20th conference on Laser Resonators, Microresonators and Beam Control. Twenty years ago, we started this conference as a one-day meeting. Back in 1998, we had just 18 papers, while this year, the number of announced presentations exceeded 70! In total we had 15 oral sessions, as well as 7 poster presenters.

We would certainly like to thank conference co-chair Dr. Lutz Ashke, as well as all members of the Program Committee, for their input in putting together the scientific program, inviting outstanding scientists, and their personal contribution to the success of our meetings. We also would like to thank the first co-chair, Dr. Pierre Galarneau, for advancing the initial success of our meetings, as well as former conference co-chair Dr. Kunihiko Washio for his important contributions.

Alexis V. Kudryashov Alan H. Paxton Vladimir S. Ilchenko