PROCEEDINGS OF SPIE

Tri-Technology Device Refrigeration (TTDR) III

Mansoor Sheik-Bahae Richard I. Epstein Bjørn F. Andresen Tonny Benschop Joseph P. Heremans Sergey V. Riabzev Editors

18 April 2018 Orlando, Florida, United States

Sponsored and Published by SPIE

Volume 10626

Proceedings of SPIE 0277-786X, V. 10626

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

Tri-Technology Device Refrigeration (TTDR) III, edited by Mansoor Sheik-Bahae, Richard I. Epstein, Bjørn F. Andresen, Tonny Benschop, Joseph P. Heremans, Sergey V. Riabzev, Proc. of SPIE Vol. 10626, 1062601 · © 2018 SPIE · CCC code: 0277-786X/18/\$18 · doi: 10.1117/12.2322384

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) III*, edited by Mansoor Sheik-Bahae, Richard I. Epstein, Bjørn F. Andresen, Tonny Benschop, Joseph P. Heremans, Sergey V. Riabzev, Proceedings of SPIE Vol. 10626 (SPIE, Bellingham, WA, 2018) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510617636

ISBN: 9781510617643 (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

Authors

vii Conference Committee **SESSION 1 MECHANICAL COOLERS: MINIATURIZATION** 10626 02 Performance of the Lockheed Martin Space MINI cryocooler [10626-1] 10626 03 Experimental investigation on the miniature mixed refrigerant cooler driven by a mini**compressor** [10626-2] 10626 04 Computational fluid dynamics study of displacer "shuttle loss" in miniature Stirling cryocoolers [10626-3] 10626 05 RMs1: the state of the art SWaP cryocooler [10626-4] **SESSION 2** MECHANICAL COOLERS: DESIGN AND TESTING I 10626 08 Ruggedizing vibration sensitive components of electro-optical module using wideband dynamic absorber [10626-7] 10626 09 A 50W@170K pulse tube cryocooler used in wide-field survey telescope [10626-8] 10626 0A MEMS based shock pulse detection sensor for improved rotary Stirling cooler end of life prediction [10626-9] **SESSION 3** LASER CRYOCOOLERS 10626 OB Realization of an all-solid-state cryocooler using optical refrigeration (Invited Paper) [10626-10] **SESSION 4** MECHANICAL COOLERS: DESIGN AND TESTING II 10626 OE Robust Stirling coolers for sensing in extreme environmental conditions [10626-13] 10626 OF Structural analysis of an infrared focal plane dewar assembly for meteorological satellite [10626-14] 10626 0G Overview of RICOR's reliability theoretical analysis, accelerated life demonstration test results and verification by field data [10626-15] 10626 OH Lifetime validation of high-reliability (>30,000hr) rotary cryocoolers for specific customer **profiles** [10626-16] 10626 OK Northrop Grumman HEC flight coaxial cryocoolers performance [10626-19]

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.

Abadie, Christian, 05 Abelson, L., 0K

Albrecht, Alexander R., OB

Arts, R., OE

Babitsky, Vladimir, 08 Baruch, Shlomi, OG Basel, G., 0K

Benschop, Tonny, 05, 0E, 0H

Bollens, P., 0E

Cauquil, Jean-Marc, 0H Chaumeau, Sylvain, 05 Chen, Gaofei, 03

Chi, D., 0K

de Jonge, G., 0E Epstein, Richard I., 0B Etchanchu, Thierry, 05

Filis, Avishai, 0G Frank, D., 02

Ghasemkhani, Mohammadreza, OB

Ghavami, A., 04 Ghiaasiaan, S. M., 04 Gong, Maoqiong, 03

Gragossian, Aram, OB Guzinski, M., 02

Hehlen, Markus P., OB Hübner, M., 0A

Jiang, Zhenhua, 09

Kirkconnell, C. S., 04 Le Bordays, Julien, 05

Lee, Eric, OB Liu, Dafu, OF

Martin, Jean-Yves, 05

Meng, Junwei, 0B Mo, Defeng, 0F

Mullié, J., 0E

Münzberg, M., 0A

Nguyen, T., 0K

Openhaim, Yaki, 08

Raynal, Gaetan, 0H

Regev, Itai, 0G

Riabzev, Sergey, OG

Roth, E., 02 Ruiz, A., 02

Russo, J., OK

Sacau, Mikel, 05

Segal, Victor, 0G

Seguineau, Cédric, 05, 0H

Sheik-Bahae, Mansoor, OB

Sokolsky, L., 02

Sun, Wen, OF Tuito, Avi, 08

Vainshtein, Igor, 0G

Van-Acker, Sébastien, 05

van Leeuwen, R., 0E

Vasse, Christophe, 05, 0H

Veprik, Alexander, 08

Volpi, Azzurra, OB

Willems, D., 0E Wu, Yinong, 03, 09

Xu, Lin, OF

Xu, Qinfei, 0F

Zhang, Lei, OF

Conference Committee

Symposium Chair

Arthur A. Morrish, Raytheon Space and Airborne Systems (United States)

Symposium Co-chair

Ruth Moser, Air Force Research Laboratory (United States)

Conference Chairs

Richard I. Epstein, The University of New Mexico (United States) and ThermoDynamic Films, LLC (United States)

Bjørn F. Andresen, Consultant, Infrared Technologies & Applications (Israel)

Tonny Benschop, Thales Cryogenics B.V. (Netherlands)

Joseph P. Heremans, The Ohio State University (United States)

Sergey V. Riabzev, RICOR Cryogenic & Vacuum Systems (Israel)

Mansoor Sheik-Bahae, The University of New Mexico (United States)

Conference Program Committee

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)

Matthew Grayson, Northwestern University (United States)

Markus P. Hehlen, Los Alamos National Laboratory (United States)

Carl S. Kirkconnell, West Coast Solutions (United States)

Ingo N. Rühlich, AIM INFRAROT-MODULE GmbH (Germany)

Alexander Veprik, SCD SemiConductor Devices (Israel)

Yinong Wu, Shanghai Institute of Technical Physics (China)

Session Chairs

Mechanical Coolers: Miniaturization
Carl S. Kirkconnell, West Coast Solutions (United States)
Ingo N. Rühlich, AIM INFRAROT-MODULE GmbH (Germany)

- 2 Mechanical Coolers: Design and Testing I Sergey V. Riabzev, RICOR Cryogenic & Vacuum Systems (Israel) Yinong Wu, Shanghai Institute of Technical Physics (China)
- 3 Laser Cryocoolers Mansoor Sheik-Bahae, The University of New Mexico (United States) Jun Zhang, Institute of Semiconductors (China)
- 4 Mechanical Coolers: Design and Testing II Tonny Benschop, Thales Cryogenics B.V. (Netherlands) Alexander Veprik, SCD SemiConductor Devices (Israel)