PROCEEDINGS OF SPIE

Photonic Heat Engines: Science and Applications

Denis V. Seletskiy Richard I. Epstein Mansoor Sheik-Bahae Editors

3–4 February 2019 San Francisco, California, United States

Sponsored and Published by SPIE

Volume 10936

Proceedings of SPIE 0277-786X, V. 10936

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

Photonic Heat Engines: Science and Applications, edited by Denis V. Seletskiy, Richard I. Epstein, Mansoor Sheik-Bahae, Proc. of SPIE Vol. 10936, 1093601 © 2019 SPIE · CCC code: 0277-786X/19/\$18 · doi: 10.1117/12.2531283

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 *Photonic Heat Engines: Science and Applications*, edited by Denis V. Seletskiy, Richard I. Epstein, Mansoor Sheik-Bahae, Proceedings of SPIE Vol. 10936 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510625143

ISBN: 9781510625150 (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 © 2019, 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/19/\$18.00.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

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

v vii	Authors Conference Committee
	LASER COOLING AND RADIATION-BALANCED LASERS IN SEMICONDUCTORS
10936 04	Evaluation of CsPbBr ₃ nanocrystals for laser cooling [10936-3]
10936 06	Anti-Stokes laser refrigeration of a nanoscale semiconductor gain medium (Invited Paper) [10936-4]
	NOVEL PHOTONIC HEAT ENGINES AND ELECTROLUMINESCENT COOLING
10936 0A	Observation of local electroluminescent cooling and identifying the remaining challenges (Invited Paper) [10936-9]
10936 OB	Practical efficiency limits of electroluminescent cooling (Invited Paper) [10936-10]
	COOLING IN RARE-EARTH-DOPED BULK AND FIBER SYSTEMS I
10936 OE	Laser cooling under ambient conditions in Yb³+:KYW (Invited Paper) [10936-13]
	COOLING IN RARE-EARTH-DOPED BULK AND FIBER SYSTEMS II
1000 / 011	
10936 OH	Progress towards optical cryocooling in Mid-IR [10936-16]
10936 0H	Progress towards optical cryocooling in Mid-IR [10936-16] Laser refrigeration of optical fibers via optically active composite cladding materials [10936-17]
	Laser refrigeration of optical fibers via optically active composite cladding materials
	Laser refrigeration of optical fibers via optically active composite cladding materials [10936-17]

10936 0M Laser cooling of solids: towards biomedical applications [10936-21]

POSTER SESSION

10936 OU	Temperature dependence of thermophotonic energy transfer in intracavity structures [10936-29]
10936 OV	Prospects for rapid laser cooling on ED-allowed transitions [10936-30]

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.

Abaie, Behnam, OK Albrecht, Alexander R., 0H Andrade, Luis H. C., 0E Andre, Laura B., OE, OV Aubert, Nicolas, 0M Casado, Alberto, 0U Cazals, Johan, 0M Chabardès, Stephan, 0M Chen, Kaifeng, OB Cheng, Long, 0E, 0V Davis, E. James, 06, 01 Dupoy, Mathieu, 0M Fan, Shanhui, OB Glière, Alain, 0M Guina, Mircea, 0A Janko, Boldizsar, 04 Kuno, Masaru, 04 Lima, Sandro M., 0E Mafi, Arash, 0K Mermillod, Quentin, 0M Mobini Souchelmaei, Esmaeil, OK Nemova, Galina, 0L Oksanen, Jani, 0A, 0U Pant, Anupum, 06, 01 Pauzauskie, Peter J., 06, 01 Peysokhan, Mostafa, OK Radevici, Ivan, OA, OU Rand, Stephen C., 0E, 0V Ranta, Sanna, OA Rostami, Saeid, 0H Sadi, Toufik, OA, OU Salkeld, Alexander J., 0E, 0V Santhanam, Parthiban, OB Sheik-Bahae, Mansoor, OH Silva, Junior R., 0E Tiira, Jonna, 0A Tripurari, Tripathi, 0A Tukiainen, Antti, 0A Volpi, Azzurra, 0H Xia, Xiaojing, 06, 01 Xiao, T. Patrick, OB Yablonovitch, Eli, OB Zhang, Shubin, 04

Zhukovskyi, Maksym, 04

Conference Committee

Symposium Chairs

Connie J. Chang-Hasnain, University of California, Berkeley (United States)

Graham T. Reed, Optoelectronics Research Centre, University of Southampton (United Kingdom) Symposium Co-chairs

Symposium Co-chairs

Sailing He, KTH Royal Institute of Technology (Sweden) and Zhejiang University (China)

Yasuhiro Koike, Keio University (Japan)

Program Track Chair

David L. Andrews, University of East Anglia (United Kingdom)

Conference Chairs

Denis V. Seletskiy, Ecole Polytechnique de Montréal (Canada) **Richard I. Epstein**, ThermoDynamic Films LLC (United States) **Mansoor Sheik-Bahae**, The University of New Mexico (United States)

Conference Program Committee

Gaurav Bahl, University of Illinois (United States)

James G. Eden, University of Illinois (United States)

Joaquín Fernández, Universidad del País Vasco (Spain)

Raman Kashyap, Ecole Polytechnique de Montréal (Canada)

Paul D. LeVan, Air Force Research Laboratory (United States)

Ali Sayir, Air Force Office of Scientific Research (United States)

Mauro Tonelli, Università di Pisa (Italy)

Qihua Xiong, Nanyang Technological University (Singapore)

Session Chairs

- Laser Cooling and Radiation-balanced Lasers in Semiconductors Markus P. Hehlen, Los Alamos National Laboratory (United States)
- 2 Novel Photonic Heat Engines and Electroluminescent Cooling Mansoor Sheik-Bahae, The University of New Mexico (United States)

- 3 Cooling in Rare-Earth-Doped Bulk and Fiber Systems I Denis V. Seletskiy, Ecole Polytechnique de Montréal (Canada)
- 4 Cooling in Rare-Earth-Doped Bulk and Fiber Systems II

 Markus P. Hehlen, Los Alamos National Laboratory (United States)
- 5 Characterization Methods and Novel Concepts in Laser Cooling **Denis V. Seletskiy**, Ecole Polytechnique de Montréal (Canada)
- 6 Radiation-balanced Lasers
 Azzura Volpi, The University of New Mexico (United States)