PROCEEDINGS OF SPIE

Tri-Technology Device Refrigeration (TTDR)

Richard I. Epstein Bjørn F. Andresen Markus P. Hehlen Joseph P. Heremans Ingo N. Rühlich Mansoor Sheik-Bahae Editors

19–20 April 2016 Baltimore, Maryland, United States

Sponsored and Published by SPIE

Volume 9821

Proceedings of SPIE 0277-786X, V. 9821

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

Tri-Technology Device Refrigeration (TTDR), edited by Richard I. Epstein, Bjørn F. Andresen, Markus P. Hehlen, Joseph P. Heremans, Ingo N. Rühlich, Mansoor Sheik-Bahae, Proc. of SPIE Vol. 9821, 982101 · © 2016 SPIE · CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2244374 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 Tri-Technology Device Refrigeration (TTDR), edited by Richard I. Epstein, Bjørn F. Andresen, Markus P. Hehlen, Joseph P. Heremans, Ingo N. Rühlich, Mansoor Sheik-Bahae, Proceedings of SPIE Vol. 9821 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number..

ISSN: 0277-786X ISSN: 1996-756X (electronic) ISBN: 9781510600621

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 © 2016, 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/16/\$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 six-digit CID article numbering system structured as follows:

- 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.

Contents

- v Authors
- vii Conference Committee

OPTICAL REFRIGERATION

- 9821 03 Measuring the anti-Stokes luminescence of CdSe/ZnS quantum dots for laser cooling applications (Invited Paper) [9821-2]
- 9821 04 Cooling enhancement in optical refrigeration by non-resonant optical cavities (Invited Paper) [9821-3]
- 9821 06 Investigation of anti-Stokes Raman processes at phonon-polariton resonances for phonon removal and laser cooling [9821-33]

MECHANICAL CRYOCOOLERS I

- 9821 07 Raytheon advanced pulse-tube cryocoolers [9821-5]
- 9821 08 Advantages of high-frequency Pulse-tube technology and its applications in infrared sensing [9821-6]

MECHANICAL CRYOCOOLERS II

- 9821 09 **RICOR development of the next generation highly reliable rotary cryocooler** [9821-7]
- 9821 0B The development of a cryogenic integrated system with the working temperature of 100K [9821-9]
- 9821 0C Overview of Sumitomo coolers and Dewars for space use [9821-10]

COOLER DEWAR INTEGRATION

- 9821 0D The integrated cryogenic system for the atmospheric vertical interferometric detector on FY-4 satellite [9821-11]
- 9821 0E Multimodal tuned dynamic absorber for split Stirling linear cryocooler [9821-13]
- 9821 OF Tuned dynamic absorber for split Stirling cryogenic cooler [9821-14]

CRYOGENIC PELTIER (TE) COOLING I

- 9821 0G Introduction to cryogenic solid state cooling (Invited Paper) [9821-15]
- 9821 0H Effect of chemical pressure manipulation on the valence and thermoelectric properties of the intermediate valence compound YbCu_{2-x}Ni_xGe₂ (Invited Paper) [9821-16]
- 9821 01 BiSb and spin-related thermoelectric phenomena (Invited Paper) [9821-17]

CYROGENIC PELTIER (TE) COOLING II

- 9821 0J Improved thermoelectric cooling based on the Thomson effect (Invited Paper) [9821-18]
- 9821 0K Cooling power of transverse thermoelectrics for cryogenic cooling (Invited Paper) [9821-19]

MECHANICAL CRYOCOOLERS III

- 9821 0N Development and optimization progress with RICOR cryocoolers for HOT IR detectors [9821-22]
- 9821 00 A high pressure ratio DC compressor for tactical cryocoolers [9821-24]
- 9821 OP Miniature Stirling cryocoolers at Thales Cryogenics: qualification results and integration solutions [9821-25]
- 9821 0Q Overview of RICOR tactical cryogenic refrigerators for space missions [9821-26]
- 9821 OR Reliability improvements on Thales RM2 rotary Stirling coolers: analysis and methodology [9821-34]
- 9821 05 Validation of accelerated ageing of Thales rotary Stirling cryocoolers for the estimation of MTTF [9821-35]
- 9821 0T Experimental investigations and applications of cryogenic heat pipes [9821-30]
- 9821 00 The development of radiant cooler and cryogenic heat pipes for 200K cryogenic optical system cooling [9821-31]

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four 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.

Albrecht, A. R., 04 Arnoult, Matt, 07 Arts, R., 08, 0P Bar Haim, Zvi, ON Barkyoumb, John H., 03 Benschop, T., 08, 0P, 0R, 0S Cameron, Benjamin H., 00 Carr, Winston D., 0H Cauquil, J.-M., OR, OS Chen, Weibo, 00 Conrad, Ted, 07 de Jonge, G., 0P Ding, Yujie J., 06 Epstein, R. I., 04 Farfan, B. G., 04 Filis, Avishai, 09, 0N, 0Q Fontenot, Ross S., 03 Ghasemkhani, M. R., 04 Gover, Dan, 0N, 0Q Gragossian, A., 04 Grayson, M., OK Heinz, Nicholas A., 0J Heremans, Joseph P., OG, Ol Hou, Jia, OB Jiang, Zhenhua, OD Jin, Hyungyu, Ol Kanao, Kenichi, OC Katz, Amiram, ON Khanna, Raghav, OJ Kikuchi, Ken'ichi, OC Kuo, Daniel, 07 Le Bordays, J., OP Lehr, Gloria J., 0H Li, Chunlai, OB Liu, En'guang, OB, OD, OT, OU Livni, Dorit, 09, 0Q Lv, Gang, OB Ma, Ming, OK Martin, J.-Y., OP, OR, OS Mathur, Veerendra K., 03 Mitsuda, Kazuhisa, OC Morelli, Donald T., OH Mu, Yongbin, 0D, 0T, 0U Mullié, J., 08, 0P Mungan, Carl E., 03 Murakami, Hiroshi, OC Murakami, Masahide, OC Nachman, Ilan, 09 Nakagawa, Takao, OC

Narasaki, Katsuhiro, OC Narayanan, Sri R., 00 Nishibori, Toshiyuki, OC Okabayashi, Akinobu, 0C Ootsuka, Kiyomi, OC Prakash, Arati, Ol Regev, Itay, 09, 0Q Riabzev, Sergey, 09, 0N, 0Q Sato, Ryota, OC Sato, Yoichi, OC Schaefer, Brian, 07 Segal, Victor, 09, 0N, 0Q Seguineau, C., OP, OR, OS Seifert, Wolfgang, OJ Sheik-Bahae, M., 04 Snyder, G. Jeffrey, 0J Sugita, Hiroyuki, OC Symonds, G., 04 Tang, Yang, OK Toberer, Eric S., OJ Tran, Thanh N., 03 Tsunematsu, Shoji, OC Tuito, Avi, OE, OF Van Acker, S., OP Veprik, Alexander, OE, OF Waldrop, Spencer L., OH Wang, Yueming, OB Watzman, Sarah J., Ol Wen, Jiajia, OB Willems, D., 08, 0P Wu, Yinong, OB, OD, OT, OU Yang, Baoyu, OD Yang, Fan, OT Yang, Xiaofeng, OU Yates, Ryan, 07 Yuan, Liyin, OB Zagarola, Mark V., 00 Zheng, Yuanhua, Ol

Conference Committee

Symposium Chair

David A. Logan, BAE Systems (United States)

Symposium Co-chair

Donald A. Reago Jr., U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Conference Chairs

Richard I. Epstein, The University of New Mexico (United States) and ThermoDynamic Films, LLC (United States)
Bjørn F. Andresen, RICOR Cryogenic & Vacuum Systems (Israel)
Markus P. Hehlen, Los Alamos National Laboratory (United States)
Joseph P. Heremans, The Ohio State University (United States)
Ingo N. Rühlich, AIM INFRAROT-MODULE GmbH (Germany)
Mansoor Sheik-Bahae, The University of New Mexico (United States)

Conference Program Committee

Tonny Benschop, Thales Cryogenics B.V. (Netherlands)
Igor D. Burlakov, Orion Research-and-Production Association (Russian Federation)
Bernardo Farfan, The University of New Mexico (United States) and ThermoDynamis Films, LLC (United States)
Carl S. Kirkconnell, West Coast Solutions (United States)
Sergey V. Riabzev, RICOR Cryogenic & Vacuum Systems (Israel)
Alexander Veprik, SCD SemiConductor Devices (Israel)
Yinong Wu, Shanghai Institute of Technical Physics (China)

Session Chairs

- Optical Refrigeration
 Richard I. Epstein, The University of New Mexico (United States)
 Mansoor Sheik-Bahae, The University of New Mexico (United States)
- Mechanical Cryocoolers I
 Ingo N. Rühlich, AIM INFRAROT-MODULE GmbH (Germany)
 Sergey V. Riabzev, RICOR Cryogenic & Vacuum Systems (Israel)

- 3 Mechanical Cryocoolers II Ingo N. Rühlich, AIM INFRAROT-MODULE GmbH (Germany) Sergey V. Riabzev, RICOR Cryogenic & Vacuum Systems (Israel)
- Keynote Session: Joint session with conferences 9819, 9821, 9822
 Paul R. Norton, U.S. Army Night Vision & Electronic Sensors Directorate (United States)
- 5 Cooler Dewar Integration Yinong Wu, Shanghai Institute of Technical Physics (China) Alexander Veprik, SCD SemiConductor Devices (Israel)
- 6 Cryogenic Peltier (TE) Cooling I Joseph P. Heremans, The Ohio State University (United States)
- 7 Cyrogenic Peltier (TE) Cooling II Joseph P. Heremans, The Ohio State University (United States)
- 8 Mechanical Cryocoolers III Tonny Benschop, Thales Cryogenics B.V. (Netherlands)
- 9 Control Electronics
 Carl S. Kirkconnell, West Coast Solutions (United States)