

PROCEEDINGS OF SPIE

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

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

**11–13 August 2008
San Diego, California, USA**

Sponsored by
Defense Threat Reduction Agency (DTRA)
SPIE

Published by
SPIE

Volume 7079

Proceedings of SPIE, 0277-786X, v. 7079

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

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 X*, edited by Arnold Burger, Larry A. Franks, Ralph B. James, Proceedings of SPIE Vol. 7079 (SPIE, Bellingham, WA, 2008) Article CID Number.

ISSN 0277-786X
ISBN 9780819472991

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 © 2008, 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/08/\$18.00.

Printed in the United States of America.

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


SPIEDigitalLibrary.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 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 CZT DETECTORS

- 7079 03 **Spectral responses of virtual Frisch-grid CdZnTe detectors and their relation to IR microscopy and x-ray diffraction topography data** [7079-02]
A. E. Bolotnikov, Brookhaven National Lab. (United States); S. Babalola, Fisk Univ. (United States) and Vanderbilt Univ. (United States); G. S. Camarda, Y. Cui, Brookhaven National Lab. (United States); S. U. Egarievwe, Fisk Univ. (United States); P. M. Fochuk, Chernivtsi National Univ. (Ukraine); R. Hawrami, Fisk Univ. (United States); A. Hossain, Brookhaven National Lab. (United States); J. R. James, Tennessee Technological Univ. (United States); I. J. Nakonechnyj, Chernivtsi National Univ. (Ukraine); G. Yang, R. B. James, Brookhaven National Lab. (United States)
- 7079 05 **Reliability of pixellated CZT detector modules used for medical imaging and homeland security (Invited Paper)** [7079-04]
H. Chen, S. A. Awadalla, F. Harris, P. H. Lu, G. Bindley, Redlen Technologies (Canada); H. Lenos, B. Cardoso, Aguila Technologies (United States)

SESSION 2 NEUTRON DETECTORS

- 7079 06 **Designs for micro-structured semiconductor neutron detectors** [7079-05]
J. K. Shultis, D. S. McGregor, Kansas State Univ. (United States)
- 7079 07 **Prospects for thermal neutron detection and imaging with the GammaTracker handheld radioisotope identifier** [7079-06]
C. E. Seifert, D. S. Barnett, M. J. Myjak, Pacific Northwest National Lab. (United States)
- 7079 08 **A novel solid state self-powered neutron detector** [7079-08]
N. LiCausi, J. Dingley, Y. Danon, J.-Q. Lu, I. B. Bhat, Rensselaer Polytechnic Institute (United States)

SESSION 3 CZT GROWTH AND CHARACTERIZATION I

- 7079 0A **Modeling the growth of CZT by the EDG process** [7079-10]
J. J. Derby, D. Gasperino, L. Lun, A. Yeckel, Univ. of Minnesota (United States)
- 7079 0B **Final surface treatment effect on performance of CdZnTe Frisch collar gamma-ray detectors** [7079-11]
A. Kargar, A. C. Brooks, K. T. Kohman, R. B. Lowell, R. C. Keyes, Kansas State Univ. (United States); H. Chen, S. Awadalla, G. Bindley, Redlen Technologies (Canada); D. S. McGregor, Kansas State Univ. (United States)

- 7079 0C **Investigation of CdZnTe crystal defects using scanning spreading resistance microscopy** [7079-12]
J. Liu, Univ. of South Carolina (United States); K. C. Mandal, EIC Labs., Inc. (United States);
G. Koley, Univ. of South Carolina (United States)

SESSION 4 CdTe CRYSTALS AND DETECTORS

- 7079 0F **Photon counting x-ray CT with 3D holograms by CdTe line sensor** [7079-15]
A. Koike, M. Yomori, H. Morii, Y. Neo, T. Aoki, H. Mimura, Shizuoka Univ. (Japan)
- 7079 0G **Features of characteristics and stability of CdTe nuclear radiation detectors fabricated by laser doping technique** [7079-16]
V. A. Gnatyuk, Shizuoka Univ. (Japan) and V.E. Lashkaryov Institute of Semiconductor Physics (Ukraine); T. Aoki, Shizuoka Univ. (Japan); O. I. Vlasenko, S. N. Levytskyi, V.E. Lashkaryov Institute of Semiconductor Physics (Ukraine); Y. Hatanaka, Aichi Univ. of Technology (Japan); C. P. Lambropoulos, Technological Educational Institute of Halkis (Greece)
- 7079 0H **X-ray computed tomography system using a multipixel photon counter** [7079-17]
E. Sato, Iwate Medical Univ. (Japan); H. Matsukiyo, A. Osawa, T. Enomoto, M. Watanabe, J. Nagao, Toho Univ. School of Medicine (Japan); P. Abderyim, Iwate Univ. (Japan); S. Nomiya, Raytec Inc. (Japan); K. Hitomi, Tohoku Institute of Technology (Japan); A. Ogawa, S. Sato, Iwate Medical Univ. (Japan)
- 7079 0I **Application of the dual energy technique by using a photon counting CdTe detector** [7079-18]
W. Zou, T. Nakashima, Y. Onishi, H. Morii, Y. Neo, H. Mimura, T. Aoki, Shizuoka Univ. (Japan)

SESSION 5 OTHER WIDE BANDGAP SEMICONDUCTORS I

- 7079 0J **Evaluation of TlBr detectors with TI electrodes (Invited Paper)** [7079-19]
K. Hitomi, Tohoku Institute of Technology (Japan) and Tohoku Univ, (Japan); Y. Kikuchi, Tohoku Univ, (Japan); T. Shoji, Tohoku Institute of Technology (Japan); K. Ishii, Tohoku Univ, (Japan)
- 7079 0K **Purification, crystal growth, and detector performance of TlBr** [7079-20]
A. V. Churilov, W. M. Higgins, G. Ciampi, H. Kim, L. J. Cirignano, Radiation Monitoring Devices, Inc. (United States); F. Olschner, Cremat, Inc. (United States); K. S. Shah, Radiation Monitoring Devices, Inc. (United States)
- 7079 0L **A systematic study of mercuric iodide platelet growth in horizontal furnaces** [7079-21]
E. Ariesanti, C. Frampton, S. Appelhans, M. Rudolph, D. S. McGregor, Kansas State Univ. (United States)

SESSION 6 OTHER WIDE BANDGAP SEMICONDUCTORS II

- 7079 ON **CdMnTe crystals for x-ray and gamma-ray detection (Invited Paper)** [7079-23]
Y. Cui, A. Bolotnikov, A. Hossain, G. Camarda, Brookhaven National Lab. (United States);
A. Mycielski, Institute of Physics (Poland); G. Yang, Brookhaven National Lab. (United
States); D. Kochanowska, M. Witkowska-Baran, Institute of Physics (Poland); R. B. James,
Brookhaven National Lab. (United States)
- 7079 OO **Layered III-VI chalcogenide semiconductor crystals for radiation detectors** [7079-24]
K. C. Mandal, A. Mertiri, G. W. Pabst, R. G. Roy, EIC Labs., Inc. (United States); Y. Cui,
P. Battacharya, M. Groza, A. Burger, Fisk Univ. (United States); A. M. Conway, R. J. Nikolic,
A. J. Nelson, S. A. Payne, Lawrence Livermore National Lab. (United States)
- 7079 OP **Unipolar charge sensing using Frisch grid technique for amorphous selenium radiation
detectors** [7079-25]
A. H. Goldan, K. S. Karim, Univ. of Waterloo (Canada)
- 7079 OQ **Theoretical studies of defect states in GaSe and GaTe** [7079-26]
Z. Rak, S. D. Mahanti, Michigan State Univ. (United States); K. C. Mandal, EIC Labs., Inc.
(United States); N. C. Fernelius, Air Force Research Lab. (United States)

SESSION 7 CZT GROWTH AND CHARACTERIZATION II

- 7079 OR **AFM characterization of laser-induced damage on CdZnTe crystal surfaces** [7079-27]
S. A. Hawkins, L. C. Teague, E. Villa-Aleman, M. C. Duff, Savannah River National Lab.
(United States); A. Burger, M. Groza, V. Buliga, Fisk Univ. (United States)
- 7079 OT **Characterization of detector grade CdZnTe material from Redlen Technologies** [7079-29]
M. C. Duff, Savannah River National Lab. (United States); A. Burger, M. Groza, V. Buliga, Fisk
Univ. (United States); J. P. Bradley, Z. R. Dai, N. Teslich, Lawrence Livermore National Lab.
(United States); S. A. Awadalla, J. Mackenzie, H. Chen, Redlen Technologies (Canada)
- 7079 OU **Defect measurements of CdZnTe detectors using I-DLTS, TCT, I-V, C-V and γ -ray
spectroscopy** [7079-30]
R. Gul, Brookhaven National Lab. (United States) and Idaho State Univ. (United States); Z. Li,
Brookhaven National Lab. (United States); R. Rodriguez, K. Keeter, Idaho State Univ. (United
States); A. Bolotnikov, R. James, Brookhaven National Lab. (United States)

SESSION 8 SCINTILLATORS

- 7079 OW **Precision crystal calorimeters in high-energy physics: past, present, and future (Invited
Paper)** [7079-32]
R.-Y. Zhu, California Institute of Technology (United States)
- 7079 OX **Transparent ceramic scintillator fabrication, properties, and applications** [7079-33]
N. J. Cherepy, J. D. Kuntz, J. J. Roberts, T. A. Hurst, O. B. Drury, R. D. Sanner, T. M. Tillotson,
S. A. Payne, Lawrence Livermore National Lab. (United States)

- 7079 0Y **SrI₂: a novel scintillator crystal for nuclear isotope identifiers** [7079-34]
R. Hawrami, Fisk Univ. (United States) and Alabama A&M Univ. (United States); M. Groza, Y. Cui, A. Burger, Fisk Univ. (United States); M. D. Aggarwal, Alabama A&M Univ. (United States); N. Cherepy, S. A. Payne, Lawrence Livermore National Lab. (United States)

SESSION 9 IMAGING I

- 7079 0Z **Energy-discriminating x-ray camera utilizing a cadmium telluride detector** [7079-35]
E. Sato, Iwate Medical Univ. (Japan); P. Abderyim, Toho Univ. School of Medicine (Japan); H. Matsukiyo, A. Osawa, T. Enomoto, M. Watanabe, J. Nagao, Iwate Univ. (Japan); S. Nomiya, Raytech Inc. (Japan); K. Hitomi, Tohoku Institute of Technology (Japan); A. Ogawa, S. Sato, Iwate Medical Univ. (Japan); T. Ichimaru, Hirosaki Univ. (Japan)
- 7079 11 **Performance of an improved readout IC for multi-energy photon-counting x-ray detector arrays** [7079-37]
M. Clajus, V. B. Cajjipe, S. Hayakawa, T. O. Tümer, Nova R&D, Inc. (United States)
- 7079 12 **CdTe x-ray image sensor driven by field emitter array (Invited Paper)** [7079-38]
T. Aoki, T. Sakata, Y. Hanawa, M. Nakagawa, H. Morii, A. Koike, Y. Neo, H. Mimura, Shizuoka Univ. (Japan)
- 7079 13 **New two-dimensional ASICs for solid state pixel detectors** [7079-39]
T. O. Tumer, V. B. Cajjipe, M. Clajus, S. Hayakawa, A. Volkovskii, Nova R&D, Inc. (United States)

SESSION 10 IMAGING II

- 7079 14 **A CMOS-based large-area high-resolution imaging system for high-energy x-ray applications** [7079-40]
B. Rodricks, B. Fowler, C. Liu, J. Lowes, Fairchild Imaging (United States); D. Haeffner, U. Lienert, J. Almer, Argonne National Lab. (United States)
- 7079 15 **An explosives detection system for airline security using coherent x-ray scattering technology** [7079-41]
R. W. Madden, J. Mahdavih, R. C. Smith, R. Subramanian, L-3 Communications Security and Detection Systems (United States)

SESSION 11 POST-DEADLINE PAPERS

- 7079 17 **Strontium iodide scintillators for high energy resolution gamma ray spectroscopy** [7079-52]
C. M. Wilson, E. V. Van Loef, J. Glodo, Radiation Monitoring Devices, Inc. (United States); N. Cherepy, G. Hull, S. Payne, Lawrence Livermore National Lab. (United States); W.-S. Choong, W. Moses, Lawrence Berkeley National Lab. (United States); K. S. Shah, Radiation Monitoring Devices, Inc. (United States)

POSTER SESSION

- 7079 1A **New application of scintillator ZnSe(Te) in scintielectronic detectors for detection of neutrons, medical imaging, explosive detection, and NDT** [7079-45]
V. D. Ryzhikov, O. D. Opolonin, A. G. Fedorov, O. K. Lysetska, Institute for Scintillation Materials (Ukraine); S. A. Kostioukevitch, Institute of Semiconductor Physics (Ukraine)
- 7079 1B **Dynamic characterizations of an 8-frame half-strip high-speed x-ray microchannel plate imager** [7079-50]
K. Moy, M. Wu, C. Kruschwitz, A. Tibbitts, M. Griffin, National Security Technologies, LLC (United States); G. Rochau, Sandia National Labs. (United States)
- 7079 1D **High spatial resolution x-ray mapping of CdZnTe detectors** [7079-47]
G. Yang, A. E. Bolotnikov, G. S. Camarda, Y. Cui, A. Hossain, R. B. James, Brookhaven National Lab. (United States)
- 7079 1E **Effect of chemical etching on the surface roughness of CdZnTe and CdMnTe gamma radiation detectors** [7079-46]
A. Hossain, Brookhaven National Lab. (United States); S. Babalola, Fisk Univ. (United States) and Vanderbilt Univ. (United States); A. E. Bolotnikov, G. S. Camarda, Y. Cui, G. Yang, Brookhaven National Lab. (United States); M. Guo, Fisk Univ. (United States); D. Kochanowska, A. Mycielski, Institute of Physics (Poland); A. Burger, Fisk Univ. (United States); R. B. James, Brookhaven National Lab. (United States)
- 7079 1F **Performance of RENA-3 IC with position-sensitive solid-state detectors** [7079-44]
T. O. Tumer, V. B. Cajipe, M. Clajus, S. Hayakawa, A. Volkovskii, Nova R&D, Inc. (United States)
- 7079 1G **Model compounds for cadmium zinc telluride (CZT) impurities** [7079-43]
D. L. Perry, Lawrence Berkeley National Lab. (United States); L. Franks, Special Technologies Lab. (United States)

Author Index

Conference Committee

Program Track Chairs

Sandra G. Biedron, Argonne National Laboratory (United States) and
Sincrotrone Trieste (Italy)

Massimo Altarelli, Deutsches Elektronen-Synchrotron (Germany)

Conference Chairs

Arnold Burger, Fisk University (United States)

Larry A. Franks, Consultant (United States)

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

Program Committee

Toru Aoki, Shizuoka University (Japan)

H. Bradford Barber, The University of Arizona (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)

Henry Chen, Redlen Technologies (Canada)

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

F. Patrick Doty, Sandia National Laboratories (United States)

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

Jonathan E. Grindlay, Harvard-Smithsonian Center for Astrophysics
(United States)

Yoshinori Hatanaka, Aichi University of Technology (Japan)

Zhong He, University of Michigan (United States)

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

Warnick J. Kernan, National Security Technologies, LLC (United States)

Glenn F. Knoll, University of Michigan (United States)

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

Longxia Li, Yinnel Tech, Inc. (United States)

Paul N. Luke, Lawrence Berkeley National Laboratory (United States)

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

Krishna C. Mandal, EIC Laboratories, Inc. (United States)

Jim L. Matteson, University of California, San Diego (United States)

Douglas S. McGregor, Kansas State University (United States)

Robert D. McLaren, Consultant (United States)

Richard W. Olsen, Consultant (United States)

Alan Owens, European Space Agency (Netherlands)

Ann M. Parsons, NASA Goddard Space Flight Center (United States)

Bradley E. Patt, Gamma Medica-Ideas, Inc. (United States)
Eugenio Perillo, Università degli Studi di Napoli Federico II (Italy)
Raulf M. Polichar, Science Applications International Corporation
 (United States)
James M. Ryan, University of New Hampshire (United States)
Eiichi Sato, Iwate Medical University (Japan)
Michael M. Schieber, The Hebrew University of Jerusalem (Israel)
Paul Siffert, Centre National de la Recherche Scientifique (France)
Michael R. Squillante, Radiation Monitoring Devices, Inc. (United
 States)
Csaba Szeles, eV Products, Inc. (United States)
Jacob I. Trombka, NASA Goddard Space Flight Center (United States)
Tümay O. Tümer, Nova R&D, Inc. (United States)
Sergey E. Ulin, Moscow Engineering Physics Institute (Russia)
Lodewijk van Den Berg, Constellation Technology Corporation (United
 States)
Peter E. Vanier, Brookhaven National Laboratory (United States)
Nikolay B. Zaletaev, Orion Research and Production Association
 (Russia)

Session Chairs

- 1 CZT Detectors
Alan Janos, U.S. Department of Homeland Security (United States)
- 2 Neutron Detectors
Douglas S. McGregor, Kansas State University (United States)
- 3 CZT Growth and Characterization I
Larry A. Franks, Consultant (United States)
- 4 CdTe Crystals and Detectors
Robert D. McLaren, Consultant (United States)
- 5 Other Wide Bandgap Semiconductors I
Lodewijk van Den Berg, Constellation Technology Corporation (United
 States)
- 6 Other Wide Bandgap Semiconductors II
Dale L. Perry, Lawrence Berkeley National Laboratory (United States)
- 7 CZT Growth and Characterization II
Aleksey E. Bolotnikov, Brookhaven National Laboratory (United States)
- 8 Scintillators
Robert D. McLaren, Consultant (USA)

- 9 Imaging I
Krishna C. Mandal, EIC Laboratories, Inc. (United States)
- 10 Imaging II
Michael Fiederle, Albert-Ludwigs-Universität Freiburg (Germany)
- 11 Post-Deadline Papers
Arnold Burger, Fisk University (United States)

Introduction

This book contains the proceedings of the SPIE conference on Hard X-Ray, Gamma-Ray and Neutron Detector Physics X. The conference was held August 11-13, 2008 in San Diego, CA. The conference was organized into technical sessions on cadmium zinc telluride (CZT), cadmium telluride, scintillators, imaging, novel semiconductor gamma-ray detectors, and applications.

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 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 and gamma cameras, 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 cadmium zinc telluride gamma detectors have provided new insights and directions to address deficiencies in the crystals and detectors.

Despite the limitations on efficiency and relatively high cost of current room-temperature semiconductor detectors, they have been increasingly deployed in systems useful for medical diagnostics, space applications, safeguarding of nuclear materials, x-ray fluorescence, 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 room-temperature semiconductor detectors without degrading their spectral performance.

A total of 49 presentations, oral and poster, were given at the conference. Although the number of attendees varied with the session and day of week, the attendance averaged approximately 60 people, with a substantial fraction of those in attendance representing organizations outside of the U.S. Some of the sessions drew more than 100 attendees.

This book provides detailed documentation describing 38 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.

Arnold Burger
Larry A. Franks
Ralph B. James