

PROCEEDINGS OF SPIE

Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XIV

**Ralph B. James
Arnold Burger
Larry A. Franks
Michael Fiederle**
Editors

**13–15 August 2012
San Diego, California, United States**

Sponsored and Published by
SPIE

Volume 8507

Proceedings of SPIE 0277-786X, v. 8507

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

Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XIV, edited by Ralph B. James, Arnold Burger, Larry A. Franks, Michael Fiederle, Proc. of SPIE Vol. 8507, 850701 · © 2012 SPIE · CCC code: 0277-786X/12/\$18 · doi: 10.1117/12.2008651

Proc. of SPIE Vol. 8507 850701-1

The papers included 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. The papers published in these proceedings 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 this book:

Author(s), "Title of Paper," in *Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XIV*, edited by Ralph B. James, Arnold Burger, Larry A. Franks, Michael Fiederle, Proceedings of SPIE Vol. 8507 (SPIE, Bellingham, WA, 2012) Article CID Number.

ISSN: 0277-786X

ISBN: 9780819492241

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 © 2012, 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/12/\$18.00.

Printed in the United States of America.

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



SPIDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first 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, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- 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. The complete citation is used on the first page,

and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID Number.

Contents

ix *Conference Committee*
xiii *Introduction*

SESSION 1 SCINTILLATORS I

- 8507 04 **Next generation CMOS SSPMs for scintillation detection applications** [8507-3]
X. J. Chen, E. B. Johnson, C. J. Stapels, C. Whitney, J. F. Christian, Radiation Monitoring Devices Inc. (United States)
- 8507 05 **Electronic structure, energy transport, and optical properties of halide scintillators** [8507-4]
M.-H. Du, K. Biswas, D. J. Singh, Oak Ridge National Lab. (United States)

SESSION 2 CZT I

- 8507 07 **Improving the growth of CZT crystals for radiation detectors: a modeling perspective (Invited Paper)** [8507-7]
J. J. Derby, N. Zhang, A. Yeckel, Univ. of Minnesota (United States)

SESSION 3 DETECTOR MATERIALS I

- 8507 0C **Assessment of 4H-SiC epitaxial layers and high resistivity bulk crystals for radiation detectors (Invited Paper)** [8507-12]
K. C. Mandal, P. G. Muzykov, S. K. Chaudhuri, Univ. of South Carolina (United States); J. R. Terry, Los Alamos National Lab. (United States)
- 8507 0F **Mercury and antimony chalcogenide semiconductors as new candidates for radiation detection applications at room temperature** [8507-15]
C. D. Malliakas, Northwestern Univ. (United States) and Argonne National Lab. (United States); A. C. Wibowo, Argonne National Lab. (United States); Z. Liu, J. A. Peters, M. Sebastian, H. Jin, Northwestern Univ. (United States); D.-Y. Chung, Argonne National Lab. (United States); A. J. Freeman, B. W. Wessels, Northwestern Univ. (United States); M. G. Kanatzidis, Northwestern Univ. (United States) and Argonne National Lab. (United States)

SESSION 4 CZT II

- 8507 0H **High energy γ -ray detection using CZT detectors with virtual Frisch grid** [8507-17]
S. K. Chaudhuri, R. M. Krishna, K. J. Zavalla, K. C. Mandal, Univ. of South Carolina (United States)

SESSION 5 DETECTOR MATERIALS II

- 8507 0M **Resistivity, carrier trapping, and polarization phenomenon in semiconductor radiation detection materials** [8507-22]
M.-H. Du, K. Biswas, D. J. Singh, Oak Ridge National Lab. (United States)
- 8507 0N **Control of the polytypes and line defects in radiation detector materials** [8507-23]
N. B. Singh, Univ. of Maryland, Baltimore County (United States); W. M. B. Duval, NASA Glenn Research Ctr. (United States); R. H. Hopkins, R. Mazelsky, D. K. Fox, M. Gottlieb, T. Henningsen, Hopkins Inc. (United States); S. R. Coriell, Consultant (United States); M. E. Glicksman, Florida Institute of Technology (United States)
- 8507 0O **Characterization of thallium-based ternary semiconductor compounds for radiation detection** [8507-24]
Z. Liu, J. A. Peters, S. Nguyen, M. Sebastian, B. W. Wessels, S. Wang, H. Jin, J. Im, A. J. Freeman, M. G. Kanatzidis, Northwestern Univ. (United States)

SESSION 6 NEUTRON DETECTORS

- 8507 0Q **Development of the new generation of glass-based neutron detection materials** [8507-26]
A. E. Dosovitskiy, G. A. Dosovitskiy, M. V. Korjik, NeoScint LLC (Russian Federation)
- 8507 0R **Metal-semiconductor-metal neutron detectors based on hexagonal boron nitride epitaxial layers** [8507-27]
S. Majety, J. Li, X. K. Cao, R. Dahal, J. Y. Lin, H. X. Jiang, Texas Tech Univ. (United States)
- 8507 0S **Direction sensitive neutron detectors in near field measurements** [8507-28]
S. Mukhopadhyay, Remote Sensing Lab. Andrews Operations (United States); S. Mitchell, NSTec (United States)

SESSION 7 CZT III

- 8507 0V **Growth of CdZnTe by the detached Bridgman method (Invited Paper)** [8507-31]
S. Motakef, P. Becla, S. Swider, K. Becla, J. Fiala, M. R. Overholt, CapeSym, Inc. (United States)
- 8507 0X **Growth of CZT using additionally zone-refined raw materials** [8507-33]
D. J. Knuteson, A. Berghmans, D. Kahler, B. Wagner, M. King, S. McLaughlin, Northrop Grumman Corp. (United States); A. Bolotnikov, R. James, Brookhaven National Lab. (United States); N. B. Singh, Univ. of Maryland, Baltimore County (United States)

SESSION 8 CZT IV

- 8507 10 **Correlation of dislocations and Te inclusions in detector-grade CdZnTe crystals grown by MVB method** [8507-36]
Y. Xu, Y. He, L. Xu, T. Wang, G. Zha, W. Jie, Northwestern Polytechnical Univ. (China)

- 8507 11 **Preliminary results on Bridgman grown CdZnTe detector crystals assisted by ampoule rotation** [8507-37]
A. Datta, S. Swain, Washington State Univ. (United States); Y. Cui, A. Burger, Fisk Univ. (United States); K. Lynn, Washington State Univ. (United States)
- 8507 15 **Reduced leakage currents of CdZnTe radiation detectors with HgTe/HgCdTe superlattice contacts** [8507-41]
Y. Chang, C. H. Grein, C. R. Becker, J. Huang, S. Ghosh, Univ. of Illinois at Chicago (United States); F. Aqariden, Sivananthan Labs., Inc. (United States); S. Sivananthan, Univ. of Illinois at Chicago (United States)

SESSION 9 SCINTILLATORS II

- 8507 16 **Latest advances in large diameter Srl:Eu and CLYC:Ce scintillators for isotope identification (Invited Paper)** [8507-42]
R. Hawrami, C. Hines, I. Abselem, V. Biteman, J. Vaghini, J. Glodo, P. O'Dougherty, K. S. Shah, Radiation Monitoring Devices, Inc. (United States); N. Cherepy, S. Payne, Lawrence Livermore National Lab. (United States); A. Burger, Fisk Univ. (United States); L. Boatner, Oak Ridge National Lab. (United States)
- 8507 17 **Transparent garnet ceramic scintillators for gamma-ray detection** [8507-43]
Y. Wang, G. Baldoni, Radiation Monitoring Devices, Inc. (United States); W. H. Rhodes, C. Brecher, ALEM Associates (United States); A. Shah, U. Shirwadkar, J. Glodo, Radiation Monitoring Devices, Inc. (United States); N. Cherepy, S. Payne, Lawrence Livermore National Lab. (United States)
- 8507 19 **CXBN: a blueprint for an improved measurement of the cosmological x-ray background** [8507-45]
L. M. Simms, Lawrence Livermore National Lab. (United States); J. G. Jernigan, Space Systems Lab. (United States); B. K. Malphrus, R. McNeil, K. Z. Brown, T. G. Rose, H. S. Lim, Morehead State Univ. (United States); S. Anderson, Sonoma State Univ. (United States); J. A. Kruth, Morehead State Univ. (United States); J. P. Doty, M. Wampler-Doty, Noqsi Aerospace, Ltd. (United States); L. R. Cominsky, K. S. Prasad, Sonoma State Univ. (United States); E. T. Thomas, M. S. Combs, R. T. Kroll, B. J. Cahall, T. T. Turba, B. L. Molton, M. M. Powell, J. F. Fitzpatrick, D. C. Graves, Morehead State Univ. (United States); S. D. Gaalema, S. Sun, Black Forrest Engineering (United States)
- 8507 1B **Medical isotope identification with large mobile detection systems** [8507-47]
S. Mukhopadhyay, R. Maurer, National Security Technologies Inc. (United States)

- 8507 1D **Design and tests of the hard x-ray polarimeter X-Calibur (Invited Paper)** [8507-49]
M. Beilicke, Washington Univ. in St. Louis (United States); M. G. Baring, Rice Univ. (United States); S. Barthelmy, NASA Goddard Space Flight Ctr. (United States); W. R. Binns, J. Buckley, R. Cowsik, P. Dowkontt, A. Garson, Q. Guo, Washington Univ. in St. Louis (United States); Y. Haba, Nagoya Univ. (Japan); M. H. Israel, F. Kislak, Washington Univ. in St. Louis (United States); H. Kunieda, Nagoya Univ. (Japan); K. Lee, J. Martin, Washington Univ. in St. Louis (United States); H. Matsumoto, T. Miyazawa, Nagoya Univ. (Japan); T. Okajima, J. Schnittman, NASA Goddard Space Flight Ctr. (United States); K. Tamura, Nagoya Univ. (Japan); J. Tueller, NASA Goddard Space Flight Ctr. (United States); H. Krawczynski, Washington Univ. in St. Louis (United States)

POSTER SESSION

- 8507 1I **Transport properties and spectrometric performances of CdZnTe gamma-ray detectors** [8507-54]
A. A. Zakharchenko, A. V. Rybka, V. E. Kutny, A. I. Skrypyuk, M. A. Khazhmuradov, National Science Ctr. Kharkov Institute of Physics and Technology (Ukraine); P. M. Fochuk, Chernivtsi National Univ. (Ukraine); A. E. Bolotnikov, R. B. James, Brookhaven National Lab. (United States)
- 8507 1J **Structural characteristics of Zn_{1-x}Mn_xTe polycrystalline films** [8507-55]
D. I. Kurbatov, O. V. Klymov, A. S. Opanasyuk, Sumy State Univ. (Ukraine); A. G. Ponomarev, Institute of Applied Physics (Ukraine); P. M. Fochuk, Chernivtsi National Univ. (United States); H. M. Khlyap, TU Kaiserslautern (Germany)
- 8507 1K **Some structural and optical properties of thin and thick CdTe and Cd_xMn_{1-x}Te films** [8507-56]
A. S. Opanasyuk, P. V. Koval, Sumy State Univ. (Ukraine); V. V. Kosyak, The Univ. of Utah (United States); P. M. Fochuk, Chernivtsi National Univ. (Ukraine); A. E. Bolotnikov, R. B. James, Brookhaven National Lab. (United States)
- 8507 1L **High-temperature treatment of In-doped CZT crystals grown by the high-pressure Bridgman method** [8507-57]
P. Fochuk, I. Nakonechnyi, O. Kopach, Y. Verzhak, O. Panchuk, Chernivtsi National Univ. (Ukraine); V. Komar, I. Terzin, Institute of Single Crystals (Ukraine); V. Kutnij, A. Rybka, National Science Ctr. Kharkov Institute of Physics and Technology (Ukraine); Y. Nykoniuk, National Univ. of Water Management and Nature Resources Use (Ukraine); A. E. Bolotnikov, G. C. Camarda, Y. Cui, A. Hossain, K. H. Kim, G. Yang, R. B. James, Brookhaven National Lab. (United States)
- 8507 1N **Registration of high-intensity electron and x-ray fields with polycrystalline CVD diamond detectors** [8507-59]
L. N. Davydov, A. V. Rybka, A. A. Vierovkin, S. F. Dudnik, V. I. Gritsyna, V. E. Kutny, O. A. Opalev, V. A. Shevchenko, I. N. Shlyahov, V. E. Strelnitsky, A. E. Tenishev, V. L. Uvarov, National Science Ctr. Kharkov Institute of Physics and Technology (Ukraine); R. B. James, A. E. Bolotnikov, Brookhaven National Lab. (United States); P. M. Fochuk, Chernivtsi National Univ. (Ukraine)

- 8507 1S **Surface processing of CdZnTe crystals** [8507-65]
V. A. Gnatyuk, V. E. Lashkaryov Institute of Semiconductor Physics (Ukraine) and Shizuoka Univ. (Japan); O. I. Vlasenko, S. N. Levytskyi, V. E. Lashkaryov Institute of Semiconductor Physics (Ukraine); E. Dieguez, J. Crocco, H. Bensalah, Univ. Autónoma de Madrid (Spain); M. Fiederle, A. Fauler, Freiburger Materialforschungszentrum (Germany); T. Aoki, Shizuoka Univ. (Japan)
- 8507 1U **Photoluminescence and absorption properties of the surface functional layer of CdTe crystals** [8507-67]
D. V. Gnatyuk, L. V. Poperenko, I. V. Yurgelevych, O. Dacenko, Taras Shevchenko National Univ. of Kyiv (Ukraine); T. Aoki, M. Kimura, Shizuoka Univ. (Japan)

Author Index

Conference Committee

Program Track Chair

Carolyn A. MacDonald, University at Albany (United States)

Conference Chairs

Ralph B. James, Brookhaven National Laboratory (United States)

Arnold Burger, Fisk University (United States)

Larry A. Franks, Consultant (United States)

Michael Fiederle, Albert-Ludwigs-Universität Freiburg (Germany)

Conference Program Committee

Toru Aoki, Shizuoka University (Japan)

Fikri Aqariden, EPIR Technologies, Inc. (United States)

Jim E. Baciak Jr., Pacific Northwest National Laboratory (United States)

Zane W. Bell, Oak Ridge National Laboratory (United States)

Lynn A. Boatner, Oak Ridge National Laboratory (United States)

Aleksey E. Bolotnikov, Brookhaven National Laboratory (United States)

Bill Cardoso, Creative Electron (United States)

Henry Chen, Redlen Technologies (Canada)

Nerine J. Cherepy, Lawrence Livermore National Laboratory (United States)

Jeffrey J. Derby, University of Minnesota, Twin Cities (United States)

Martine C. Duff, Savannah River National Laboratory (United States)

Petro M. Fochuk, Yuriy Fedkovych Chernivtsi National University (Ukraine)

Jan Franc, Charles University in Prague (Czech Republic)

Fei Gao, Pacific Northwest National Laboratory (United States)

Yoshinori Hatanaka, Aichi University of Technology (Japan)

Zhong He, University of Michigan (United States)

Keitaro Hitomi, Tohoku University (Japan)

Alan Janos, U.S. Department of Homeland Security (United States)

Warnick J. Kernan, Pacific Northwest National Laboratory (United States)

Henric Krawczynski, Washington University in St. Louis (United States)

Kelvin G. Lynn, Washington State University (United States)

Krishna C. Mandal, University of South Carolina (United States)

Douglas Scott McGregor, Kansas State University (United States)

Robert D. McLaren, Consultant (United States)

Shariar Motakef, CapeSym, Inc. (United States)
Sanjoy Mukhopadhyay, National Security Technologies, LLC (United States)
Stephen A. Payne, Lawrence Livermore National Laboratory (United States)
Utpal N. Roy, ICx Technologies, Inc. (United States)
Carolyn E. Seifert, Pacific Northwest National Laboratory (United States)
Paul J. Sellin, University of Surrey (United Kingdom)
Narsingh B. Singh, SMS&T (United States)
Michael R. Squillante, Radiation Monitoring Devices, Inc. (United States)
Ashley C. Stowe, Y-12 National Security Complex (United States)
Csaba Szeles, EI Detection & Imaging Systems (United States)
Tumay O. Tumer, Nova R&D, Inc. (United States)
Sergey E. Ulin, National Research Nuclear University MEPhI (Russian Federation)
Lodewijk van den Berg, Constellation Technology Corporation (United States)
Peter E. Vanier, Brookhaven National Laboratory (United States)

Session Chairs

- 1 Scintillators I
Ralph B. James, Brookhaven National Laboratory (United States)
- 2 CZT I
Robert D. McLaren, Consultant (United States)
- 3 Detector Materials I
Michael Fiederle, Albert-Ludwigs-Universität Freiburg (Germany)
- 4 CZT II
Robert D. McLaren, Consultant (United States)
- 5 Detector Materials II
Aleksey E. Bolotnikov, Brookhaven National Laboratory (United States)
- 6 Neutron Detectors
Robert D. McLaren, Consultant (United States)
- 7 CZT III
Krishna C. Mandal, University of South Carolina (United States)

- 8 CZT IV
Sanjoy Mukhopadhyay, National Security Technologies, LLC (United States)
- 9 Scintillators II
Robert D. McLaren, Consultant (United States)
- 10 CZT V
David J. Knuteson, Northrop Grumman Electronic Systems (United States)

Introduction

This book contains the proceedings of the SPIE conference on Hard X-Ray, Gamma-Ray and Neutron Detector Physics XIV. The conference was held on August 13-15, 2012 in San Diego, California. The conference was organized into technical sessions on cadmium zinc telluride (CZT), cadmium telluride, scintillators, methodology, imaging, neutron detectors, and alternative semiconductor detector materials. Plenary and poster sessions were also provided.

The purpose of the conference was to provide a forum for scientists and engineers from the detector development and user communities to present and evaluate the most recent results on X-ray, gamma-ray, and neutron detectors and to discuss the requirements for a variety of radiation-sensing and imaging applications. The primary theme of the conference was on the development of improved semiconductor and scintillator radiation detectors and imaging arrays, which combine the advantages of room-temperature operation with the ability to spectrally resolve the energies of emitted X- and gamma-rays. By eliminating the cryogen, new radiation-sensing instruments, such as spectrometers, gamma cameras and radiographic systems, can be manufactured that are portable, lightweight, easy to operate, and relatively maintenance-free. Recent research and development on detectors have resulted in measurable progress in the availability of single detectors and imaging arrays. In addition, recent reports of the material properties limiting the performance of semiconductor and scintillator detectors have provided new insights and directions to address deficiencies in the crystals and devices.

Despite the limitations on efficiency and relatively high cost of current room-temperature semiconductor detectors and new emerging scintillators, they have been increasingly deployed in systems useful for medical diagnostics, space applications, safeguarding of nuclear materials, material identification, baggage scanning, position sensing, and gamma-ray spectroscopy. Although significant progress has occurred over recent years, there is still a pressing need to lower the cost of the detectors and to increase the efficiency of the detectors while improving their spectral performance.

A total of 67 presentations, including 15 posters, were given at the conference. Although the number of attendees varied with the session and day of week, the attendance averaged approximately 75 people with a substantial fraction of those in attendance representing organizations outside of the U.S.

This book provides detailed documentation describing a portion of the presentations. The editors hope that it will serve as an important record of the meeting, provide an update on the status of X-ray, gamma-ray, and neutron

detector technology, and serve as a useful source of information for those working in the field.

The Conference Chairs would like to thank the session chairs and members of the Conference Program Committees, who offered their time to enlist the involvement of many researchers working in the field.

Ralph B. James
Arnold Burger
Larry A. Franks
Michael Fiederle