

PROCEEDINGS OF SPIE

# ***Infrared Technology and Applications XXXVI***

**Bjørn F. Andresen  
Gabor F. Fulop  
Paul R. Norton**  
*Editors*

**5–9 April 2010  
Orlando, Florida, United States**

*Sponsored and Published by*  
SPIE

Part One of Two Parts

**Volume 7660**

Proceedings of SPIE, 0277-786X, v. 7660

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 *Infrared Technology and Applications XXXVI*, edited by Bjørn F. Andresen, Gabor F. Fulop, Paul R. Norton, Proceedings of SPIE Vol. 7660 (SPIE, Bellingham, WA, 2010) Article CID Number.

ISSN 0277-786X  
ISBN 9780819481245

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 © 2010, 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](http://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/10/\$18.00.

Printed in the United States of America.

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

**SPIE**   
Digital Library

[SPIDigitalLibrary.org](http://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 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

xvii	<i>Conference Committee</i>
xxii	<i>Introduction</i>

---

## INFRARED IN THE SERVICE OF THE NAVY

---

7660 03	<b>Simulator ofIRST system with ATR embedded functions</b> [7660-01] B. Sozzi, E. Fossati, G. Barani, N. Santini, Selex Galileo Firenze (Italy); A. Ondini, G. Colombi, C. Quaranta, Selex Galileo Nerviano (Italy)
7660 04	<b>New generation of navalIRST: example of EOMS NG</b> [7660-02] D. Maltese, O. Deyla, G. Vernet, C. Preux, G. Hilt, P.-O. Nouguès II, SAGEM DS (France)
7660 05	<b>Performance characteristics of a submarine panoramic infrared imaging sensor</b> [7660-03] J. M. Nichols, J. R. Waterman, U.S. Naval Research Lab. (United States); R. Menon, Remote Reality, Inc. (United States); J. Devitt, L-3 Cincinnati Electronics (United States)
7660 06	<b>ARTEMIS: first naval staringIRST in service</b> [7660-04] J.-C. Fontanella, D. Delacourt, Y. Klein, Thales Optronique S.A. (France)
7660 07	<b>SASS: a bi-spectral panoramicIRST - results from measurement campaigns with the Italian Navy</b> [7660-05] S. U. de Ceglie, M. Lo Moro, CISAM (Italy); R. Vita, A. Neri, CSSN ITE (Italy); G. Barani, M. Cavallini, C. Quaranta, G. Colombi, SELEX Galileo (Italy)
7660 08	<b>Passive shortwave infrared technology and hyperspectral imaging for maritime applications</b> [7660-06] K. P. Judd, J. R. Waterman, J. M. Nichols, Naval Research Lab. (United States)
7660 09	<b>Search and tracking system architecture using 1-D scanning sensors</b> [7660-128] S. Nam, B. Choi, S. Joung, J. Kim, Samsung Thales Co., Ltd. (Korea, Republic of)

---

## SYSTEMS FOR HIGH SITUATIONAL AWARENESS

---

7660 0A	<b>Innovative optronics for the new PUMA tank</b> [7660-07] J. Fritze, M. Münzberg, H. Schlemmer, Carl Zeiss Optronics GmbH (Germany)
7660 0B	<b>Mid-wave infrared (MWIR) panoramic sensor for various applications</b> [7660-08] C. Bjork, W. Wan, Lockheed Martin Coherent Technologies (United States)
7660 0C	<b>Low-power XGA thermal camera for ground applications</b> [7660-09] S. Kummer, L-3 Communications Corp. (United States)

---

## TARGET ACQUISITION

---

- 7660 OD **A night sight clip on module based on uncooled infrared detector technology as one part of a modular equipment for the well-armed soldier** [7660-11]  
C. Berlips, B. Ledertheil, Carl Zeiss Optronics GmbH, Wetzlar Site (Germany); M. Münzberg, Carl Zeiss Optronics GmbH (Germany)
- 7660 OE **A high-performance clip on thermal sight for combat rifle scopes** [7660-12]  
S. P. Way, N. Jolivet, J. Hansen, FLIR Systems, Inc. (United States); D. Schick, T. Maciak, Trijicon, Inc. (United States)
- 7660 OF **The role of SWIR building blocks in Hostile Fire Indication and Missile Warning Systems** [7660-122]  
G. A. Tidhar, O. Aphek, M. Gurovich, IAI - ELTA (Israel)
- 7660 OI **Uncooled infrared development for small unmanned aerial vehicles** [7660-147]  
T. S. Pitt, S. B. Wood, C. E. Waddle, U.S. Army Aviation and Missile Research, Development and Engineering Ctr. (United States); W. D. Edwards, B. S. Yeske, Dynefics, Inc. (United States)

---

## PASSIVE IMAGING IN SWIR AND BELOW

---

- 7660 OJ **Parameterized nonuniformity corrections (NUC) for non-temperature stabilized InGaAs SWIR sensing** [7660-16]  
J. Battaglia, Sensors Unlimited, Inc., part of Goodrich Corp. (United States); V. Burzi, Process Automation Corp. (United States); B. Moyer, T. Sudol, J. Passe, Sensors Unlimited Inc., part of Goodrich Corp. (United States)
- 7660 OK **Low-Light-Level InGaAs focal plane arrays with and without illumination** [7660-17]  
M. MacDougal, J. Geske, C. Wang, D. Follman, Aerius Photonics, LLC (United States)
- 7660 OL **Development of low dark current SiGe-detector arrays for visible-NIR imaging sensor** [7660-18]  
A. K. Sood, R. A. Richwine, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); N. DiLello, J. L. Hoyt, Microsystems Technology Labs. (United States); T. I. Akinwande, Microsystems Technology Labs. (United States); N. Dhar, DARPA/MTO (United States); S. Horn, Night Vision and Electronic Sensors Directorate (United States); R. S. Balcerak, Raymond S. Balcerak LLC (United States); T. G. Bramhall, U.S. Army Aviation and Missile Research, Development and Engineering Ctr. (United States)
- 7660 OM **Wide-band imaging for enhanced day and night vision** [7660-19]  
C. Rafferty, C. King, B. Ackland, J. Sproul, I. Aberg, J. O'Neill, T. S. Sriram, C. Godek, A. Lattes, S. Pappas, A. Buck, V. Jovanovic, NoblePeak Vision (United States)
- 7660 ON **Black silicon enhanced photodetectors: a path to IR CMOS** [7660-20]  
M. U. Pralle, J. E. Carey, H. Homayoon, S. Alie, J. Sickler, X. Li, J. Jiang, D. Miller, C. Palsule, J. McKee, SiOnyx Inc. (United States)
- 7660 OO **High performance CMOS image sensor for digitally fused day/night vision systems** [7660-21]  
B. Fowler, P. Vu, C. Liu, S. Mims, H. Do, W. Li, J. Appelbaum, Fairchild Imaging (United States)

7660 OP **Hybrid infrared optical upconversion devices with a built-in electrical gain** [7660-22]  
J. Chen, D. Ban, Univ. of Waterloo (Canada); M. G. Helander, Z. Lu, Univ. of Toronto (Canada); P. Poole, H. C. Liu, National Research Council Canada (Canada)

7660 OQ **SWIR HgCdTe HDVIP detectors MTF Monte Carlo modeling and data** [7660-23]  
A. I. D'Souza, M. G. Stapelbroek, C. Yoneyama, P. Ely, DRS Sensors & Targeting Systems (United States); M. R. Skokan, H. D. Shih, DRS Sensors & Targeting Systems, Infrared Technologies Division (United States)

---

#### UNCOOLED FPAS AND APPLICATIONS I

---

7660 OS **A digital 25- $\mu\text{m}$  pixel-pitch uncooled amorphous silicon TEC-less VGA IRFPA with massive parallel Sigma-Delta-ADC readout** [7660-25]  
D. Weiler, M. Russ, D. Würfel, R. Lerch, P. Yang, J. Bauer, H. Vogt, Fraunhofer Institute of Microelectronic Circuits and Systems (Germany)

7660 OT **High performance uncooled amorphous silicon VGA IRFPA with 17- $\mu\text{m}$  pixel-pitch** [7660-26]  
J. L. Tissot, A. Durand, Th. Garret, C. Minassian, P. Robert, S. Tinnes, M. Vilain, ULIS (France)

7660 OU **Low-resistance a-SiGe-based microbolometer pixel for future smart IR FPA** [7660-27]  
J. J. Yon, J. P. Nieto, L. Vandroux, P. Imperinetti, E. Rolland, V. Goudon, C. Vialle, A. Arnaud, CEA-LETI, MINATEC (France)

7660 OV **DRS uncooled VOx infrared detector development and production status** [7660-28]  
C. Li, C. J. Han, G. D. Skidmore, C. Hess, DRS Reconnaissance, Surveillance & Target Acquisition (United States)

7660 OW **New developments in SCD's 17- $\mu\text{m}$  VOx  $\mu$ -bolometer product line** [7660-29]  
U. Mizrahi, L. Bikov, A. Giladi, N. Shiloah, S. Elkind, T. Czyzewski, I. Kogan, S. Maayani, A. Amsterdam, I. Vaserman, Y. Hirsh, A. Fraenkel, SCD Semiconductor Devices (Israel)

---

#### UNCOOLED FPAS AND APPLICATIONS II

---

7660 OX **Advances in high rate uncooled detector fabrication at Raytheon** [7660-30]  
S. H. Black, R. Kraft, A. Medrano, T. Kocian, D. Bradstreet, R. Williams, T. Yang, Raytheon Vision Systems (United States)

7660 OY **Small pixel uncooled imaging FPAs and applications** [7660-31]  
R. Blackwell, G. Franks, D. Lacroix, S. Hyland, R. Murphy, BAE Systems (United States)

7660 OZ **A 320 x 240 pixel uncooled TEC-less infrared radiation focal plane array with the reset noise canceling algorithm** [7660-32]  
H. Honda, H. Funaki, I. Fujiwara, H. Yagi, K. Ishii, K. Suzuki, K. Sasaki, M. Ogata, R. Ueno, H. Kwon, Toshiba Corp. (Japan)

7660 IO **Design and performance of PIR security sensors using 10 to 25- $\mu\text{m}$  microbolometer technology** [7660-33]  
K. C. Liddiard, Electro-optic Sensor Design (Australia)

- 7660 11 **Beyond the blackbody radiation limit: high sensitivity thermal detectors** [7660-34]  
J. J. Talghader, Univ. of Minnesota (United States) and Ascir, Inc. (United States);  
A. S. Gawarikar, R. P. Shea, Univ. of Minnesota (United States)
- 7660 12 **Amorphous silicon thin-films for uncooled infrared microbolometer sensors** [7660-151]  
S. K. Ajmera, A. J. Syllaios, G. S. Tyber, M. F. Taylor, L-3 Communications Electro-Optical  
Systems (United States); R. E. Hollingsworth, ITN Energy Systems (United States)
- 7660 13 **Performance enhancement of  $\mu$ -bolometer by increasing fill factor** [7660-144]  
S. Park, S. Han, C. H. Chun, C. S. Han, Hoseo Univ. (Korea, Republic of)
- 7660 14 **Uncooled microbolometers with  $\text{Ge}_x\text{Si}_{1-x}$  thermo-sensing layer deposited by plasma with  
different device configurations** [7660-145]  
M. Moreno, A. Torres, A. Kosarev, National Institute for Astrophysics, Optics and Electronics  
(Mexico)

---

#### NOVEL UNCOOLED TECHNOLOGIES

---

- 7660 15 **Optical properties of antenna-coupled vanadium dioxide films** [7660-35]  
K. Lewis, Sciovis Ltd. (United Kingdom)
- 7660 16 **High-performance long wave infrared bolometer fabricated by wafer bonding** [7660-36]  
A. Lapadatu, G. Kittilsland, A. Elfving, E. Hohler, T. Kvisterøy, Sensoror Technologies AS  
(Norway); T. Bakke, SINTEF (Norway); P. Ericsson, Acreo AB (Sweden)
- 7660 17 **Photomechanical imager FPA design for manufacturability** [7660-37]  
M. Erdtmann, G. Simelgor, S. Radhakrishnan, L. Zhang, Y. Liu, P. Y. Emelie, J. Salerno, Agiltron,  
Inc. (United States)
- 7660 18 **Skin depth effects in wavelength-selective infrared microbolometers based on lossy  
frequency selective surfaces** [7660-38]  
J.-Y. Jung, J. Y. Park, D. P. Neikirk, The Univ. of Texas at Austin (United States); A. S. Weling,  
Foster-Miller, Inc. (United States); W. T. Haffer, J. H. Goldie, Infoscitex Corp. (United States);  
P. Wilson, U.S. Army RDECOM-ARDEC (United States)
- 7660 1A **Advanced dynamic pyroelectric focal plane array** [7660-40]  
R. A. G. Unglaub, J. B. Celinska, C. R. McWilliams, C. A. Paz de Araujo, Symetrix Corp. (United  
States); T. Forbes, J. D. Pankin, Delphi Corp. (United States)
- 7660 1B **Properties of reactively sputtered nickel oxide films as a microbolometer sensing material**  
[7660-137]  
D. S. Kim, I. W. Kwon, C. H. Hwang, H. C. Lee, Korea Advanced Institute of Science and  
Technology (Korea, Republic of); Y. S. Lee, Kyungpook National Univ. (Korea, Republic of)
- 7660 1C **Fabrication of wavelength selective germanium dielectric supported microbolometers**  
[7660-139]  
J. Y. Park, J.-Y. Jung, D. P. Neikirk, The Univ. of Texas at Austin (United States); A. S. Weling,  
Foster-Miller, Inc. (United States); W. T. Hafer, J. H. Goldie, Infoscitex Corp. (United States);  
P. Wilson, U.S. Army RDECOM-ARDEC (United States)

- 7660 1D **Development of infrared detector with slot antenna-coupled microbolometer** [7660-146]  
K. Son, Nano CVD Co. (United States) and Univ. of South Florida (United States); N. Kislov,  
Nano CVD Co. (United States); J. Wang, Univ. of South Florida (United States)

---

#### TYPE-II SUPERLATTICE FPAS I

- 7660 1E **Developing high-performance III-V superlattice IRFPAs for defense: challenges and solutions (Invited Paper)** [7660-42]  
L. Zheng, Institute for Defense Analyses (United States); M. Tidrow, L. Aitchison, U.S. Army RDECOM CERDEC NVESD (United States); J. O'Connor, Cobham Analytic Solutions (United States); S. Brown, Space Dynamics Lab. (United States)
- 7660 1F **Type-II antimonide-based superlattices for the third generation infrared focal plane arrays (Invited Paper)** [7660-43]  
M. Razeghi, E. K. Huang, B.-M. Nguyen, S. Abdollahi Pour, P.-Y. Delaunay, Northwestern Univ. (United States)
- 7660 1G **Type-II superlattices: the Fraunhofer perspective (Invited Paper)** [7660-44]  
R. Rehm, M. Walther, J. Schmitz, F. Rutz, A. Wörl, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); R. Scheibner, J. Ziegler, AIM INFRAROT-MODULE GmbH (Germany)
- 7660 1H **Type-II superlattice materials research at the Air Force Research Laboratory (Invited Paper)** [7660-45]  
G. J. Brown, Air Force Research Lab. (United States); S. Elhamri, Univ. of Dayton (United States); H. E. Smith, Air Force Research Lab. (United States) and Univ. of Dayton Research Institute (United States); K. Mahalingam, H. J. Haugan, Air Force Research Lab. (United States) and Universal Technology Corp. (United States); S. Pacley, Air Force Research Lab. (United States); B. Ullrich, Universal Technology Corp. (United States); F. Szmulowicz, Air Force Research Lab. (United States) and Univ. of Dayton Research Institute (United States)
- 7660 1J **MBE growth of Sb-based type-II strained layer superlattice structures on multiwafer production reactors (Invited Paper)** [7660-47]  
D. Lubyshev, J. M. Fastenau, X. Gu, A. W. K. Liu, IQE Inc. (United States); J. Prineas, E. J. Koerperick, J. T. Olesberg, ASL Analytical, Inc. (United States); E. M. Jackson, J. A. Nolde, C. Yi, E. H. Aifer, Naval Research Lab. (United States)
- 7660 1K **Epitaxy ready 4" GaSb substrates: requirements for MBE grown type-II superlattice infrared detectors (Invited Paper)** [7660-48]  
M. J. Furlong, R. Martinez, S. Amirhaghi, Wafer Technology Ltd. (United Kingdom); D. Loubychev, J. M. Fastenau, X. Gu, A. W. K. Liu, IQE Inc. (United States)
- 7660 1L **Optimization of MWIR type-II superlattices for infrared detection (Invited Paper)** [7660-49]  
C. Grein, M. E. Flatté, EPIR Technologies, Inc. (United States)

---

**TYPE-II SUPERLATTICE FPAS II**

---

- 7660 1M **LWIR high performance focal plane arrays Based on type-II strained layer superlattice (SLS) materials (Invited Paper)** [7660-50]  
A. Hood, A. J. Evans, A. Ikhlassi, G. Sullivan, E. Piquette, D. L. Lee, W. E. Tennant, Teledyne Imaging Sensors (United States); I. Vurgafman, C. L. Canedy, E. M. Jackson, J. A. Nolde, C. Yi, E. H. Aifer, U.S. Naval Research Lab. (United States)
- 7660 1N **Characterization of barrier effects in superlattice LWIR detectors (Invited Paper)** [7660-51]  
D. R. Rhiger, R. E. Kvaas, S. F. Harris, B. P. Kolasa, Raytheon Vision Systems (United States); C. J. Hill, D. Z. Ting, Jet Propulsion Lab. (United States)
- 7660 1O **Fabrication and performance of InAs/GaSb-based superlattice LWIR detectors (Invited Paper)** [7660-52]  
S. Terterian, B. Nosh, H. Sharifi, P. Patterson, R. Rajavel, HRL Labs., LLC (United States)
- 7660 1P **SLS technology: the FPA perspective (Invited Paper)** [7660-53]  
M. Sundaram, A. Reisinger, R. Dennis, K. Patnaude, D. Burrows, J. Bundas, K. Beech, R. Faska, QmagiQ, LLC (United States)
- 7660 1Q **Recent developments in type-II superlattice-based infrared detectors (Invited Paper)** [7660-54]  
E. H. Aifer, U.S. Naval Research Lab. (United States); S. I. Maximenko, Global Strategies Group (United States); M. K. Yakes, C. Yi, C. L. Canedy, I. Vurgafman, E. M. Jackson, J. A. Nolde, C. A. Affouda, U.S. Naval Research Lab. (United States); M. Gonzalez, Global Strategies Group (United States); J. R. Meyer, U.S. Naval Research Lab. (United States); K. P. Clark, P. R. Pinsukanjana, Intelligent Epitaxy Technology, Inc (United States)
- 7660 1R **Antimonide-based barrier infrared detectors (Invited Paper)** [7660-55]  
D. Z. Ting, C. J. Hill, A. Soibel, J. Nguyen, S. A. Keo, M. C. Lee, J. M. Mumolo, J. K. Liu, S. D. Gunapala, Jet Propulsion Lab. (United States)
- 7660 1S **Growth and performance of superlattice-based long wavelength complementary barrier infrared detectors (CBIRDs) (Invited Paper)** [7660-56]  
C. J. Hill, A. Soibel, S. A. Keo, M. C. Lee, J. M. Mumolo, J. Nguyen, S. B. Rafol, D. Z. Ting, B. Yang, S. D. Gunapala, Jet Propulsion Lab. (United States)
- 7660 1T **Heterostructure band engineering of type-II InAs/GaSb superlattice based longwave infrared photodiodes using unipolar current blocking barriers (Invited Paper)** [7660-57]  
N. Gautam, E. Plis, H. S. Kim, M. N. Kutty, S. Myers, A. Khoshakhlagh, L. R. Dawson, S. Krishna, Univ. of New Mexico (United States)
- 7660 1U **SU-8 passivation of type-II InAs/GaSb strained layer superlattice detectors (Invited Paper)** [7660-58]  
H. S. Kim, E. Plis, N. Gautam, A. Khoshakhlagh, S. Myers, M. N. Kutty, Y. Sharma, L. R. Dawson, S. Krishna, Univ. of New Mexico (United States)
- 7660 1V **Carrier lifetime measurements in InAs/GaSb strained layer superlattice structures (Invited Paper)** [7660-59]  
S. P. Svensson, U.S. Army Research Lab. (United States); D. Donetsky, D. Wang, Stony Brook Univ. (United States); P. Maloney, U.S. Army Night Vision & Electronic Sensors Directorate (United States); G. Belenky, Stony Brook Univ. (United States)

- 7660 1W **Dual-carrier multiplication high-gain MWIR strain layer superlattice impact ionization engineered avalanche photodiodes (Invited Paper)** [7660-154]  
S. Ghosh, K. Banerjee, Q. Duan, C. H. Grein, Univ. of Illinois at Chicago (United States);  
E. A. Plis, S. Krishna, M. M. Hayat, The Univ. of New Mexico (United States)

---

## IR OPTICS

---

- 7660 1X **MWIR continuous zoom with large zoom range** [7660-60]  
M. C. Sanson, J. Cornell, Corning Inc. (United States)
- 7660 1Y **An alternative approach to infrared optics** [7660-61]  
R. Morrison, R. Stack, Distant Focus Corp. (United States); G. Euliss, R. Athale, The MITRE Corp. (United States); C. Reese, J. Vizgaitis, J. Stevens, U.S. Army Night Vision & Electronic Sensors Directorate (United States); E. Tremblay, J. Ford, Univ. of California, San Diego (United States)
- 7660 1Z **Design of a cryogenic IR detector with integrated optics** [7660-62]  
M. Singer, Semiconductor Devices (Israel); D. Oster, Israeli Ministry of Defense (Israel)
- 7660 20 **Molding aspheric lenses for low-cost production versus diamond turned lenses** [7660-63]  
G. Cogburn, A. Symmons, L. Mertus, LightPath Technologies (United States)
- 7660 21 **1280 x 960 pixel microscanned infrared imaging module** [7660-64]  
L. Le Noc, B. Tremblay, A. Martel, C. Chevalier, N. Blanchard, M. Morissette, L. Mercier, F. Duchesne, L. Gagnon, P. Couture, F. Lévesque, N. Desnoyers, M. Demers, F. Lamontage, H. Jerominek, A. Bergeron, INO (Canada)
- 7660 22 **Integration of advanced optical functions on the focal plane array for very compact MCT-based micro cameras** [7660-65]  
M. Fendler, G. Lasfargues, CEA, LETI, MINATEC (France); S. Bernabé, CEA, LETI, MINATEC (France); G. Druart, F. De la Barriere, S. Rommeluère, N. Guérineau, ONERA (France); N. Lhermet, H. Ribot, CEA, LETI, MINATEC (France)
- 7660 23 **A zero-Focal-Length superlens for QWIPs and other infrared detectors** [7660-66]  
T. Antoni, M. Carras, Alcatel-Thales III-V Lab. (France); V. Berger, Univ. Paris Diderot (France); P. Guiset, A. de Rossi, Thales Research & Technology (France)
- 7660 24 **Dynamic Sunlight Filter (DSF): a passive way to increase the dynamic range in visible and SWIR cameras** [7660-67]  
A. Donval, T. Fisher, G. Blecher, M. Oron, KiloLambda Technologies, Ltd. (Israel)

## Part Two

- 7660 25 **Thermally robust IBS coatings for deep concave surfaces** [7660-68]  
D. Ness, D. Pitrat, C. Wood, Precision Photonics Corp. (United States)
- 7660 26 **Optical coatings for deep concave surfaces** [7660-69]  
T. D. Rahmlow, Jr., J. E. Lazo-Wasem, Rugate Technologies, Inc. (United States); M. B. Moran, L. F. Johnson, U.S. Navy Air Warfare Ctr. Weapons Division (United States)

- 7660 27 **Development of shutter subsystems for infrared imagers** [7660-70]  
F. DeWitt, D. Durfee, S. Stephenson, CVI Melles Griot (United States); G. Wagner, Ontario Tech. Inc. (United States)
- 7660 28 **The radiation tolerance of chalcogenide glasses** [7660-136]  
M. Naitoh, H. Katayama, M. Harada, M. Suganuma, Y. Okamura, Y. Tange, Japan Aerospace Exploration Agency (Japan); K. Rogers, Umicore Coating Services LTD (United Kingdom); Y. Guimond, Umicore IR Glass (France)
- 7660 29 **Optical design of a broadband (3-12  $\mu\text{m}$ ) athermal infrared imager** [7660-155]  
A. Uçar, TÜBİTAK SAGE (Turkey); M. Kabak, Ankara Univ. (Turkey)
- 7660 2A **Comparison of four midwave (3-5  $\mu\text{m}$ ) f2 objectives in the sense of their thermal performance** [7660-157]  
A. Uçar, K. D. Kandemir, Ş. Şendoğdu Yılmaz, TÜBİTAK SAGE (Turkey)
- 7660 2B **Practical applications of Zernike phase surfaces in optical system modeling** [7660-153]  
S. H. Vogel, StingRay Optics, LLC (United States)

---

#### HYPER- AND MULTISPECTRAL IMAGING

- 7660 2C **A novel multipixel imaging differential standoff chemical detection sensor** [7660-71]  
L. Moreau, F. Prel, ABB Bomem Inc. (Canada); H. Lavoie, F. Bouffard, J.-M. Thériault, Defense Research and Development Canada (Canada); C. Vallieres, C. Roy, L. Lévesque, ABB Bomem Inc. (Canada); D. Dubé, Defense Research and Development Canada (Canada)
- 7660 2D **Quantum dot infrared photodetectors with highly tunable spectral response for an algorithm based spectrometer** [7660-72]  
P. Vines, C. H. Tan, J. P. R. David, The Univ. of Sheffield (United Kingdom); R. S. Attaluri, T. E. Vandervelde, S. Krishna, W.-Y. Jang, M. M. Hayat, The Univ. of New Mexico (United States)
- 7660 2E **Multispectral UV-Vis-IR imaging using low-cost quantum dot technology** [7660-73]  
E. J. Klem, J. S. Lewis, D. Temple, RTI International (United States)
- 7660 2F **Noise properties of a corner-cube Michelson interferometer LWIR hyperspectral imager** [7660-74]  
D. Bergstrom, I. Renhorn, T. Svensson, R. Persson, T. Hallberg, R. Lindell, Swedish Defense Research Agency (Sweden); G. Boreman, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)
- 7660 2G **A miniature snapshot multispectral imager** [7660-75]  
N. Gupta, U.S. Army Research Lab. (United States); P. R. Ashe, S. Tan, Infotonics Technology Ctr. (United States)
- 7660 2H **Analysis of background irradiation in thermal IR hyper-spectral imaging systems** [7660-125]  
W. Xu, L. Yuan, Y. Lin, Z. He, R. Shu, J. Wang, Shanghai Institute of Technical Physics (China)

- 7660 2I **Cryogenic Fourier transform spectrometer for infrared spectral calibrations from 4 to 20 micrometers** [7660-149]  
S. I. Woods, S. G. Kaplan, T. M. Jung, A. C. Carter, R. U. Datla, National Institute of Standards and Technology (United States)

---

#### CRYOCOOLERS FOR IR FOCAL PLANE ARRAYS

---

- 7660 2J **Development of miniature, high frequency pulse tube cryocoolers (Invited Paper)** [7660-76]  
R. Radebaugh, I. Garaway, National Institute of Science and Technology (United States);  
A. M. Veprik, RICOR, Cryogenic and Vacuum Systems (Israel)
- 7660 2K **Split Stirling linear cryogenic cooler for a new generation of high temperature infrared imagers** [7660-77]  
A. Veprik, S. Zechtzer, N. Pundak, RICOR, Cryogenic and Vacuum Systems (Israel)
- 7660 2L **Cryocoolers for infrared missile warning systems** [7660-78]  
A. Filis, N. Pundak, Y. Zur, R. Broyde, M. Barak, RICOR-Cryogenic and Vacuum Systems (Israel)
- 7660 2M **The digital onboard drive electronics optimizes the rotary cryocooler functionalities for your demanding applications** [7660-79]  
D. Balax, Thales Cryogénie S.A. (France); J.-C. Terme, SOFRADIR (France); B. Shlomovich, Semi Conductor Devices (Israel); T. Etchanchu, J. Martin, J.-M. Cauquil, A. Bourillon, Thales Cryogénie S.A. (France)
- 7660 2N **Performance and reliability enhancement of linear coolers** [7660-80]  
M. Mai, I. Rühlich, A. Schreiter, S. Zehner, AIM INFRAROT-MODULE GmbH (Germany)
- 7660 2O **High-reliable linear cryocoolers and miniaturization developments at Thales Cryogenics** [7660-81]  
H. van der Weijden, A. Benschop, W. v. d. Groep, D. Willems, J. Mullié, Thales Cryogenics B.V. (Netherlands)
- 7660 2P **Performance of the SITP 35K two-stage Stirling cryocooler** [7660-126]  
D. Liu, A. Li, S. Li, Y. Wu, Shanghai Institute of Technical Physics (China)
- 7660 2Q **Development of a miniature coaxial pulse tube cryocooler for a space-borne infrared detector system** [7660-131]  
H. Z. Dang, L. B. Wang, Y. N. Wu, K. X. Yang, W. B. Shen, Shanghai Institute of Technical Physics (China)
- 7660 2R **Development of high-capacity U-type pulse tube cryocoolers for a cold optics system in space applications** [7660-132]  
H. Z. Dang, S. S. Li, L. B. Wang, K. X. Yang, W. B. Shen, Y. N. Wu, Shanghai Institute of Technical Physics (China)
- 7660 2S **Development of a 2.0W at 60K single-stage coaxial pulse tube cryocooler for long wave infrared focal plane array applications** [7660-133]  
H. Z. Dang, L. B. Wang, Y. N. Wu, K. X. Yang, S. S. Li, W. B. Shen, Shanghai Institute of Technical Physics (China)

- 7660 2T **Development of space Stirling and pulse tube cryocoolers in Shanghai Institute Technical Physics, Chinese Academy of Sciences** [7660-134]  
H. Z. Dang, Y. N. Wu, Shanghai Institute of Technical Physics (China)

---

#### HOT-HIGH OPERATING TEMPERATURE FPAS

---

- 7660 2U **Operating temperature: a challenge for cooled IR technologies** [7660-82]  
M. Vuillermet, P. Tribolet, SOFRADIR (France)
- 7660 2V **High operating temperature MWIR detectors** [7660-83]  
M. A. Kinch, H. F. Schaake, R. L. Strong, P. K. Liao, M. J. Ohlson, J. Jacques, C.-F. Wan, D. Chandra, R. D. Burford, C. A. Schaake, DRS-RSTA, Inc. (United States)
- 7660 2W **Performance of MWIR and SWIR HgCdTe-based focal plane arrays at high operating temperatures** [7660-84]  
L. Melkonian, J. Bangs, L. Elizondo, R. Ramey, E. Guerrero, Raytheon Vision Systems (United States)
- 7660 2X **Thermo electrically cooled focal plane arrays based on MCT** [7660-85]  
N. T. Gordon, QinetiQ Ltd. (United Kingdom)
- 7660 2Y **MWIR InAsSb X<sub>Bn</sub> detectors for high operating temperatures** [7660-86]  
P. Klipstein, O. Klin, S. Grossman, N. Snapi, B. Yaakobovitz, M. Brumer, I. Lukomsky, D. Aronov, M. Yassen, B. Yofis, A. Glozman, T. Fishman, E. Berkowitz, O. Magen, I. Shtrichman, E. Weiss, SCD Semiconductor Devices (Israel)
- 7660 2Z **Mid-wavelength InAsSb detectors based on nBn design** [7660-87]  
A. Khoshakhlagh, S. Myers, E. Plis, M. N. Kuty, B. Klein, N. Gautam, H. Kim, Univ. of New Mexico (United States); E. P. G. Smith, D. Rhiger, S. M. Johnson, Raytheon Vision Systems (United States); S. Krishna, Univ. of New Mexico (United States)
- 7660 30 **Spin split-off band-based high operating temperature IR detectors in 3-5  $\mu\text{m}$  and beyond** [7660-88]  
A. G. U. Perera, S. G. Matsik, M. S. Shishodia, R. C. Jayasinghe, P. K. D. D. P. Pitigala, Georgia State Univ. (United States)
- 7660 31 **Dark currents, responsivity, and response time in graded gap HgCdTe structures** [7660-89]  
J. Piotrowski, W. Gawron, Z. Orman, J. Pawluczyk, K. Kłos, D. Stepień, A. Piotrowski, Vigo Systems S.A. (Poland)
- 7660 32 **Carbon nanotube-based noncryogenic cooled multispectrum focal plane array** [7660-90]  
N. Xi, K. W. C. Lai, H. Chen, C. K. M. Fung, Michigan State Univ. (United States)
- 7660 33 **Performance limits of room-temperature InAsSb photodiodes** [7660-91]  
J. Wróbel, R. Ciupa, A. Rogalski, Military Univ. of Technology (Poland)
- 7660 34 **VPD PbSe technology: the road toward the industrial maturity** [7660-92]  
R. Linares Herrero, M. T. Montojo Supervielle, A. Baldasano Ramírez, New Infrared Technologies, Ltd. (Spain)

---

## NEXT-GENERATION HGCDTE DETECTORS

---

- 7660 35 **Advances in dual-band IRFPAs made from HgCdTe grown by MOVPE** [7660-94]  
P. Abbott, L. Pillans, P. Knowles, R. K. McEwen, SELEX Galileo Infrared Ltd. (United Kingdom)
- 7660 37 **Wide-band (2.5 - 10.5  $\mu\text{m}$ ), high-frame rate IRFPAs based on high-operability MCT on silicon** [7660-96]  
M. J. Crosbie, J. Giess, N. T. Gordon, D. J. Hall, J. E. Hails, D. J. Lees, C. J. Little, T. S. Phillips, QinetiQ Ltd. (United Kingdom)
- 7660 38 **Recent results of two-dimensional LW- and VLW-HgCdTe IR FPAs at AIM** [7660-97]  
J. Ziegler, D. Eich, S. Hanna, A. Bauer, H. Bitterlich, M. Bruder, K.-M. Mahlein, H. Lutz, T. Schallenberg, J. Wenisch, R. Wollrab, AIM INFRAROT-MODULE GmbH (Germany)
- 7660 39 **MCT IR detection modules with 15  $\mu\text{m}$  pitch for high-reliability applications** [7660-98]  
R. Breiter, T. Ihle, J. Wendler, H. Lutz, S. Rutzinger, T. Schallenberg, K. Hofmann, J. Ziegler, AIM INFRAROT-MODULE GmbH (Germany)
- 7660 3A **Noise processes modeling in HgCdTe infrared photodiode detectors** [7660-138]  
I. D. Burlakov, A. Y. Selyakov, Orion Research-and-Production Association (Russian Federation); V. P. Ponomarenko, Orion Research-and-Production Association (Russian Federation) and Moscow Institute of Physics and Technology (Russian Federation); A. M. Filachev, Orion Research-and-Production Association (Russian Federation)

---

## ACTIVE IMAGING

---

- 7660 3B **Low IR input flux condition operations thanks to MCT e-APD** [7660-99]  
F. Pistone, P. Tribolet, G. Decaens, S. Verdet, SOFRADIR (France); J. Rothman, E. De Borniol, CEA Leti-MINATEC (France)
- 7660 3C **Developments in HgCdTe avalanche photodiode technology and applications** [7660-100]  
A. Ashcroft, I. Baker, SELEX Galileo Infrared Ltd. (United Kingdom)
- 7660 3D **HgCdTe-based APD focal plane array for 2D and 3D active imaging: first results on a 320 x 256 with 30  $\mu\text{m}$  pitch demonstrator** [7660-101]  
E. de Borniol, F. Guellec, J. Rothman, A. Perez, J.-P. Zanatta, M. Tchagaspanian, P. Castelein, G. Destéfanis, CEA Leti - MINATEC (France); J.-C. Peyrard, DGA CELAR/MC (France); F. Pistone, Sofradir (United States)
- 7660 3E **Single-photon imaging camera development for night vision** [7660-102]  
S. Vasile, aPeak, Inc. (United States); J. Cheng, Massachusetts Institute of Technology (United States); J. Lipson, aPeak, Inc. (United States); J. Liu, J. Michel, Massachusetts Institute of Technology (United States)
- 7660 3H **High-gain high-sensitivity resonant Ge/Si APD photodetectors** [7660-105]  
J. E. Bowers, D. Dai, Univ. of California, Santa Barbara (United States); Y. Kang, M. Morse, Intel Corp. (United States)
- 7660 3I **Advances in HgCdTe APDs and LADAR receivers** [7660-158]  
S. Bailey, W. McKeag, J. Wang, M. Jack, Raytheon Vision Systems (United States)  
F. Amzajerjian, NASA Langley Research Ctr. (United States)

---

**QWIP, QCD, QDIP, AND DWELL FPAS**

---

- 7660 3J **The QWIP focal plane assembly for NASA's Landsat Data Continuity Mission** [7660-106]  
M. Jhabvala, D. Reuter, NASA Goddard Space Flight Ctr. (United States); K. Choi, U.S. Army Research Lab. (United States); M. Sundaram, QmagiQ, LLC (United States); C. Jhabvala, A. La, A. Waczynski, NASA Goddard Space Flight Ctr. (United States); J. Bundas, QmagiQ, LLC (United States)
- 7660 3K **C-QWIPs for far infrared detection** [7660-107]  
K. K. Choi, U.S. Army Research Lab. (United States); M. D. Jhabvala, NASA Goddard Space Flight Ctr. (United States); D. P. Forrai, L3-Cincinnati Electronics (United States); J. Sun, U.S. Army Research Lab. (United States); D. Endres, L3-Cincinnati Electronics (United States)
- 7660 3L **Demonstration of 1024x1024 pixel dual-band QWIP focal plane array** [7660-108]  
S. D. Gunapala, Jet Propulsion Lab. (United States); S. V. Bandara, U.S. Army Night Vision & Electronic Sensors Directorate (United States); J. K. Liu, J. M. Mumolo, D. Z. Ting, C. J. Hill, J. Nguyen, S. B. Rafol, Jet Propulsion Lab. (United States)
- 7660 3M **QWIP responsivity prediction using the transfer matrix method** [7660-109]  
R. A. Tavares Santos, F. D. P. Alves, Instituto Tecnológico de Aeronáutica (Brazil)
- 7660 3N **Uncooled SWIR InGaAs/GaAsSb type-II quantum well focal plane array** [7660-110]  
H. Inada, K. Miura, H. Mori, Y. Nagai, Y. Iguchi, Sumitomo Electric Industries, Ltd. (Japan); Y. Kawamura, Osaka Prefecture Univ. (Japan)
- 7660 3O **Design and characterization of strain-compensated InGaAs/GaAsSb type-II MQW structure with operation wavelength at  $\sim 3\mu\text{m}$**  [7660-111]  
W. Y. Jiang, B. Chen, J. Yuan, A. L. Holmes, Jr., Univ. of Virginia (United States)
- 7660 3P **Backside illuminated infrared detectors with plasmonic resonators** [7660-113]  
J. Montoya, A. Barve, R. Shenoj, M. Naydenkov, H. Kim, Z. Ku, S. R. J. Brueck, S. Krishna, Univ. of New Mexico (United States); S. J. Lee, S. K. Noh, Korea Research Institute of Standards and Science (Korea, Republic of)
- 7660 3Q **State of the art of quantum cascade photodetectors** [7660-114]  
A. Buffaz, Univ. Paris Diderot (France) and Alcatel-Thales III-V Lab. (France); M. Carras, Alcatel-Thales III-V Lab. (France); L. Doyennette, Univ. Paris Diderot (France); A. Nedelcu, P. Bois, Alcatel-Thales III-V Lab. (France); V. Berger, Univ. Paris Diderot (France) and Alcatel-Thales III-V Lab. (France)
- 7660 3R **Absolute temperature measurements using a two-color QWIP focal plane array** [7660-115]  
J. Bundas, R. Dennis, K. Patnaude, D. Burrows, R. Faska, M. Sundaram, A. Reisinger, D. Manidakos, QmagiQ, LLC (United States)

---

**PROCESSING**

---

- 7660 3S **"On chip" Fourier processing to enhance SNR in the presence of background noise** [7660-116]  
R. J. Tansey, Lockheed Martin (United States)

- 7660 3T **A 25 $\mu$ m pitch LWIR focal plane array with pixel-level 15-bit ADC providing high well capacity and targeting 2mK NETD** [7660-117]  
F. Guellec, A. Peizerat, M. Tchagaspanian, E. De Borniol, S. Bisotto, L. Mollard, P. Castelein, J.-P. Zanatta, CEA Leti-MINATEC (France); P. Maillart, M. Zécéri, Sofradir (France); J.-C. Peyrard, DGA (France)
- 7660 3U **Improved MWIR reference sources for FPA non-uniformity correction** [7660-118]  
M. J. Crosbie, N. T. Gordon, D. J. Hall, J. E. Hails, C. J. Little, QinetiQ Ltd. (United Kingdom); S. Ashley, C. Axcell, SELEX GALILEO (United Kingdom)
- 7660 3V **Scaling and application of commercial, feature-rich, modular mixed-signal technology platforms for large format ROICs** [7660-120]  
A. Kar-Roy, M. Racanelli, D. Howard, G. Miyagi, M. Bowler, S. Jordan, T. Zhang, W. Krieger, TowerJazz, U.S.A. Aerospace and Defense (United States)
- 7660 3W **Radiation hardening of low-noise readout integrated circuit for infrared focal plane arrays** [7660-129]  
M. S. Lee, Korea Advanced Institute of Science and Technology (Korea, Republic of); Y. S. Lee, Kyungpook National Univ. (Korea, Republic of); H. C. Lee, Korea Advanced Institute of Science and Technology (Korea, Republic of)
- 7660 3X **Design of a ROIC for scanning type HgCdTe LWIR focal plane arrays** [7660-135]  
M. Yazici, H. Kayahan, O. Ceylan, Y. Gurbuz, Sabanci Univ. (Turkey)
- 7660 3Y **The calibration stand for thermal camera module with infrared focal plane array** [7660-140]  
T. Sosnowski, G. Bieszczad, H. Madura, M. Kastek, K. Firmanty, Military Univ. of Technology (Poland)
- 7660 3Z **Adaptable infrared image processing module implemented in FPGA** [7660-141]  
G. Bieszczad, T. Sosnowski, H. Madura, M. Kastek, J. Bareta, Military Univ. of Technology (Poland)

---

#### SELECTED APPLICATION PRESENTATIONS

- 7660 41 **Passive ranging using mid-wavelength infrared atmospheric attenuation** [7660-123]  
D. J. Macdonald, M. R. Hawks, K. C. Gross, Air Force Institute of Technology (United States)
- 7660 42 **Analysis and quantification of laser-dazzling effects on IR focal plane arrays** [7660-124]  
N. Hueber, Institut Franco-Allemand de Recherches de Saint-Louis (France); D. Vincent, A. Morin, Defence Research and Development Canada (Canada); A. Dieterlen, Univ. de Haute Alsace (France); P. Raymond, Institut Franco-Allemand de Recherches de Saint-Louis (France)
- 7660 43 **Mid-infrared backscattering measurements of building materials using a quantum cascade laser** [7660-143]  
M. Lwin, P. Corrigan, B. Gross, F. Moshary, S. Ahmed, The City College of New York (United States)

7660 44 **Comparison of midwave and longwave infrared detectors used in aerial applications**  
[7660-156]  
A. Uçar, B. Özkan, TÜBİTAK SAGE (Turkey)

*Author Index*

# Conference Committee

## *Symposium Chair*

**Michael T. Eismann**, Air Force Research Laboratory (United States)

## *Symposium Cochair*

**William Jeffrey**, HRL Laboratories, LLC (United States)

## *Conference Chairs*

**Bjørn F. Andresen**, Elbit Systems Electro-Optics ELOp Ltd. (Israel)

**Gabor F. Fulop**, Maxtech International, Inc. (United States)

**Paul R. Norton**, U.S. Army Night Vision & Electronic Sensors Directorate  
(United States)

## *Program Committee*

**Christopher C. Alexay**, StingRay Optics, LLC (United States)

**Timothy Ashley**, QinetiQ Ltd. (United Kingdom)

**Stefan T. Baur**, Raytheon Vision Systems (United States)

**Philippe F. Bois**, Alcatel-Thales III-V Laboratoire (France)

**Wolfgang A. Cabanski**, AIM Infrarot-Module GmbH (Germany)

**John T. Caulfield**, Cyan Systems (United States)

**John W. Devitt**, L-3 Communications Cincinnati Electronics  
(United States)

**Nibir K. Dhar**, Defense Advanced Research Projects Agency  
(United States)

**Michael T. Eismann**, Air Force Research Laboratory (United States)

**Martin H. Effenberg**, Sensors Unlimited, Inc., part of Goodrich  
Corporation (United States)

**Sarath D. Gunapala**, Jet Propulsion Laboratory (United States)

**Charles M. Hanson**, L-3 Communications Infrared Products  
(United States)

**Stuart B. Horn**, Defense Advanced Research Projects Agency  
(United States)

**Masafumi Kimata**, Ritsumeikan University (Japan)

**Hee Chul Lee**, Korea Advanced Institute of Science and Technology  
(Korea, Republic of)

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

**Wei Lu**, Shanghai Institute of Technical Physics (China)

**Mark A. Massie**, Nova Sensors (United States)

**Paul L. McCarley**, Air Force Research Laboratory (United States)

**R. Kennedy McEwen**, SELEX GALILEO (United Kingdom)

**John L. Miller**, FLIR Systems, Inc. (United States)  
**A. Fenner Milton**, U.S. Army RDECOM CERDEC NVESD (United States)  
**Peter W. Norton**, BAE Systems (United States)  
**Joseph G. Pellegrino**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)  
**Ray Radebaugh**, National Institute of Standards and Technology (United States)  
**Manijeh Razeghi**, Northwestern University (United States)  
**Colin E. Reese**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)  
**Ingmar G. Renhorn**, Swedish Defence Research Agency (Sweden)  
**Antoni Rogalski**, Military University of Technology (Poland)  
**Ingo Rühlich**, AIM Infrarot-Module GmbH (Germany)  
**Mike J. Scholten**, DRS Sensors & Targeting Systems, Inc. (United States)  
**Piet B. W. Schwering**, TNO Defence, Security and Safety (Netherlands)  
**Itay Shtrichman**, SCD Semiconductor Devices (Israel)  
**Rengarajan Sudharsanan**, Spectrolab, Inc. (United States)  
**Stefan P. Svensson**, Army Research Laboratory (United States)  
**Venkataraman S. Swaminathan**, U.S. Army Research, Development and Engineering Command (United States)  
**Simon Thibault**, ImmerVision (Canada)  
**Meimei Z. Tidrow**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)  
**Jean-Luc M. Tissot**, ULIS (France)  
**Philippe Tribolet**, SOFRADIR (France)  
**Jay N. Vizgaitis**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)  
**Kadri Vural**, Teledyne Imaging Sensors (United States)  
**James R. Waterman**, Naval Research Laboratory (United States)  
**Lucy Zheng**, Institute for Defense Analyses (United States)

### *Session Chairs*

Opening Remarks

**Bjørn F. Andresen**, Elbit Systems Electro-Optics ELOp Ltd. (Israel)

1 Infrared in the Service of the Navy

**James R. Waterman**, Naval Research Laboratory (United States)

**Piet B. W. Schwering**, TNO Defence, Security and Safety (Netherlands)

2 Systems for High Situational Awareness

**Ingmar G. Renhorn**, Swedish Defence Research Agency (Sweden)

**Gil A. Tidhar**, IAI - ELTA - Integrated Microwave Systems Division, Optigo Directorate (Israel)

3 Target Acquisition

**Mario O. Münzberg**, Carl Zeiss Optronics GmbH (Germany)

- 4 Passive Imaging in SWIR and Below  
**Martin H. Eitenberg**, Sensors Unlimited, Inc., part of Goodrich Corporation (United States)
- 5 Uncooled FPAs and Applications I  
**Stefan T. Baur**, Raytheon Vision Systems (United States)  
**Jean-Luc M. Tissot**, ULIS (France)
- 6 Uncooled FPAs and Applications II  
**Masafumi Kimata**, Ritsumeikan University (Japan)  
**Charles M. Hanson**, L-3 Communications Infrared Products (United States)
- 7 Novel Uncooled Technologies  
**Colin E. Reese**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)
- 8 Type-II Superlattice FPAs I  
**Meimei Z. Tidrow**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)  
**Manijeh Razeghi**, Northwestern University (United States)  
**Lucy Zheng**, Institute for Defense Analyses (United States)
- 9 Type-II Superlattice FPAs II  
**Meimei Z. Tidrow**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)  
**Manijeh Razeghi**, Northwestern University (United States)  
**Lucy Zheng**, Institute for Defense Analyses (United States)
- 10 IR Optics  
**Jay N. Vizgaitis**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)  
**Christopher C. Alexay**, StingRay Optics, LLC (United States)
- 11 Hyper- and Multispectral Imaging  
**Ingmar G. Renhorn**, Swedish Defence Research Agency (Sweden)
- 12 Cryocoolers for IR Focal Plane Arrays  
**Alexander M. Veprik**, RICOR-Cryogenic & Vacuum Systems (Israel)  
**Ingo Rühlich**, AIM INFRAROT-MODULE GmbH (Germany)
- 13 HOT-High Operating Temperature FPAs  
**Michael T. Eismann**, Air Force Research Laboratory (United States)  
**Joseph G. Pellegrino**, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

- 14 Keynote Session  
**Paul R. Norton**, U.S. Army Night Vision & Electronic Sensors Directorate  
(United States)
- 15 Next-Generation HgCdTe Detectors  
**Philippe Tribolet**, SOFRADIR (France)  
**Timothy Ashley**, QinetiQ Ltd. (United Kingdom)  
**Neil T. Gordon**, QinetiQ Ltd. (United Kingdom)
- 16 Active Imaging  
**R. Kennedy McEwen**, SELEX GALILEO (United Kingdom)
- 17 QWIP, QCD, QDIP, and Dwell FPAs  
**Philippe F. Bois**, Alcatel-Thales III-V Laboratory (France)  
**John W. Devitt**, Georgia Tech Research Institute (United States)
- 18 Processing  
**Paul L. McCarley**, Air Force Research Laboratory (United States)  
**John T. Caulfield**, Cyan Systems (United States)
- 19 Selected Application Presentations  
**John L. Miller**, FLIR Systems, Inc. (United States)  
**Bjørn F. Andresen**, Elbit Systems Electro-Optics ELOp Ltd. (Israel)

# Introduction

The Thirty-Sixth conference on Infrared Technology and Applications was held the week of April 5-9, 2010 at the Orlando World Center Marriott Resort and Convention Center in Orlando, Florida. The agenda was divided into 19 sessions:

1. Infrared in the service of the Navy
2. Systems for high situational awareness
3. Target acquisition
4. Passive imaging in SWIR and below
5. Uncooled FPAs and Applications I
6. Uncooled FPAs and Applications II
7. Novel uncooled technologies
8. Type II superlattice FPAs I
9. Type II superlattice FPAs II
10. IR Optics
11. Hyper- and multispectral imaging
12. Cryocoolers for IR Focal Plane Arrays
13. HOT—High Operating Temperature FPAs
14. Keynote—The critical role of MOVPE technology in thermal imaging capability
15. Next generation HgCdTe detectors
16. Active imaging
17. QWIP, QCD, QDIP, and Dwell FPAs
18. Signal processing
19. Selected Application Presentations

In addition, there were twenty-five poster papers presented for discussion on Thursday evening. Highlights of five topical areas are summarized below:

- Applications
- Optics
- Uncooled thermal detectors
- Photon detectors
- Cryocoolers

## Applications

Applications can roughly be divided into three types:

1. Situational awareness systems
2. Soldier systems
3. Hyper- and multi-spectral imaging systems

Target search systems covering 360° in azimuth and, typically, 40° to 60° in elevation were discussed in two sessions. One session reported on naval systems while the other was concerned with systems mounted on

army platforms. All of the presented Infrared Search and Track,IRST, systems employ two-dimensional FPAs in order to increase the signal integration time and achieve longer range performance. One group presented a system using continuous panoramic scan and the TDI technique, while another combined the horizontal scan with a de-rotator in order obtain a scan-stop-and-stare action. Wide panoramic search without the use of a scanning head was demonstrated by using various techniques such as optical multiplexing; a 2048 × 2048 pixel FPA combined with a catadioptric omnidirectional optical system; and a simple panoramic lens whose highly distorted image may be corrected by a computer. The distributed aperture system, DAS, which employs a number of thermal imagers around the platform, was also discussed.

Detection of missiles and aircraft with a low false alarm rate at long ranges requires a high spatial resolution (small IFOV) and a high update rate. These requirements, combined with need for an elevation coverage of several tens of degrees, call for a large FPA. Lacking these FPAs, all the presenters of the various IRST system designs chose an IFOV which by far exceeded the rule-of-the-thumb IFOV of 100 μrad. Among the solutions considered in order to retain good discrimination against false targets were the addition of an active sensor (radar or laser), dual waveband, and man-in-the-loop.

Several papers were devoted to “IR for the Soldier” systems. Two night-sight modules for mounting in front of a rifle’s day-sight were presented. Both modules employed uncooled microbolometers.

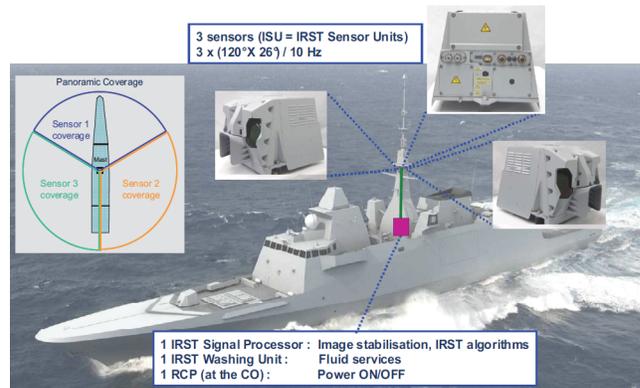


Fig. 1 Thales Optronique's Artemis IRST architecture



Fig. 2 Carl Zeiss Optronics' IRV 900 mounted on an HK 417 rifle in front of a 4x30 day-sight aiming optics.

Sensor systems operating in the ultra-violet and MWIR spectral regions have traditionally been used for detection of gun flashes, detonations and missile launches. One paper reviewed the relative performance of gun-flash sensor technologies and concluded that SWIR technology is optimal for these systems. A trade-off analysis showed the InGaAs:InP to be the optimal detector. Temporal discrimination against background sun-clutter interference on a clear cloudless day was hinted at but not demonstrated.

The presented hyper- and multi-spectral imagers were using widely different techniques and technologies. The preferred concept depends on the specific application.

The concept of a Fourier-transform micro-spectrometer on chip, developed for very fast acquisition of spectral signatures, was discussed. The spectrometer is made by grinding the HgCdTe detector's CdZnTe substrate to the shape of a wedge. With backside irradiation the internal reflections occurring in the wedge will result in a Fizeau interferometer with low reflectivity mirrors.

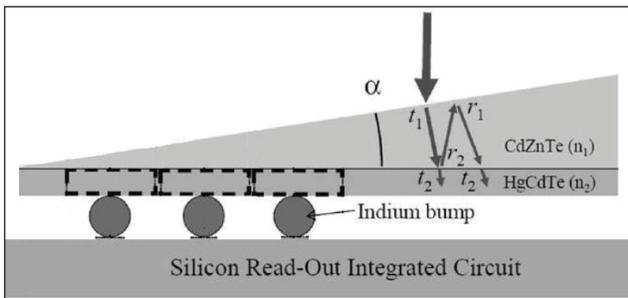


Fig. 3 CEA, LETI, MINATEC's on-chip FTIR-FPA based on HgCdTe detector technology.

A Fourier Spectrometer, based on a Michelson Interferometer, for stand-off detection and quantification of chemicals was described. It operates in the VLWIR and utilizes a linear detector array and differential acquisition in order subtract the non-contaminated background spectrum. The noise properties of a corner-cube Michelson interferometer LWIR hyperspectral imager based on an uncooled a-Si microbolometer FPA were also discussed.

By incorporating quantum dots in quantum wells DWELL QDIPs can be designed to exhibit a spectral response that can be tuned across a wide wavelength range by varying the bias voltage. A single QDIP combined with an algorithmic spectrometer technique for multi-spectral or hyper-spectral imaging was outlined.

A quantum dot photodiode (QDP) technology, which uses a unique low-cost nanotechnology-enabled photo-detector, was discussed. This technology is capable of efficiently detecting light with sensitivity spanning the 250 – 1800 nm spectral region. These devices show response times less than 10  $\mu$ sec, making them suitable for high speed imaging.

A miniature snapshot multispectral imager that operates in the short wavelength infrared region (SWIR) was presented. The imager uses a 4x4 Fabry-Perot filter array operating from 1487 to 1769 nm with a spectral bandpass of approximately 10 nm. The design of the filters is based on use of a MEMS shadow mask technique to fabricate a Fabry-Perot etalon with multi-layer dielectric mirrors.

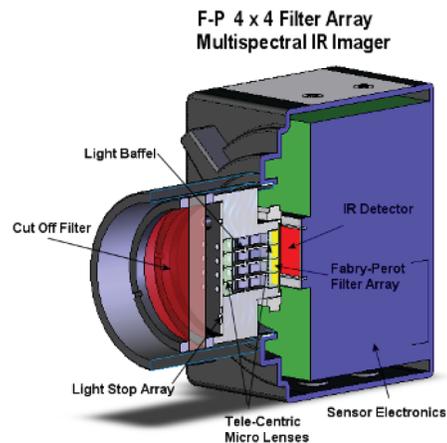


Fig. 4 U.S. Army Research Laboratory's snapshot multispectral imager. A 4x4 filter array is installed in front of the SWIR FPA.

## Optics

Advanced infrared systems require multiband or hyperspectral operation. Thermal imagers of generation 3 and above will operate in two or all of the three bands SWIR, MWIR and LWIR. Good refractive optical materials which cover all three bands hardly exist and in last year's conference reflective optics was discussed as a possible solution to this three-band problem. Using conventional design, these optical systems become large. An alternative approach to infrared optics was outlined in the present conference. Concentric, aspheric reflective surfaces were used in this novel design to fold the optical path and achieve, typically, a four-fold reduction of the lens' form factor in the axial dimension while retaining high radiation collection efficiency. A stacked multiple-band compact imaging system answering the requirements of next-generation thermal imagers now becomes a reality.

Two papers presented techniques for coating of aspheric surfaces. Among the challenges discussed were how to obtain uniform performance over a wide range of look angles, good mechanical and optical performance across a temperature range of ambient to 1000 °C, and cost effective production. Some of these techniques are expected to be applicable to coating of surfaces in the unconventional optical systems referred to above.

Compactness is a main requirement for most security and defense related systems. Two papers presented wide field of view infrared optics integrated into the detector dewar. Apart from achieving compactness, this optics will not suffer defocusing due to ambient temperature drifts nor contribute noise due to emissions from the optics. The cooled optics also reduces significantly the need for periodic non-uniformity corrections. Actuators which can be compatible with the cooled dewar were reported on. These may be used in the design of an integrated zoom.

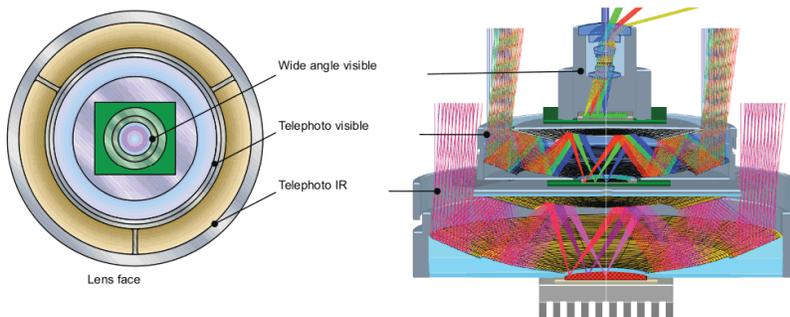


Fig. 5 Distant Focus Corporation's coaxial arrangement of folded LWIR and visible telephoto optics together with wide field-of-view visible optical systems.

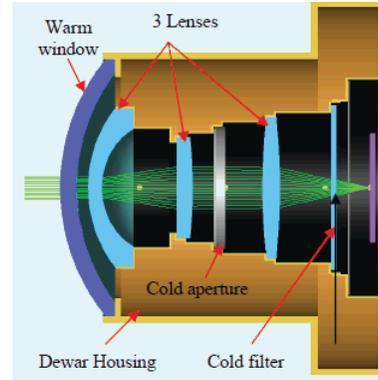


Fig. 6 SCD Semiconductor Devices' optics inside DDCA

For several years some signal processing designs have been inspired by invertebrate vision. One paper discussed a multichannel optical design inspired by the eyes of an insect called *Xenos Peckii*. The system is composed of multiple telescopes – each with a micro-prism in front of its entrance pupil.

Among other new optical techniques that were presented was the use of surface plasmon engineering tools which concentrate light power without regard for limits set by diffraction. It was claimed that zero focal length super-lenses may allow for use of smaller detector areas, having less noise, without an accompanying decrease in signal power. Another development that was discussed was the DSF (Dynamic Sunlight Filter) which increases the dynamic range of an infrared system by selectively and reversibly decreasing the high intensity radiation due to sun, fires etc.

### Uncooled thermal detectors

Presentations at this conference underlined the fact that uncooled infrared focal plane array technology is reaching a new level of maturity. The two predominant technologies—vanadium oxide ( $\text{VO}_x$ ) microbolometers and amorphous silicon microbolometers—are being driven to new levels of performance.

All of the leading microbolometers suppliers have developed  $640 \times 480$  FPAs with  $17 \mu\text{m}$  pixels. Some have also developed  $1024 \times 768$  arrays and are working on even larger ones with sub- $17 \mu\text{m}$  pixels.



Fig. 7 BAE Systems microbolometer roadmap

Some uncooled FPA module suppliers are using outside foundries for production of the basic FPA chips and are investing in sophisticated packaging techniques in order to lower the cost of their products.

Recent new developments include a 640 × 480 (25 μm pixels) VO<sub>x</sub> microbolometer made by a German research institute and a 640 × 480 (25 μm pixels) SOI (silicon-on-insulator) microbolometer by a Japanese company.

The use of amorphous SiGe instead of α-Si is also being investigated by a number of groups. One group concluded that, although these films have a number of advantages, they are not expected to have higher signal-to-noise because the presence of Ge results in higher 1/f noise.

The development of novel uncooled detectors is also continuing. Some of the approaches reported on in this conference include a photo-mechanical imager (an array of bi-material microcantilevers that are read out optically) which is capable of 1000 frames per second in

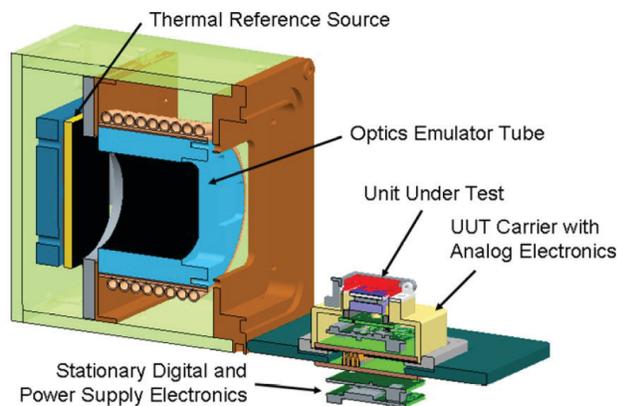


Fig. 8 Raytheon's Micro-environment for rapid temperature calibration of microbolometers.

the MWIR; a microbolometer based on single-crystal Si/SiGe quantum wells which is expected to have a higher TCR and lower 1/f noise than conventional microbolometers; an active pyroelectric array; and the use of nickel oxide films in microbolometers.

There were also reports on research into the optical properties of antenna-coupled VO<sub>x</sub> films, with the objective to enhance infrared absorption in small pixel microbolometers.

### Photon detectors

Photon detector presentations reported good progress across the spectrum.

Beginning with the short wave infrared (SWIR), InGaAs is the leading material for passive imaging. The dark current for these detectors has been gradually going down, while the readout noise is also being reduced. An image from an InGaAs array is shown in Fig. 9.

Alternative SWIR technologies—HgCdTe, Ge, SiGe, and black Si—also reported progress in developing SWIR capabilities.

Type II superlattice FPAs have demonstrated excellent progress in recent years. They are already in production for a dual-color MWIR threat-warning sensor in Germany. The appeal of these artificial narrow bandgap materials is that they can potentially have longer lifetimes than HgCdTe material. The rate of progress has been summarized in Fig. 10 where the dark current of



Fig. 9 A SWIR image taken with a 640 × 480 InGaAs array under minimal street-lighting conditions.

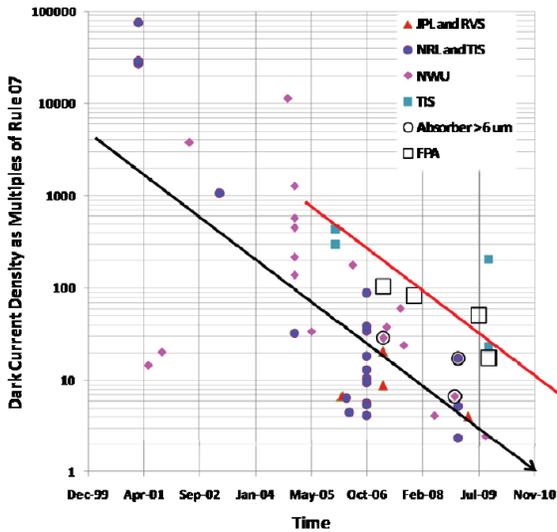


Fig. 10 Dark current density as a multiple of Rule 07 vs. time. The long black line is drawn as an eye aid to show the trend of dark current reduction along time for single-element detector, and the shorter red line helps to show the trend for FPAs. Type II materials is compared with that of HgCdTe as calculated from Rule 7. The suggested trend line forecasts that by November 2013, the dark current of Type II LWIR superlattice FPAs will be reduced to that of HgCdTe, and that by July 2016 the dark current will be an order of magnitude less.

A notable change in traditional FPA development and procurement is planned along with the maturation of the Type II superlattice technology; namely, a transition from vertically-integrated suppliers to one where materials-technology expertise is resident in III-V commercial growth foundries rather than at FPA suppliers.

There are several remaining challenges to bring Type II superlattice technology into a competitive position with the more mature HgCdTe. First, the lifetime of Type II superlattice materials remains more than an order of magnitude shorter than that of HgCdTe—the result of which is that the dark current is significantly higher—see Fig. 10 above. At present, the cause of the short lifetime has not been identified.

FPA builders have responded to this challenge in two ways. One is to dope the absorber layer more heavily to minimize the minority carrier concentration. The second is to incorporate barriers by putting the junction in the wider bandgap region of a heterojunction—one result of which is to require ~100 mV reverse bias before photocurrent can be collected. These temporary fixes have allowed progress to continue, but ultimately the fundamental issues must be addressed.

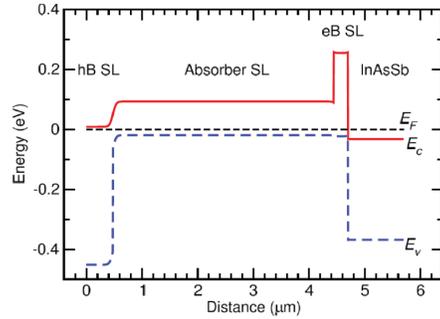


Fig. 11 The energy band diagram of the CBIRD structure showing the conduction and valence band edges and the Fermi level. The substrate is toward the right. The electron barrier (eB) appears in the conduction band at the right and the hole barrier (hB) in the valence band on the left. The thickness of the absorber region in this illustration is 600 periods. Reverse bias is defined as a negative voltage on the InAsSb layer.

Barriers that block majority carriers, analogous to those used in nBn detectors have also been employed in the Type II materials. Figure 11 illustrates one of these, the CBIRD structure.

Finally, the science of passivation remains to be established for the Type II superlattice detectors, in particular those employing InAs.

A half-day session was devoted to high-operating temperature (HOT) detectors. The main technologies in this arena include HgCdTe and nBn structures, with secondary contenders using split-off band detectors, carbon nanotubes, and PbSe. In this session, DRS showed HgCdTe results with low NEΔT for an MWIR 640 × 480 array having 12 μm pixels at 160 K as illustrated in Fig. 12.

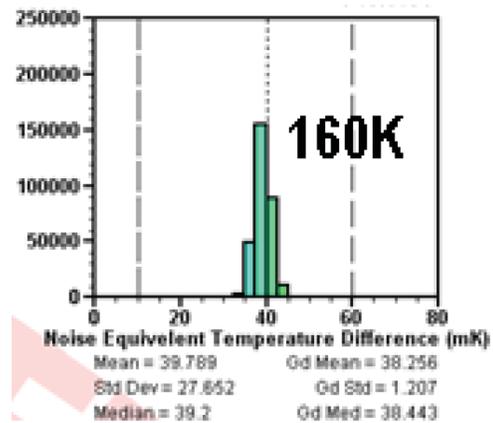


Fig. 12 Histogram of DRS HgCdTe NEΔT at f/3 of a MWIR 640 × 480 12 μm pitch FPA at 160 K.

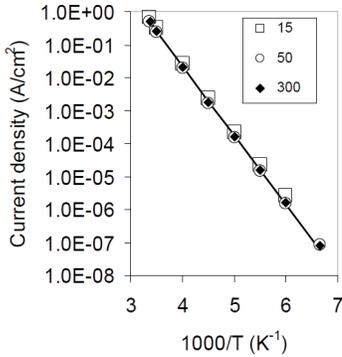


Fig. 13 Arrhenius plot of the dark current density of an nBn device at -0.2 V bias vs. reciprocal temperature for mesa dimensions of 15, 30, and 300  $\mu\text{m}$ . The solid line is an exponential fit to the data points for the 300  $\mu\text{m}$  device.

Progress with nBn detectors is extremely active. The barrier in this structure is used to block majority carrier current, eliminating g-r currents and allowing the diffusion current to dominate to much lower temperatures, as illustrated in Fig. 13. However, at higher temperatures where g-r currents are not dominant, nBn structures will not provide an advantage over diode structures.

The conference keynote session, presented by Vic Levett of Finmeccanica U.K. discussed the important role of MOVPE technology in advanced HgCdTe detector technology developments. Growth on large GaAs substrates, including arrays of dual-band and avalanche photodiodes has been successfully demonstrated with this technique. Overall the cost per pixel has been reduced—doubling the number of pixels that can be built for the same cost every five years.

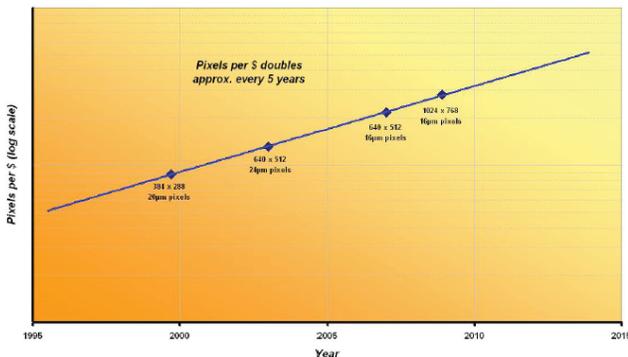


Fig. 14 Trend of pixels/\$ for HgCdTe FPAs grown by MOVPE.

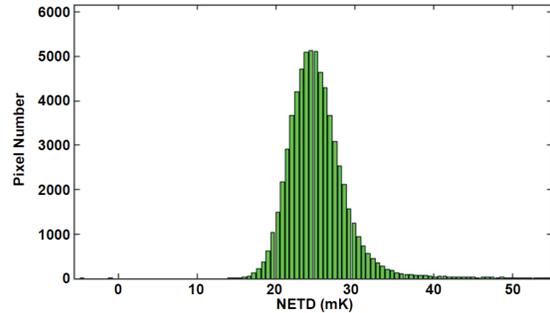


Fig. 15 A histogram of NEAT at 55 K for a 14.7  $\mu\text{m}$  cutoff detector at halfwell condition showing a mean NEAT of  $23.9 \pm 3.1$  mK.

Advances in HgCdTe detectors were reported, including the reduction of pixel size to 12  $\mu\text{m}$  for some MWIR arrays, plans for further pixel reduction to 10  $\mu\text{m}$  by 2012, the development of arrays that can operate in passive or active mode, fast frame-rate arrays for FTIR applications, improved CdZnTe substrate quality, and improved performance for LWIR and VLWIR arrays. Fig. 15 shows an example of the NEAT for an array with a cutoff of 14.7  $\mu\text{m}$  at 55 K—relevant to space sensors for important weather forecasting applications

Active imaging technology was likewise able to show off significant progress at the conference. Active imaging is based on the avalanche process in materials such as HgCdTe, InGaAs, Si, Ge, and SiGe alloys. These materials feature photo-signal gain via a carrier-multiplication process that is a function of bias across the device junction. Progress was reported in developing effective readout circuits that can operate such arrays in both

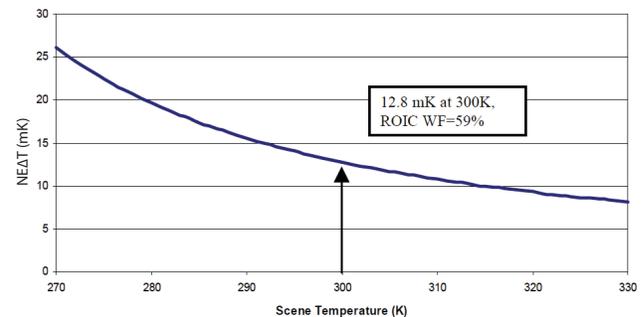


Fig. 16 NEAT as a function of scene temperature for a HgCdTe MWIR array operating in the 3.4 - 4.15  $\mu\text{m}$  band with f/4 optics. Device gain is used to prevent readout noise from dominating at low flux levels.



Fig. 17 Compact room-temperature avalanche-photodiode package containing a  $256 \times 256$  HgCdTe array with a readout that can process multiple signal returns from a pulsed laser.

passive, non-avalanche conditions, and in active mode where the internal gain is used to overcome dominant amplifier noise under low flux sensing conditions. Fig. 16 shows how this allows for very low NE $\Delta$ T for a passive MWIR sensor operating in the 3.4 - 4.15  $\mu$ m band at f/4.

Other active imaging work is being carried out to implement 2D and 3D laser radar (LADAR) capabilities. A compact 3D sensor with  $M = 300$  was described that provides essentially noiseless gain at room temperature combined with a readout that can process multiple pulse return signals. The sensor package containing a  $256 \times 256$  array with 60  $\mu$ m pixels is shown in Fig. 17.

GeSi APDs were also reported having gain-bandwidth products in the range of 350 - 860 GHz at 1.31  $\mu$ m. Fig. 18 shows the device cross-section. The devices are deployed in a waveguide structure.

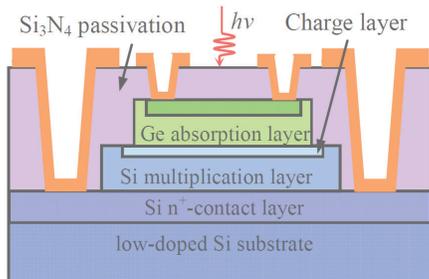


Fig. 18 SiGe APD pixel from UCSB/Intel with very high gain-bandwidth products at 1.31  $\mu$ m.

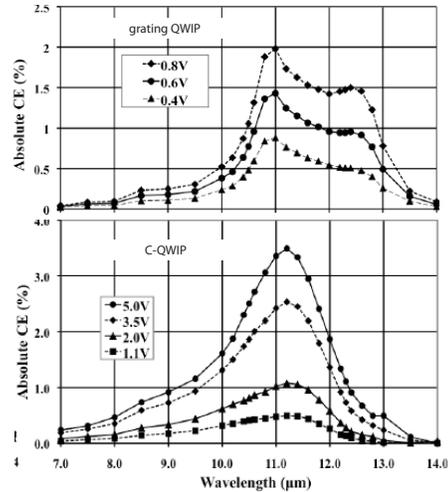


Fig. 19 The absolute collection efficiency (quantum efficiency  $\times$  gain) for two QWIP technologies—grating QWIP and C-QWIP—to be used on the Landsat continuity mission.

QWIP and other quantum-structured technologies reported new milestones in development. The first QWIP devices operating at 43 K are slated to go into orbit on a NASA Landsat Continuity mission. Production of QWIP arrays were summarized and quantum cascade detectors for a broad range of the infrared spectrum were introduced.

Signal processing papers included a description of the Jazz silicon foundry features for readout production. Additionally, Fourier processing on-chip was described to enhance signal-to-noise ratio and an update on negative-luminescence in HgCdTe as a calibration reference source.

### Cryocoolers

Fine progress was reported on the development of compact split Stirling linear cryogenic coolers. Re-design resulted in elimination of the advantages that traditionally have been associated with rotary integral coolers – smaller size, lower weight and lower power consumption. Among the applications listed for these coolers are portable hand-held cameras, thermal weapon sights, ground fixed and vehicle mounted surveillance cameras and gyro-stabilized imagers.

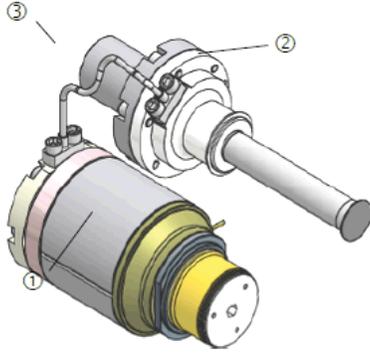


Fig. 20 Ricor's K527 split Stirling linear cryogenic cooler

One paper discussed the adaption and application of integral rotary cryogenic coolers for airborne infrared missile warning systems where the ambient temperature inside the system may reach up to 110 °C with random vibration above 10 g rms and catapulting and landing shocks of up to 300 g. Other cryocooler characteristics which were demonstrated were digital drive electronics, and endurance and reliability. It was shown that the very high acoustic power density achieved at higher pressures and higher frequencies in pulse-tube cryocoolers lead to very short cooldown times and very compact devices.

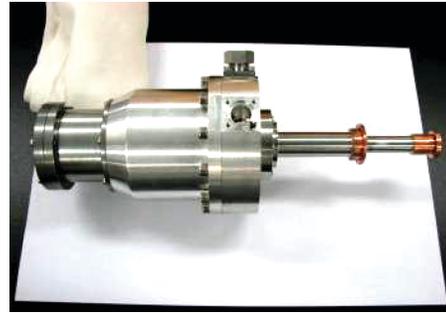


Fig. 21 SITP's 35K two-stage Stirling cryocooler

Five papers presented by researchers from Shanghai Institute of Technical Physics, SITP, showed fine progress in the development of both single- and double-stage Stirling cryocoolers. The cooling temperature covers 30 K to 100 K. The main presented applications of their Stirling and pulse tube cryocoolers were space-related.

**Paul R. Norton**  
**Bjørn F. Andresen**  
**Gabor F. Fulop**