Development in quantum structure based infrared photodetector (QSIP) technologies, including quantum wells, dots, superlattices, and novel heterostructures, over the last three decades has led to the realization of high performance infrared detectors, large-format focal plane arrays, and infrared cameras that are now readily available commercially through several manufacturers. The QSIP conference is held every second year and aims to bring together scientists, engineers, industrial collaborators, students, and users to discuss recent advances in this field. The conference provides an international forum for attendees to present and discuss new progress in device physics, materials growth and processing issues, focal plane array development and characterization, as well as commercialization and applications of QSIP technologies. The conference also explores the benefits and drawbacks of these technologies, and clarifies their role in the competitive market of thermal imaging technology. The program of QSIP 2018 will include oral presentations, panel discussion, as well as ample opportunities for informal interactions among conference participants.

Previous Conferences in this Conference series:
QSIP 2016 International Conference, Tel Aviv, Israel (June 12-17, 2016)
QSIP 2014 International Conference, Santa Fe, New Mexico (June 29 – July 3, 2014)
QSIP 2012 International Conference, Corsica, France (June 17 – 22, 2012)
QSIP 2010 International Conference, Istanbul, Turkey (August 15 – 20, 2010)
QSIP 2009 International Conference, Yosemite, California, USA (January 18 – 23, 2009)
QWIP 2006 Workshop, Kandy, Sri Lanka (June 18 – 24, 2006)
QWIP 2004 Workshop, Kananaskis, Canada (August 9 – 12, 2004)
QWIP 2002 Workshop, Torino, Italy (October 13 – 17, 2002)
QWIP 2000 Workshop, Dana Point, California (July 27 – 29, 2000)
IRnova as a long term, reliable merchant supplier of excellent manufacturing track records have positioned house volume production of cooled IR detectors with competitive advantage. Years of experience of T2SL-based infrared capabilities, providing a clear customers and OEM partners leading QWIP- and technology. IRnova is dedicated to providing of high-end cooled infrared detectors and related technology assets serve challenging military and industrial re-

IRnova is an independent Swedish company engaged in the development, manufacturing and marketing of high-end cooled infrared detectors and related technology. IRnova is dedicated to providing customers and OEM partners leading QWIP- and T2SL-based infrared capabilities, providing a clear competitive advantage. Years of experience of in-house volume production of cooled IR detectors with excellent manufacturing track records have positioned IRnova as a long term, reliable merchant supplier of unique and highly competitive infrared technology. IRnova’s leading researchers and state of the art production assets serve challenging military and industrial requirements as well as emerging infrared applications. Recent breakthroughs in both 15 µm pitch QWIP and HOT T2SL focal plane array production has strengthened IRnova’s position as the European leader in the field of III-V material based IR sensors.

i3system, Inc. is the unique company which designs and manufactures infrared sensors and camera cores in South Korea. The company, established in 1988, has been designated as a defense contractor since 2010 by Korean Government. i3system, Inc. provides military qualified high-quality infrared detectors and OEM modules with both cooled and uncooled types. The detector portfolio covers 1280 x 1024, 640 x 512, 256 x 256, 1280 x 1024, 320 x 256, and 1280 x 1024 types as well as IR camera cores. i3system is also developing InGaAs based 640 x 512, 1280 x 1024, and 256 x 256 MWIR detectors and T2SL based MWIR detectors and is manufacturing CdTe based X-ray detectors for dental application.
Program Sunday 17 June

4:00-4:20 Welcome to QWIP & QDIP I
Chair: Gunapala, Höglund

1. The Story of QWIPs in Sweden
Jan Y. Andersson, Mid Sweden University, Hofgatan 10, 851 70 Sundsvall, Sweden

2. LWIR QWIPs at IRnova for next generation Polarimetric imaging
Eric Costard, Rhôna AB, labygiftsgatan 22 CS, SE-164 40 Kista, Sweden

3. Small pitch resonator-QWIP detectors and arrays
K. K. Chin, U.S. Army Research Laboratory, Adelphi, MD 20783

4. Quantum Well Infrared Photodetector Technology: Status and Outlook
Cargi Beexeski, Quantum Devices and Nanophotonics Research Laboratory, Electrical and Electronics Engineering Department, Middle East Technical University, Ankara, Turkey

5. Disentangling the origin of the photovoltaic effect in double barrier quantum well infrared photodetectors (QWIPs) using advanced transmission electron microscopy techniques
E. Luna, Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany

6. QWP structures with lateral bias: An alternative approach to achieve high-temperature operation
Aleks Guzien, Instituto de Sistemas Optoelectronicos y Microelectronica (SOMI), Universidad Politecnica de Madrid, ETSI de Telecomunicacion, Avda. Complutense 30, 28040 Madrid, Spain

7. In0.5Ga0.5Xa Bilayer Quantum Dot Heterostructures for mid-infrared photodetection
Deliprabhu Pande, Department of Electrical Engineering, Indian Institute of Technology Bombay, INDIA

10:45-11:00 Fika

11. Trends in radiometric and radiation tolerance characterization results of IR photodiodes employing unipolar barrier detectors with bulk and T3SLS III-V absorbers
Vincent M. Cowan, Air Force Research Laboratory/Space Vehicles Directorate, Kirtland AFB, NM, USA

12. Effects of 63 MeV Proton-Irradiation on the Dark-current in III-V-based Unipolar Barrier Infrared Detectors
Sachidananda Babu, Air Force Research Laboratory, Space Vehicles Directorate, Kirtland AFB, NM, USA

13. Small pitch resonator-QWIP detectors and arrays
K. K. Chin, U.S. Army Research Laboratory, Adelphi, MD 20783

14. Thermal polarimetric infrared imaging and signatures
Johan Eriksson, Anders GM Dahlberg, Air Force Research Laboratory, Space Vehicles Directorate, Kirtland AFB, NM, USA

15. Quantum Well Infrared Photodetector Technology: Status and Outlook
Cargi Beexeski, Quantum Devices and Nanophotonics Research Laboratory, Electrical and Electronics Engineering Department, Middle East Technical University, Ankara, Turkey

16. Defect detection in steel products with IR imaging
B. Noharet, 3x3makeup, Higtland

17. Cocktail reception sponsored by FUR

SCD is a worldwide leader in development and manufacture of infra-red detectors and diode lasers for the Defense, HLS, and Commercial markets. SCD’s unique technologies are deployed in Cooled and Uncooled detectors based on a variety of sensing materials such as InSb, MCT, InGaAs, T2SL and VOx from all across the infrared spectrum: NIR, SWIR, MWIR, and LWIR. SCD detectors, video cores, and laser diodes are designed for commercial and defense applications in the Air, Land, Sea and Space domains where environmental qualifications are mandatory: Missile Seekers, Fire Control Systems, Commander Thermal Sight, Hand Held, Long Range Surveillance, Border Security and Causal security, Airborne Payloads, Thermal Weapon Sights, Night Vision Driving Systems, Missile Warning Systems.

With infrared sensing now all around us, IQE’s IR materials are the key technology to enable these applications to ‘see’ – helping to keep us safe, monitor the environment and lead the next generation of imaging technologies. An industry pioneer, IQE were first to supply InSb substrates to the commercial market in 1980. Today, IQE’s IR advanced, proprietary technologies are the key enabling technology for infrared sensors and emitters, enabling customers to develop applications in the security, defence, medical and industrial sectors. With unique depth and breadth of infrared semiconductor materials – including InSb, GaSb, InAs, InP and GaAs – IQE manufactures the widest range of IR specific compound semiconductor materials, covering all IR wavelengths and supplied in wafers up to 4” in diameter. With manufacturing sites in both the UK & US, dual sourcing enables IQE customers to secure their infrared materials supply chain and take advantage of combined IR substrate and epitaxial wafer purchases.

The Air Force Research Laboratory (AFRL) leads the discovery, development and product delivery of new air, space and cyberspace technologies for the United States (US) Air Force. The Space Vehicles Directorate within AFRL serves as the US Air Force’s “Center of Excellence” for space technology research and development. The Advanced Electro-Optical Space Sensors group investigates ways to improve the performance of existing sensor technologies (in both clear and space-radiation environments), and investigates new sensor technologies and concepts (such as unipolar barrier architectures and multicolor plasmonic field enhancement).
Program Monday 18 June

LWR T2SL, I
Chair: Christie, Tucson

08:00-08:25
17. Current Status and Challenges in III-V Material Superlattice Infrared Detector Technology
Sumith Bandara, US Army RDEC/GEM/EDC, 302/27 Brook Rd, Ft. Belvoir, VA 22060, USA

08:25-08:50
18. III-V semiconductor unipolar barrier infrared detectors and focal plane arrays
David C. Fag, JPL, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA

08:50-09:10
19. VLRIR InAs/GaSb superlattice infrared photodetectors and focal plane arrays for space applications
L. Holmgren, IRnova AB, Electrum 205-21, SE-164 40 Kista, Sweden

09:10-09:30
20. Dark current improvement due to dry-etch process in InAs/GaSb type-II superlattice LWR photodetector with nln structure
Hyun-Jin Lee, GISTech Inc., 26-32, Gajung-dong, Yuseong-gu, Daejeon, Korea

09:30-09:50
21. Development of Type-II superlattice (T2SL) detector in JAXA: Electrical and optical evaluation of InAs/GaSb T2SL LWR photodetector with AOD3 passivation layer
Ayaka Kameza, Japan Aerospace Exploration Agency

09:50-10:35
Break

LWR T2SL, II
Chair: Alipetin, Steenbergen

10:35-11:00
22. SLS FPAs with cutoff wavelengths from 5 microns to 14 microns
Mark Sanderson, OMRc, LLC, 20 Cotton Road, Nashua, NH 03063, US

11:00-11:20
23. Challenges and Opportunities for Antimonide Based Superlattice Detectors
Sanjay Krishna, Department of Electrical and Computer Engineering, The Ohio State University, Columbus OH

11:20-11:40
24. High operating temperature InAs/GaSb type-II superlattice detectors on GaSb substrate for the long wavelength infrared
R. Mann, Fraunhofer Institute for Applied Solid State Physics (IAF), Freiburg (Germany)

11:40-12:00
25. Demonstration of HOT LWR T2SL InGaAs/GaSb photodetectors grown on GaSb substrate
SK. Michalczewski, Institute of Applied Physics, Military University of Technology, 2 Kaliskiego Str., 00-908 Warsaw, Poland

12:00-12:20
26. High operating temperature LWR and VLRIR InAs1-xSbx superlattice infrared photodetectors grown on GaSb substrates
L. Kuliszyn, Vigo System S.A., 129/133 Pomorska St., 05-850 Goleniów Maciejkowicki, Poland

12:20-12:45
Lunch

MWR T2SL and nln
Chair: Ceretti, Cagliari

12:40-12:45
27. III-V SLS PPA Development in U.S. after VISTA
Miri Meir, US Army RDEC/GED/NO, 15221 Butts Road, Ft. Belvoir, Va 22060, USA

12:45-13:10
28. Status review of InGaAs/GaSb type-II superlattice infrared detector technology in Germany
R. Rehm, Fraunhofer Institute for Applied Solid State Physics (IAF), Freiburg (Germany)

13:10-13:25
29. T2SL Manufacturing Capability at L3 Space & Sensors Technology Center
Derek Forman, L3 Space & Sensors Technology Center, 7500 Innovation Way, Macom, OH 45404

13:20-13:45
30. MWR nln detector monolithically integrated with micromachined unipolar barrier detector architecture with bulk III-V absorbers
Alexander Solcak, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA

13:40-14:00
31. Small Pitch Compatible Processing and Passivation of III-V Antimonide Based Infrared Detectors
Nail Bari, U. S. Army RDEC/COM/GED/NO, Fort Belvoir, Virginia 22060, USA

14:00-14:30
Break

VCD
Chair: Dhruva, Sanaul

14:30-14:40
32. Flip-Chip Technology for Image Sensors
Jean-Luc Mottet, ST Corporation S.A., 135 Impasse Barthoulat, 74400 Saint jean, FRANCE

14:40-14:50
33. Sub-atomic resolution chemical mapping of quantum cascade detectors: a tool for predictive quantum engineering
A. Delga, III-VLab, Thales Research & Technology, France

14:50-15:10
34. Optimal absorber thickness in interband cascade photodetectors
Katarzyna Raczyńska, Military University of Technology, Institute of Applied Physics, 2 Urbanowicza St., 00-908 Warsaw, Poland

15:10-15:20
35. Noise and Gain Characterization of Long-Wavelength Interband Cascade Infrared Photodetectors
Elia A. Gobbi, Air Force Research Laboratory, Space Vehicles Directorate, 3550 Aberdeen Ave, Kirtland AFB, NM 87117, USA

15:20-15:40
Break

QCD
Chair: Fika

15:40-15:50
36. Demonstration of HOT LWIR T2SL detectors grown on GaSb substrate
Ayaka Kushima, Japan Aerospace Exploration Agency

15:50-16:00
37. Demonstration of HOT LWIR T2SL detectors grown on GaAs substrate
L. Holmgren, IRnova AB, Electrum 205-21, SE-164 40 Kista, Sweden

16:00-16:20
38. Demonstration of HOT LWIR T2SL detectors grown on GaAs substrate
L. Holmgren, IRnova AB, Electrum 205-21, SE-164 40 Kista, Sweden

16:20-16:40
39. Demonstration of HOT LWIR T2SL detectors grown on GaAs substrate
L. Holmgren, IRnova AB, Electrum 205-21, SE-164 40 Kista, Sweden

16:40-17:30
40. Demonstration of HOT LWIR T2SL detectors grown on GaAs substrate
L. Holmgren, IRnova AB, Electrum 205-21, SE-164 40 Kista, Sweden

17:30 Special event: Women leaders in science and technology

Women leaders in science and technology
To promote personal and professional growth for women in Science, Technology, Engineering and Mathematics (STEM), this special networking event will be arranged as part of the QSIP 2018 conference. Six top female leaders are invited and will give talks to share their personal successful experience with the participants and to inspire female professionals and PhD students to be future leaders in STEM areas and to encourage all participants to promote women to leadership positions.

Information
Time: Monday, 18 June, 17:30-19:00
Place: Vår Gård, Saltsjöbaden, Sweden
Room: Isaac
Food: A light meal and wine/beer/softdrink will be served at the session.
Cost: The event is free of charge, sponsored by IEEE Photonics Society, IRnova AB and RISE AB
Registration: PRE REGISTRATION IS MANDATORY

Organisers and event chairs: Qin Wang (RISE Acreo) & Linda Höglund (IRnova)

Program 17:30 Welcome and opening introduction, Dr. Qin Wang, RISE Acreo AB
17:40 Sigbrit Karlsson (Principal at the Royal Institute of Stockholm (KTH)) Title: “The future is too bright to be left to men”
17:50 Ingrid Nordmark (CEO of RISE SICS AB) Title: “In search of a world where women help other women”

18:00 Ulrika Norden Lidberg (CEO IRnova) Title: To spin off a company from a research institute- the IRnova success story”
18:10 Isabelle Ribet Mohammed (Department Manager, ONERA) Title: How to inspire tomorrow’s researchers
18:20 Kyriski Mignonou (Technical Expert, European Space Agency) Title: Women and leadership in the technology industry
18:30 Meinie Tidrow (Chief Scientist for Focal Plane Arays, US Army, NVESD) Title: How to survive in the man’s world and successfully promote a new technology
18:40 Panel discussions, all speakers will be in the panel to interact with the audience and to discuss the above mentioned topics.
19:00 End
FLIR offers a family of 2-dimensional readout integrated circuits (ROICs) including the industry standard 320 x 256 format ISC9705 and ISC9809 as well as the standard 640 x 512 format devices; ISC9802, ISC4092, ISC1201 and ISC4091. These arrays make excellent imagers for InSb, QWIP, SLS and InGaAs based camera products. FLIR also offers several 2-color ROICs including the ISC9093, ISC9095 and ISC3198 for more advanced imaging systems. The standard ROIC product line mega-pixel format devices include 1K x 1K and 2K x 2K element ROICs. FLIR ROICs are known for ease of integration with common electrical interfaces and features.

Sofradir is the leading developer and manufacturer of key classes of advanced infrared (IR) detectors for military, space, scientific and industrial applications. Its vast IR product portfolio covers the entire spectrum from visible and near infrared to very far infrared. Sofradir pioneers developments in cooled IR detectors based on a sophisticated high performance technology: MCT, to which Sofradir has added InSb, InGaAs and QWIP technologies. Sofradir owns two subsidiaries: ULIS, a high volume manufacturer of uncooled micro-bolometers based in Veyres-Vorize and US-based Sofradir-EC. Together Sofradir, ULIS and Sofradir-EC employ more than 1000 staff. The group generated an annual turnover of $270M in 2017.
Pulse Instruments is a leading manufacturer of systems and equipment for characterization and production of infrared detectors. These detectors are used in various applications, including defense, security, and industrial imaging. The company is known for its high-quality detector systems and its commitment to advancing the state of the art in infrared imaging technology.

ASELSAN, the Electro-Optics Systems developer and manufacturer in Turkey, has been investing into the development of infrared technologies. In recent years, ASELSAN has been utilizing their high-profile science applications, including the development of 2D arrays (IR, X-Ray, Gamma), opto-electronics components, micro-LED displays, and for 3D integration. SET Flip-Chip Bonders are appreciated for their flexibility to address a large variety of processes on the same platform.
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speakers</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00-9:25</td>
<td><strong>NIR-eSWIR Detector Science, formation</strong></td>
<td>G. R. Savitch, Ampron Research, 123 Case Circle, Andmore, Oklahoma, OK 73401</td>
<td>16</td>
</tr>
<tr>
<td>9:25-9:50</td>
<td><strong>Ultra-Sensitive and Fast SWIR based on Nano-Photo-Transistors</strong></td>
<td>Professor Monleone, ESCS Department, and Department of Physics and Astronomy, Northeastern University, Evanston, IL, USA</td>
<td>19</td>
</tr>
<tr>
<td>9:50-10:00</td>
<td><strong>Growth of InGaAs/GaSb Type II Superlattice for eSWIR Photodetector using MOCSVD</strong></td>
<td>D. C. Elias, Solid State Physics Department, Applied Physics Division, Soreq NRC, Yehu 81100, Israel</td>
<td>16</td>
</tr>
<tr>
<td>10:00-10:30</td>
<td><strong>Characterization of Deposited In-Device Passivation Layer for InGaAs Photodetectors</strong></td>
<td>Kubra Cicek, Kubra Cicek, M. Hatt Dalles and Serder Kocaman, Middle East Technical University, Ankara / TURKEY</td>
<td>19</td>
</tr>
<tr>
<td>10:35-11:00</td>
<td><strong>The opportunity in InGaAsN/AlGaAs quantum wells for SWIR detection</strong></td>
<td>Yong-Hang Zhang, Center for Photonics Innovation, School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, AZ 85287, USA</td>
<td>16</td>
</tr>
<tr>
<td>11:00-11:20</td>
<td><strong>Nano-Device Concepts</strong></td>
<td>Hooman Mohseni, EECS Department, and Department of Physics and Astronomy, and Department of Electrical Engineering and Computer Science, Northwestern University, Evanston, IL, USA</td>
<td>19</td>
</tr>
<tr>
<td>11:20-11:40</td>
<td><strong>III-V absorbers architectures with bulk and T2SLS employing unipolar barrier detector architectures with bulk and T2SLS III-V absorbers</strong></td>
<td>Debiprasad Panda, In0.5Ga0.5As Bilayer Quantum Dot Heterostructure for mid-infrared photodetection</td>
<td>16</td>
</tr>
<tr>
<td>11:40-12:00</td>
<td><strong>Self-Consistent Theory for Stimulated Transitions and DC-Field Driven e-Plasma Applications to Photodetectors</strong></td>
<td>L. Höglund, A.G. Unil Perera, and Sumith Bandara, School of Physics, University of Florida, Gainesville, FL 32601, USA</td>
<td>19</td>
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<tr>
<td>12:00-12:30</td>
<td><strong>Infrared Image Sensor developments</strong></td>
<td>Sumith Bandara, School of Physics, University of Florida, Gainesville, FL 32601, USA</td>
<td>16</td>
</tr>
<tr>
<td>12:30-13:00</td>
<td><strong>Defect detection in steel products with IR imaging</strong></td>
<td>B. Norhbet, School of Physics, University of Florida, Gainesville, FL 32601, USA</td>
<td>19</td>
</tr>
<tr>
<td>13:00-14:00</td>
<td><strong>Small pitch resonator-QWIP detectors and arrays</strong></td>
<td>Cengiz Besikci, Quantum Well Infrared Photodetector Technology: Status and Outlook</td>
<td>16</td>
</tr>
<tr>
<td>14:00-15:00</td>
<td><strong>Quantum Well Infrared Photodetector Technology: Status and Outlook</strong></td>
<td>E. Luna, Quantum Well Infrared Photodetector Technology: Status and Outlook</td>
<td>19</td>
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<tr>
<td>15:00-16:00</td>
<td><strong>Current Status and Challenges in III-V Material Superlattice Infrared Detector Technology</strong></td>
<td>David Z. Ting, A.S. University of Colorado, Boulder, CO 80309, USA</td>
<td>16</td>
</tr>
<tr>
<td>16:00-17:00</td>
<td><strong>Dark current improvement due to dry-etch process in InAs/GaSb type-II superlattice LWIR photodetector with nBn structure</strong></td>
<td>Hyun Jin Lee, professor of electrical engineering at the University of Texas at Austin, Austin, TX 78712, USA</td>
<td>19</td>
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<tr>
<td>17:00-18:00</td>
<td><strong>Development of Type-II superlattice (T2SL) detector in JAXA</strong></td>
<td>Aya Kametani, professor of electrical engineering at the University of Tokyo, Tokyo, Japan</td>
<td>16</td>
</tr>
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<td>18:00-19:00</td>
<td><strong>The Story of QWIPs in Sweden</strong></td>
<td>Jan Y. Andersson, professor of electrical engineering at the University of Gothenburg, Gothenburg, Sweden</td>
<td>19</td>
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<tr>
<td>19:00-20:00</td>
<td><strong>The Story of QWIPs in Sweden</strong></td>
<td>Eric Costard, professor of electrical engineering at the University of Gothenburg, Gothenburg, Sweden</td>
<td>16</td>
</tr>
<tr>
<td>20:00-21:00</td>
<td><strong>The Story of QWIPs in Sweden</strong></td>
<td>K. K. Choi, professor of electrical engineering at the University of Gothenburg, Gothenburg, Sweden</td>
<td>19</td>
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<tr>
<td>21:00-22:00</td>
<td><strong>Small pitch resonator-QWIP detectors and arrays</strong></td>
<td>Cengiz Besikci, Quantum Well Infrared Photodetector Technology: Status and Outlook</td>
<td>16</td>
</tr>
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<td>22:00-23:00</td>
<td><strong>Quantum Well Infrared Photodetector Technology: Status and Outlook</strong></td>
<td>E. Luna, Quantum Well Infrared Photodetector Technology: Status and Outlook</td>
<td>19</td>
</tr>
<tr>
<td>23:00-24:00</td>
<td><strong>Current Status and Challenges in III-V Material Superlattice Infrared Detector Technology</strong></td>
<td>David Z. Ting, A.S. University of Colorado, Boulder, CO 80309, USA</td>
<td>16</td>
</tr>
<tr>
<td>24:00-01:00</td>
<td><strong>Basic science of IR spectroscopy of blood components for subcutaneous melanoma</strong></td>
<td>Nat Bendor, professor of biology at the University of California, Berkeley, Berkeley, CA 94720, USA</td>
<td>19</td>
</tr>
</tbody>
</table>
The Story of QWIPs in Sweden

Jan Y. Andersson

Presentation Title
The Story of QWIPs in Sweden

Abstract
An overview of QWIP R&D and commercialization in Sweden will be presented, from a technical as well as from an industrial perspective. The story of QWIPs started around 1986 by detection of QW intersubband absorption, and continued with grating couplers for enhancing absorption. The work switched early from single detectors to imaging arrays since it was here that QWIPs had the real advantage due to the mature material technology which allowed superior uniformity.

In parallel with development of the GaAs detector chip a CMOS based ASIC for readout was also developed. The first fully operating QWIP prototype, a 320×240 pixels array, was finished 1997. All the component parts, the QWIP chip, readout circuit, and flip-chip bonding, were processed in Acreo’s fab, Electrum laboratory, Kista. Furthermore, besides technology, the various interactions and collaborations with many external partners nationally and internationally were of utmost importance, without which the development had been impossible. This included Swedish finan-
cing and cooperating authorities and industries (FLIR Systems, FMV, Vinnova, and Saab). Commercializing QWIPs was very challenging. Especially in that phase the importance of the “ecology” became evident and it was necessary to get access to and optimize many technologies such as high-resolution flip chip technology, efficient Stirling coolers, and IR modules including vacuum chamber, external optics and electronics. Finally, the QWIP array and the camera based upon it (via FLIR) went into production around 1999. The startup company IRnova was spun off from Acreo in 2007, with their first product QWIP arrays of different formats.

Keywords: QWIP, grating, array, review, Sweden, system integration, commercialization

LWIR QWIPs at IRnova for next generation Polarimetric imaging

Eric Costard1
Ruslan Ivanov1
Dean Evans1
Staffan Hellström1
Linda Höglund1
Johan Eriksson2
David Bergström2

Presentation Title
LWIR QWIPs at IRnova for next generation Polarimetric imaging

Abstract
From the design of the revolutionary 2D-grating1 structure to the realization of first QWIPs based thermal imagers, IRnova AB has been at the forefront of the development, marketing and sales of GaAs/AlGaAs based Quantum Well Infrared Photodetectors (QWIPs) for Long Wave Infrared (LWIR) band. Versatility provided by QWIPs allows it to be used for next generation applications like polarimetric2 and multispectral3 imaging. Exploiting on to the polarimetric properties of QWIPs and utilizing our vast experience with design, modelling and fabrication, IRnova AB has now developed its first monolithically integrated polarizer-detector QWIP FPA. In this paper, the development of Polarimetric-QWIP (Pol-QWIP) FPAs in two different formats: 320×256 with 30 µm pixel pitch and 640×512 with 15 µm pixel pitch will be presented. Instead of conventional 2D-gratings, lamellar or 1D-gratings have been implemented to obtain the on pixel polarizer elements. Simulations have been performed to optimize the width and the period of the gratings. To evaluate the polarization contrast, signals from individual pixels with different 1D-grating elements are compared and the measured responsivity (polarization) contrast of both pixel formats will be presented and compared.


Keywords: QWIP, Polarimetric, FPA

1 IRnova AB, Isafjordsgatan 22 C, SE-164 40 Kista, Sweden
2 School of Electrical and Computer Engineering, University of Oklahoma, Norman, OK 73019, USA
K. K. Choi1
S. C. Allen,2
J. G. Sun,1
K. A. Olver,1
R. X. Fu2

Presentation Title
Small pitch resonator-QWIP detectors and arrays

Abstract
We are developing the “resonator-pixel” technology to improve detector sensitivity in a wide range of infrared spectrum from short-wave to very-long-wave. A resonator-pixel consists of a resonant active volume for light trapping and absorption to produce a large quantum efficiency. Detector material under development includes colloidal quantum dot, QWIP, MCT, and SLS, in a number of team efforts. In this talk, we focus on demonstrating small pixel, high density resonator-QWIP (R-QWIP) arrays for their many advantages in terms of SWaP-C and detection range. To determine the size limit of this approach, we optimized the detector at different pixel pitches p (= 30, 12, 6, 3 and 2 microns) using 3-dimensional electromagnetic modeling. We found that their quantum efficiency can be kept relatively constant, and an especially large QE of ~80% appears at p = 3 microns at the wavelength of 9 microns, indicating a great potential for pixel miniaturization. To confirm the detector design, we conducted experiments on test detectors with p = 30, 12 and 6 microns. The set of wafers have two different active layer thicknesses and three different doping densities to create a wide range of detector characteristics. The experimental result is in good agreement with the prediction. For a proof-of-principle FPA demonstration, we are currently producing 6- and 12-micron pitch, single-color and two-color arrays with 1280×1024 format. In this talk, we will discuss both the test detector and FPA results.

Keywords: QWIP, resonance, focal plane arrays

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Cengiz Besikci

Presentation Title
Quantum Well Infrared Photodetector Technology: Status and Outlook

Abstract
This talk covers a survey of the recent advancements in the Quantum Well Infrared Photodetector (QWIP) Technology as well as discussing the potential of alternative III-V material systems for future developments toward the enhancement of the quantum efficiency and low background/high speed imaging performance of QWIP focal plane arrays (FPAs) operating in the MWIR and LWIR bands as single- and dual-band imagers. The talk will also present the recent achievements by the Quantum Devices and Nanophotonics Research Laboratory of the Middle East Technical University yielding QWIP FPA performances compatible with the strict needs of high performance thermal imaging applications.

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Presentation Title
Disentangling the origin of the photovoltaic effect in double barrier quantum well infrared photodetectors (QWIPs) using advanced transmission electron microscopy techniques

Abstract
The double barrier (Al,Ga)As/AlAs/GaAs structure was proposed few years ago as an attractive design for QWIPs in the 3-5 µm range. One feature offered by the structure was its versatility for careful tuning of the detection wavelength with slight variations in the layer design. In addition, the structures exhibited a strong photovoltaic (PV) effect where unintentional internal fields and/or asymmetries in the potential profile enabled a strong photoresponse even at 0 V bias. Si dopant segregation and/or unintentional asymmetries in the growth of the thin 1-2 nm AlAs inner barriers were proposed as possible origins for this intriguing behavior, although the question was not finally clarified. In this work we revisit the subject using a combination of transmission electron microscopy (TEM) techniques. We use chemically sensitive g002 dark-field TEM to determine the composition (i.e. potential) profile. The procedure allows quantification of the interface intermixing, revealing an intrinsic broadening at the (Al,Ga)As/AlAs interface of 2.5 nm (10% - 90% criterion), which is larger than the AlAs thickness (2 nm). Hence, the inner barriers consist of (Al,Ga)As instead of pure AlAs, which will have an obvious impact on the QWIP response. In addition, using off-axis electron holography we have found the existence of an unexpected electrostatic potential due to unintentional transients during opening of the Si shutter, which could explain the intriguing PV response. Finally, the analysis presented here can be extended to other materials for infrared detection such as InAs/ GaSb or the emerging dilute bismides compounds.

Keywords: Double barrier QWIPs, photovoltaic response, internal asymmetries, electrostatic potential

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Presentation Title
QWIP structures with lateral bias: An alternative approach to achieve high-temperature operation

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Abstract
Lateral quantum-well infrared photodetectors (LQWIP) have been proposed as good candidates for tunable detection over a wide spectral range, which operate with a reduced dark current and unity gain [1]. These devices contain two adjacent QWs (one doped and one undoped), which are spatially sufficiently close to each other be coupled by tunneling. The photo-carriers generated in the doped QW tunnel out into the undoped QW, in which they drift to the contacts by the application of an external lateral bias, giving rise to a net photocurrent. Since under these operating conditions only the undoped QW is biased, the dark current is very low, leading to detectors with an improved signal-to-noise ratio (SNR).

In this work, we exploit this improved SNR of the LQWIP to fabricate new devices for high-temperature operation. Following the design proposed in Ref. [1], we have realized three different structures containing two QWs and two Ohmic contacts on the sides of the QWs. The dark current is further reduced by blocking the direct conduction through the QWs. These structures exhibit a photoresponse up to room temperature, and the measured peak detection wavelengths are in good agreement with numerical simulations. The presented results clearly demonstrate that the lateral processing of QWIPs improves the high-temperature operation of these devices.

Keywords: QWIPs, lateral bias, room temperature operation

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Presentation Title
In0.5Ga0.5As Bilayer Quantum Dot Heterostructure for mid-infrared photodetection

Abstract
Quantum dot infrared photodetectors (QDIPs) have numerous advantages such as normal incidence radiation, lower dark current and higher S/N ratio. Moreover, the bilayer quantum dot (QD) heterostructures have taken over single layer QD structures due to their longer wavelength emission, homogeneity in dot size and optimum dot density. The optical characteristics of a In0.5Ga0.5As bilayer QDIP having photoreponse in the mid-infrared regime has been shown in this study. The heterostructure is grown with a 6.5 nm GaAs spacer between the seed and top QD layers, following a new growth strategy. The monolayer coverage for top QD layer is less compared to the seed layer. However, a similar QD size has been observed for both layers due to the existing strain propagation from seed to top QD layer through the GaAs spacer with optimum thickness. Moreover, the presence of strain reducing In0.15Ga0.85As capping layer on the top QD has an active participation in preserving the QD size, inhibiting In-Ga intermixing. The photoluminescence emission peak from the device is obtained at 1.31 μm at room temperature along with full width half maximum (FWHM) of 21 meV and activation energy of 326 meV. The lower FWHM and higher activation energy are the consequences of homogeneous dot size distribution and better carrier confinement. Hence, the proposed bilayer QDIP has a spectral response in the mid-infrared regime (6-8 μm) with a very low dark current density (4E-7 A/cm²) and high responsivity (33 mA/W) at -2V and 90K. DST Nanomission, IITBNF and ISRO has been acknowledged.

Keywords: InGaAs, Quantum dot, Photoluminescence, Spectral response.

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Presentation Title
Infrared Image Sensor developments supported by the European Space Agency

Abstract
The European Space Agency (ESA) has an on-going interest in the development of new detectors and the continuous optimization of available detectors across the waveband for space instrumentation. Detectors form a cornerstone in the measurement capabilities of space missions, sensing radiation from infrared to X-rays and beyond, and consequently the Agency is always concerned to have the highest possible detector performance available to instrument developers. In addition to on-going developments focusing on visible CCDs and CMOS image sensors, high-performance infrared detectors are identified as key components for several upcoming ESA missions in both astronomy and earth observation applications. In support of these demands, the Agency is undertaking developments in the NIR/SWIR, MWIR and LWIR/VLWIR wavebands aiming at ensuring the availability of suitable detection systems for these and other future missions.

This paper presents the status of current infrared detector and related development activities supported by the Agency. In the first section of the paper, the general detector requirements in space applications are addressed. In both the visible and infrared wavebands, there are a number of common instrument-level, performance drivers where improvements in related parameters are in turn the drivers behind the detector development activities that will be described in the following sections.

Keywords: ESA, infrared detectors, space missions, earth observation, astronomy.

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**NASA/ESTO investments in innovative sensor technologies**

**Abstract**

For over 20 years NASA Earth Science Technology Office (ESTO) has been investing in remote sensing related technologies like sensors, subsystems and software. During this period ESTO has invested in more than 900 research and development projects. Many of these technologies have been successfully infused into NASA space missions like Landsat/TIRS, Aquarius, SMAP, CYGNSS, SWOT, TEMPO and others. Researchers are demonstrating remote sensing instruments with various improved capabilities. Such as extending the boundaries of operation in wavelength, operating temperature, pixel counts, and incorporating new capabilities like full spectral imaging on a single chip. Unique infrared device structures are evolving from new capabilities in nanotechnology. Recent technological developments in novel sensor materials such as type-II strained layer superlattice (T2SL) and barrier architectures, with promise of significant improvements in extending into LWIR spectrum and performance. Various read-out integrated circuit architectures are improving functionality for higher-performance focal plane arrays, including incorporating intelligence into focal planes. Going forward machine learning, autonomous operation into sensors will lead to efficient utilization of limited onboard resources like power, and data rate.

ESTO is actively investing in sensor technologies, instrument concepts, information technology and data processing algorithms for both active and passive remote sensing space applications. ESTO has track record as one of the early supporters of innovative technologies. As one of the first supporters of QWIP technology, we are still in fore front of supporting T2SL sensors for VLWIR applications. This presentation will focus on sensor development and related technology investments by NASA/ESTO.

**Sachidananda Babu**  
**Parminder Ghuman**  
**Pamela Millar**

**Presentation Title**  
NASA/ESTO investments in innovative sensor technologies

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**A comparison of II-VI and III-V infrared detector materials for space applications**

**Abstract**

Ever since narrow bandgap superlattices were first proposed in the 1970’s, they have been compared to bulk HgCdTe with several advantages being touted: (i) bandgap engineering enabling larger effective masses, lower band-to-band tunneling, and Auger recombination suppression; (ii) stronger bonds leading to greater structural stability; (iii) greater control of compositional variation across wafers; and (iv) less expensive substrates for III-V superlattices. While these advantages still ring true, the highest performing III-V materials are currently limited by Shockley-Read-Hall recombination due to defects, unlike the highest performing HgCdTe materials that are limited by either intrinsic radiative or Auger recombination. The performance of III-V superlattice infrared detectors is sufficient for tactical applications where they compete with HgCdTe, as they are being commercially sold, but their performance is still relatively lacking for space applications where sensitivity requirements are higher and their performance degrades with proton-radiation-induced displacement damage more rapidly than that of HgCdTe (~10X). To understand how to improve displacement damage tolerance in III-Vs, the bond strengths, atomic masses and diffusion coefficients, and lattice constants of infrared materials must be considered. This work will compare HgCdTe and III-V superlattice infrared materials and revisit the above advantages from the perspective of low-light, radiation-laden, space applications.

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**Presentation Title**  
A comparison of II-VI and III-V infrared detector materials for space applications

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**Air Force Research Laboratory/Space Vehicles Directorate, Kirtland AFB, NM, USA.**  
**Keywords: HgCdTe, superlattice, infrared detector, radiation tolerance.**
**Trends in radiometric and radiation tolerance characterization results of IR photodiodes employing unipolar barrier detector architectures with bulk and T2SLS III-V absorbers**

**Abstract**

For space-based imaging systems, radiation tolerance of the detector array to both displacement damage and total ionizing dose (TID) effects continues to be a major performance concern. Here, results on the TID and proton irradiation tolerance of a variety of infrared photodiodes employing various unipolar barrier architectures with bulk and type-II strain layer superlattice (T2SLS) III-V based absorbers is presented. Protons with an energy of 63 MeV were used to irradiate the detectors under test to a proton fluence of $7.5 \times 10^{11}$ protons/cm$^2$, corresponding to a TID of 100 kRads(Si), while the detectors were under-bias and held at 130 K. The performance of detectors yielded from a suite of growths were characterized by dark current, quantum efficiency and optical collection length measurements. The results show an increase in dark current, while yet maintaining roughly diffusion-limited performance, and a reduction in the quantum efficiency and optical collection lengths consistent with an increase in the trap density and degradation of minority carrier recombination lifetime as shown from hard data collected via time resolved photoluminescence. An in-depth examination of the collective results from underlying experiments quantifying the performance degradation rates of III-V-based, unipolar barrier infrared detectors with various designs, cutoff wavelengths and operating conditions due to 63 MeV proton irradiation is presented. Complementary proton induced minority carrier lifetime degradation results collected using time resolved photoluminescence will also be reported on.

**Keywords:** infrared detector, unipolar barriers, nBn, proton irradiation, gamma irradiation, damage factors

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**Effects of 63 MeV Proton-Irradiation on the Dark-current in III-V-based Unipolar Barrier Infrared Detectors**

**Abstract**

III-V-based, unipolar barrier infrared (IR) detectors, such as nBn’s, have made significant progress since their introduction and are currently being considered for space applications. The latter imposes the additional requirement for radiation tolerance, which also necessitates an understanding of how detector dark-current changes with proton irradiation. An early study on diffusion current in defect-limited nBn detectors demonstrated that, based on simple theoretical considerations, the dark-current transitions from a linear to square-root dependence on the proton fluence as proton irradiation generates additional defects, thereby degrading the minority carrier lifetime and diffusion length, which then becomes smaller than the absorber length.\[1\] The included empirical data did indeed exhibit a transition, but the power-law dependence was unexpectedly below the predicted levels.\[1\] A more recently published study indicated similar proton irradiation of III-V infrared materials were accompanied by an increase in n-type doping levels.\[2\] Taken together, these results suggest the effects of increasing proton fluence on dark-current in III-V-based nBn detectors must be reinvestigated as any related increase in doping level would lower the expected power-law dependence. Here, a re-analysis of the original published data comparing it with simple 1-D numerical modeling and new dark-current and capacitance-voltage measurements on additional nBn detectors under similar irradiation conditions are presented. The results were found to be consistent with an increase in n-type doping level due to 63 MeV proton irradiation. The implications of this on how future nBn’s are designed to improve their rad-tolerance are discussed as are future experiments.


**Keywords:** infrared detector, unipolar barriers, nBn, dark-current, doping level, proton irradiation, damage factors
MWIR or LWIR? A choice based on physics or money?

Abstract
In 1999 FLIR Systems AB started to deliver QWIP-based thermal imagers for commercial and military applications. A number of different products have been developed and delivered in total quantities exceeding 3000 units to end-users worldwide and OEM:s. The QWIP technology delivered on the promises of excellent performance, operability, and reliability but was not successful to meet the high hopes of a low cost, high performance detector. While conventional wisdom from the 1990’s dictated the use of LWIR in colder climates, advances in MWIR system design has proved that this waveband is viable in most climates and foremost offers a much more economical alternative for long range applications. However, there is still merit in LWIR for many applications. This paper will discuss the pros and cons of these two wavebands and available detector technologies, what is required in different applications, and which requirements will have to be met by coming detector materials and technologies in order to exploit this.

Keywords: QWIP, MWIR, LWIR, SWIR

Thermal polarimetric infrared imaging and signatures

Abstract
The polarimetric content of optical radiation can convey unique information on source properties such as surface orientation and roughness. A polarization sensitive imager can use the spatially variable and complementary polarimetric and radiometric information to enhance or introduce new capabilities in comparison to conventional imagers. In this work, polarimetric properties of emitted and reflected radiation in the thermal infrared spectral region are explored to investigate the possibility of enhanced capabilities in areas such as detection and identification of targets or threats. The persistence and variability of thermal polarimetric signatures, captured in various outdoor and indoor settings using a calibrated polarimetric thermal imager based on the division-of-time principle, are analyzed. Based on these investigations, basic requirements on polarimetric sensor performance for use in different applications are derived.

Keywords: Polarimetric imaging, signatures, LWIR, calibration, DoT, division-of-time, wiregrid polarizer, microbolometer
IR spectroscopy of blood components for subcutaneous melanoma and non-Hodgkin’s lymphoma cancer detection

Abstract
Epidemiological studies have shown the global increasing trend of cutaneous melanoma over the last few decades. At the same time, non-Hodgkin’s lymphoma (NHL) is one of common cancer in regions like the US and other westernized countries, that accounts 4.3% of all cancer cases. Existing diagnostic techniques for melanoma and lymphoma include the histological examination using biopsy, are time-consuming, invasive, and costly. Developing a rapid and reliable detection is thus critical because early diagnosis and treatment of such malignancies improve the patient’s chances of survival. Using rapid and reliable Fourier transform infrared spectroscopy of serum sample in attenuated total reflectance sampling mode accompanied with different data handling frameworks, we have studied diseases induced biochemical alteration in serum samples. This experimental demonstration on a B16 mouse model of subcutaneous melanoma and an EL4 mouse model of NHL emphasizes the diagnostic potential of this approach as a screening technique. Infrared absorbance values of different spectral band positions and integral area covered by Gaussian energy bands obtained via spectral deconvolution show a significant difference, p-value < 0.5, between control (n=15) and tumorous mouse models of melanoma (n=8) and lymphoma (n=8). This technique may thus also be used for rapid evaluation of different treatment strategies.

Keywords: IR Spectroscopy, Subcutaneous melanoma, non-Hodgkin’s lymphoma

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Presentation Title: IR spectroscopy of blood components for subcutaneous melanoma and non-Hodgkin’s lymphoma cancer detection

Defect detection in steel products with IR imaging

Abstract
Surface quality of steel products has become increasingly important since the quality of the surface is not only affecting the aesthetic look and cost of the finished product, but also the surface sustainability against corrosion processes. The rapid development of thermal vision systems has provided new opportunities for defect detection in steel production lines. Whereas commercially available quality monitoring systems that use conventional vision cameras perform poorly in the steel production environment, thermal cameras enable quality control on warm and cold steel products by detecting and identifying surface and possibly sub-surface defects that occur in different manufacturing stages. Increased emissivity for cracks, oxides, marks and rough areas have been observed both when illuminating the steel objects with a high power lamp and when heated up above room temperature. Process monitoring with IR imaging may therefore provide new on-line tools to increase product quality and production yield. Results from lab tests obtained with commercial IR cameras (InSb and microbolometers) as well as prototype cameras (T2SL and QWIP) will be presented, showing the clear benefits of IR imaging for detection of defects in steel products, in particular for cracks not visible with conventional vision cameras.

Keywords: IR imaging, steelmaking, process monitoring, defect detection, quality control

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Current Status and Challenges in III-V Material Superlattice Infrared Detector Technology

Abstract
Due to substantial investments in research and development, the last decade has shown remarkable progress in Sb-based Type-II Superlattice (T2SL) infrared detector technology. Today, T2SL materials grown on very large diameter (up to 6") GaSb substrates with higher processing yield provide a much lower cost option for staring imagers in mid and long wavelength infrared. The sensitivities of these FPAs are on par with, if not exceeding, the state of the art with additional system level benefits due to their inherent operability, uniformity and stability advantages. This talk reviews the remaining challenges in T2SL IR detector technology followed by a discussion of current device and material research being conducted to address these technical hurdles. It describes the formation of superlattices with different alloy combinations and material system properties such as variable bandgap, electron and hole mobility, and minority carrier lifetime which is a critical factor for detector performance. It discusses widely varying results of experimentally measured minority carrier lifetimes, which range from 30 nanoseconds to 9 microseconds depending on the bandgap and the inclusion of gallium compounds in the superlattice material, and explains present understanding of the minority carrier lifetime and its dependence on the material parameters. It compares advantages and disadvantages of SLS in both device performance and FPA fabrication and details technical challenges such as lower hole mobility in n-type SLS materials, surface pinning of p-type material and their effect on infrared FPA performance.

III-V semiconductor unipolar barrier infrared detectors and focal plane arrays

Abstract
The advent of the unipolar barrier infrared detector device architecture has in many instances greatly alleviated generation-recombination (G-R) and surface leakage dark current issues that had been problematic for III-V photodiodes. Meanwhile advances in bulk III-V material such as InGaAsSb and metamorphic InAsSb, as well as in a variety type-II superlattices (T2SLS) such as InGaAs/GaAsSb, InAs/ GaSb, and InAs/InAsSb, have provided continuously adjustable cutoff wavelength coverage from the short wavelength infrared (SWIR) to the very long wavelength infrared (VLWIR). We will report results in extended-SWIR, MWIR, and LIR III-V unipolar barrier infrared detectors, and show that they have consistently led to high focal plane arrays (FPA) operability and uniformity. One concern for T2SL is the low mobility in the growth direction due to the large effective masses which can result in short diffusion lengths, leading to reduced collection quantum efficiency (QE). We have formulated a theoretical method for calculating thermally averaged conductivity effective masses that takes into account superlattice band structure effects relevant to carrier transport. We apply the method to compare different approaches to achieving extended-SWIR, MWIR and LWIR detectors.

Keywords: infrared detector, unipolar barrier, type-II superlattice, nBn, antimonide, e-SWIR, MWIR, LWIR, effective mass
VLWIR InAs/GaSb superlattice infrared photodetectors and focal plane arrays for space applications

Abstract
In this paper, results from the development of InAs/GaSb superlattice focal plane arrays (FPAs) for detection in the very long wavelength infrared (VLWIR) regime will be presented. The detectors are tailored for space applications with cut-off wavelengths of 11.5 µm, 14.5 µm and 16.5 µm. VLWIR detectors are important for the space industry for use in meteorology and for monitoring of climate changes, but also for numerous commercial and military applications. In this work, dark currents comparable to the HgCdTe benchmark (Rule07) have been measured on FPA level and quantum efficiencies (QE) of the detectors exceed 30% without antireflection coating. Furthermore, excellent uniformity from pixel to pixel has been observed, which is crucial for high performance imaging. Bias and temperature dependencies of the QE have been studied showing very low turn on bias (>25 mV) and no variation of the peak QE value with temperature. These results show that there are no unintentional barriers in the detector structures and that the diffusion lengths are long enough to provide efficient collection of carriers. The performance in terms of QE and dark current will be presented for photodiodes with cut-off wavelengths of 11.5 µm and 14.5 µm.

Keywords: InAs/GaSb, superlattice, barrier structure, LWIR, VLWIR, FPA

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Dark current improvement due to dry-etch process in InAs/GaSb type-II superlattice LWIR photodetector with nBn structure

Abstract
In long wavelength infrared (LWIR) type-II superlattice (T2SL) detector, the dark current must be reduced to improve performance or decrease the system size, weight, and power consumption (SWaP). Accordingly, we present the process to reduce the dark current of LWIR T2SL detector with nBn structure. The nBn structure consists of InAs/GaSb 14 monolayers/7 monolayers contact and absorber layer separated by Al0.2Ga0.8Sb barrier layer. The dark current was affected by the isolation etch process for pixel definition. It was found that AlGaSb material was etched in an organic solution such as acetone. Thus, the process was developed so that AlGaSb barrier is not damaged by any solution from the isolation etch process to the passivation process. In this process, CHF3 plasma treatment after the isolation etch using dry etch reduced significantly the dark current than using wet etch. We attribute this to a damage reduction of AlGaSb barrier by CHF3 plasma treatment. The 15 μm pitch devices fabricated with optimal process conditions showed the dark current density of less than 2E-5 A/cm² at -0.3 V and 80 K.

Keywords: InAs/GaSb type-II superlattice, Long wavelength infrared, nBn detector, Dark current

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Presentation Title
Development of Type-II superlattice (T2SL) detector in JAXA: Electrical and optical evaluation of InAs/GaInSb T2SL VLWIR detector with Al2O3 passivation layer

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Abstract
Type-II superlattice (T2SL) very long-wavelength infrared (VLWIR) detector is under development in JAXA. The T2SL sample is a 15μm-cutoff wavelength pBiBn diode having a slightly p-type 300 pairs InAs/GaInSb T2SL as an absorption layer grown by MBE on a n-type GaSb substrate. Plasma CVD deposited SiO2 is commonly used for surface passivation material of the T2SL sample, but we tried to use ALD deposited Al2O3 instead of the SiO2 towards higher detecting sensitivity of the T2SL sample. In this paper, we will describe the results of electrical and optical performance of InAs/GaInSb T2SL VLWIR detector with Al2O3 passivation layer.

Keywords: InAs/GaInSb Type-II superlattice, very long-wavelength infrared, Al2O3

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Presentation Title
SLS FPAs with cutoff wavelengths from 5 microns to 14 microns

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Kim Beech
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Kelly Patraude
Ross Faska
Jason Bundas
Axel Reisinger

Abstract
We review the current performance of strained layer superlattice (SLS) focal plane arrays (FPAs) with cutoff wavelengths ranging from 5 microns to 14 microns. With a proper antireflection coating, quantum efficiencies in our FPAs now exceed 80% in the midwave infrared and 40% in the longwave infrared. Significantly, dark current for longwave SLS is now lower than MCT Rule07, as predicted by early SLS theories, and the result of bandgap engineering, effective passivation, and the reduction of defects in material growth. The combination of high quantum efficiency and low dark current allows high temperature operation, e.g. SLS FPAs show background-limited performance (BLIP) at 130K (5 micron cutoff) and 75K (12 micron cutoff) with F/4 optics and 300K scene temperature. Formats up to 2048x2048 and pixel pitches down to 10 microns have been realized. The superb array uniformity and pixel operability testify to the benefits of the growth and processing of III-V materials on 3- and 4-inch GaSb substrates.

Keywords: Strained layer superlattice, SLS, Type-II, T2SL, infrared, focal plane array, FPA

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Challenges and Opportunities for Antimonide Based Superlattices Detectors

Sanjay Krishna
George R Smith

Presentation Title
Challenges and Opportunities for Antimonide Based Superlattices Detectors

Abstract
One of the unique aspects of the 6.1A family of semiconductors (InAs, GaSb and AlSb) is the ability to engineer the bandstructure to obtain designer band-offsets with different types of band-alignments (nested, straddled and staggered). There has been significant advance progress in the development of antimonide based detectors in the past decade with new materials like InAsSb, InAs/GaSb superlattices and InAs/InAsSb superlattices demonstrating very good performance, especially in the mid-wave infrared. However, there are several challenges that need to be addressed. In this talk, I will describe the material science and device physics of the antimonide systems. I will also discuss the challenges in these systems including the identification of defects that limit the performance of the detector. The use of “unipolar barrier engineering” to realize high performance infrared detectors and focal plane arrays will be discussed. I will discuss a few interesting research directions including superlattice membranes, ultra-low noise avalanche photodiodes and antenna coupled infrared detectors.

Keywords: infrared detector, unipolar barriers, nBn, proton irradiation, gamma irradiation, damage factors

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High operating temperature InAs/GaSb type-II superlattice detectors on GaAs substrate for the long wavelength infrared

Presentation Title
High operating temperature InAs/GaSb type-II superlattice detectors on GaAs substrate for the long wavelength infrared

Abstract
InAs/GaSb type-II superlattice (T2SL) infrared photodetectors are investigated regarding their potential for applications at high operation temperature (HOT). Our efforts are targeted at commercial applications such as identification and quantification of substances in gases and liquids by means of characteristic absorption bands in the fingerprint region.

We fabricated T2SL detectors designed for operation under HOT conditions (180-300K) with precisely tunable cutoff wavelength in the longwave infrared region. Our detector structures are grown on semi-insulating GaAs and operated in a horizontal, photo-conductive mode. Besides cost reduction and high yield this allows for backside illumination and compatibility with immersion lens technology that enables increased detectivity. The lattice mismatch between the GaAs substrate and the T2SL is compensated by an appropriate buffer layer. Design of the superlattice layer composition is supported by the Superlattice Empirical Pseudopotential Method (SEPM) that we previously employed for cryogenically cooled devices and recently adapted to the HOT regime.

Keywords: InAs/GaSb, T2SL, HOT, LWIR, infrared detector

Fraunhofer Institute for Applied Solid State Physics (IAF), Freiburg, Germany

Keywords: InAs/GaSb, T2SL, HOT, LWIR, infrared detector
Presentation Title
Demonstration of HOT LWIR T2SL InAs/InAsSb photodetectors grown on GaAs substrate

Abstract
Type II InAs/InAsSb superlattices are promising material for MWIR and LWIR high-performance photon detectors due to longer minority carrier lifetimes [1,2]. The less complicated growth process and simpler interfaces control growth can yield in better structural quality of Ga-free T2SL. Nevertheless, the influence of the growth conditions on the T2SL material quality remains a critical issue. More detailed investigation of the structural properties seems essential for further improvement of the materials and device performance. In order to fabricate low-cost infrared focal plane arrays production devices, it is recommended to utilize GaAs substrate. The latter has better structural, optical and thermal properties than GaSb. In addition, GaAs substrates are more affordable and available as large size "epi-ready" wafers. Transparent GaAs substrate allows the backside device illumination and the fabrication of monolithic optical immersion lenses which improves the devices’ performance. In this work, we demonstrate HOT LWIR T2SL InAs/InAsSb photodetectors grown on GaAs substrates using MBE. The authors would like to acknowledge the support by the Polish National Science Centre grant no. PL-TW4/3/2017/PPPN/34-534/2017/WAT.


Keywords: InAs/InAsSb superlattice, GaAs, HOT, LWIR, Infrared

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III-V SLS FPA Development in U.S. after VISTA

Abstract
The Vital Infrared Sensor Technology Acceleration (VISTA) Program was a five year (2011-2015) program managed by the U.S. Tri-Service and funded by the Office of the Secretary Defense (OSS/ASD). In just five years, VISTA made tremendous strides in the development of III-V antimony-based detectors, pioneering much of the work in this area. As part of this success, the program demonstrated very large-format high operating temperature mid-wavelength as well as mid-wavelength/long-wavelength dual band 720x1280 12-um pitch infrared focal plane arrays. While the program ended in 2015, the U.S. continues to pursue this highly flexible technology for advanced infrared sensors. In this presentation, we will focus on the VISTA products and the funded activities on the application of the VISTA products.

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Presentation Title
Status review of InAs/GaSb type-II superlattice infrared detector technology in Germany

Abstract
InAs/GaSb type-II superlattice (T2SL) technology enables fabrication of high-performance focal plane array (FPA) detectors for the mid-wavelength infrared (MWIR, 3-5 µm) and the long-wavelength infrared (LWIR, 8-12 µm) regimes. After roughly two decades of research and development (R&D) at Fraunhofer IAF our most advanced T2SL branch, i.e., dual-color MWIR FPA technology, has reached a technology readiness level (TRL) of 8. With our R&D we cover a multitude of aspects ranging from fundamental materials research to small-scale fabrication for high-performance defense technology projects. Today, we employ this unique in-house expertise for a continuous evolution of the electrooptical (e/o) performance of T2SL FPAs both in the MWIR as well as the LWIR. The talk will review the status of our current T2SL technology activities focusing on topics such as theoretical modelling, dark current reduction for increased operating temperature and next-generation dual-color imaging. We will give insight into recent research results on the minority carrier lifetime in InAs/GaSb T2SL absorbers as well as noise current investigations and other aspects relevant for raising the e/o device performance. Latest FPA achievements will be discussed.

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T2SL Manufacturing Capability at L3 Space & Sensors Technology Center

Abstract
L3 Space & Sensors Technology Center (L3 SSTC) has a nearly 60-year history developing and manufacturing infrared (IR) detectors. Starting with crystal growth of indium arsenide antimonide (InAsSb1-x) and lead tin telluride (PbSnTe) crystals for single detectors in the 1960’s, we moved into producing linear arrays of InAs and InSb in the 1970’s and 1980’s, and in the 1990’s consolidated production on two dimensional focal plane arrays (FPAs) using commercially available InSb wafers. The tri-service Vital infrared Sensor Technology Acceleration (VISTA) program rapidly matured III-V semiconductor epitaxy to produce tactically viable detectors using Type II Superlattice (T2SL) structures. Our participation in this program allowed us to develop a manufacturing capability for T2SL higher operating temperature (HOT) mid-wave infrared (MWIR) detectors on 125 mm substrates. Our work started by defining the characteristics of the gallium antimonide (GaSb) substrates. We leveraged the literature from silicon maturation to define the thickness and edge bevel. Next, we worked with the epitaxial suppliers developed under the VISTA program to establish the multi-wafer growth capability. Through a program funded by the Office of the Secretary of Defense (OSD) and managed by the Army Night Vision and Electronic Sensor Directorate (NVESD), we were able to improve FPA yield to match InSb manufacturing levels.

Keywords: Type 2 Superlattice, Mid-wave Infrared, Focal Plane Array

MWIR nBn detector monolithically integrated with microlens

Abstract
The signal-to-noise ratio and the operating temperature of infrared (IR) detectors can be increased by integrating detectors with optical concentrators such as refractive microlenses (μlenses). The single μlens and μlens arrays operating in the visible and near-IR are well-developed and commonly used in many applications. However, μlens technology in the mid- and long- wavelength infrared (M- and LWIR) spectral bands lags behind. In the last two decades, new IR detector architectures and material systems such as nBn or XbN barrier photodetectors have emerged. Integration of these novel detectors with μlenses will further enhance their performance. In the current work, we realized InAsSb nBn detector monolithically integrated with μlens fabricated on the back side of the detector. The increase in the optical collection area of the detector resulted in significant increase of the responsivity and operating temperature.

Keywords: nBn detectors, microlens, high operating temperature
Small Pitch Compatible
Processing and Passivation of
III-V Antimonide Based Infrared Detectors

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Daniel Sidor
Benjamin Pinkie
Alexander Brown
Randolph Jacobs
Marvin Jaime-Vasquez
Leo A. Almeida
Sumith Bandara

Abstract
Antimonide based infrared detector materials lattice matched to GaSb are being intently studied in the pursuit of lower cost and higher performance focal plane arrays (FPA). One of the greatest advantages of the III-V materials system is the potential for uniformity stemming from the incorporation of lattice matched wide bandgap unipolar barrier layers. However with the increasing demand for larger format smaller pitch focal plane arrays new processing and passivation techniques are needed to attain higher aspect ratio features and block surface leakage currents. The conductivity of the pixel mesa sidewalls is determined by the chemistry, which is a result of the process history and composition of the active layers. Several strategies to both improve consistency and reduce surface current in antimony based infrared photodetectors will be discussed. Inductively coupled plasma etch chemistries, surface cleaning techniques, and passivation with chalcogenide based compounds will be presented.

Keywords: Superlattice, Infrared detector, Passivation

Flip-Chip Technology
for Image Sensors

Jean-Stéphane Mottet1

Abstract
Image sensors are used to detect different wave lengths (infrared, X-ray, ultra-violet, gamma…) for many different final applications from automotive, industrial, medical, aerospace to military. Some of these sensors are monolithic, some are made of 2 parts (sensor + Roic) and assembled by a flip-chip technology. This presentation focuses on the second kind. Typically, indium bumps (but not only) are used, with the well-known challenge of dealing with oxide. Thermo-compression or reflow techniques can be used according to the constraints of the components. Because the size of the image sensors increases and because the pitch and the size of the bumps reduce, the required alignment and parallelism accuracy is becoming more and more demanding.

This presentation will summarize the different bonding processes with pros and cons factors to take into account when assembling image sensors. One of the main challenges with indium bumps being the strong oxidation layer, a description of the possible solutions to remove this oxide will be presented: flux, mechanical scrubbing and formic acid vapor. Some alternatives to indium have been developed with also pros and cons factors.

Flip-Chip Bonders must respect the high sensitivity of these materials and must be able to align, level and bond these devices managing the high force constraints and the thermo-expansions. They also must bring solutions to remove or break the oxidation layer on the indium bumps

Keywords: Assembly of bi-component image sensors using different Flip-Chip technologies

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**Sub-atomic resolution chemical mapping of quantum cascade detectors: a tool for predictive quantum engineering**

**Abstract**

The ability to model device performances from quantum principles is a strong asset for the production and industrialization of Quantum Cascade structures, both Lasers (QCLs) or Detectors (QCDs). Indeed, predictive quantum engineering allows for short developments cycles and fast reaching of optimal performances. In this paper, we show that by correlating High Angle Annular Dark Field measurements of a Scanning Transmission Electron Microscope (HAADF-STEM) with Energy-Dispersive X-ray spectroscopy (EDX), we are able to get, down to sub-atomic resolution, a quantitative picture of the conduction-band offset that defines the electronic cascade at the core of QCLs and QCDs operating principle. The method and its benefits are illustrated on a case study of a MWIR QCD.

**Keywords:** Quantum Cascade Detectors, STEM-HAADF, EDX, Quantum engineering

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**Optimal absorber thickness in interband cascade photodetectors**

**Abstract**

The paper presents the performance of the interband cascade type-II infrared superlattice photodetectors. Such photodetectors are made up of multiple stages, which are connected in series using an interband tunneling heterostructure. We compare two different architectures of the cascade detector: equal absorber thickness in all stages and varied absorber thickness. Making the assumption of bulk like absorbers, we show influence of the thickness change of the first absorber in cascade on the thickness of subsequent absorbers, which results in a change of the final parameters of the entire device. The selection of the correct absorber thickness depends on the number of cascade stages, which results in the highest possible detectivity value. We pay attention to the value of the diffusion length, which in the case of this type of detectors has a decisive impact on quantum efficiency, and therefore also on detectivity. For high value of diffusion length $L$, detectivity $D^*$ increases with the value of number of stages $N_s$ for matched absorbers, but for the equal absorbers the situation is reversed. If the $L$ value is low, as the number of cascades increases, the maximum $D^*$ value increases for both detector architectures. Moreover, detectivity is almost independent of the number of stage when $N_s > 20$. If the electrical current gain for the architecture with equal absorbers is taken into account, the optimal thickness of the individual absorber increases and higher detection values are obtained with a larger number of stages.

We acknowledge support by The National Science Centre the grant no. OPUS/UMO 2015/19/B/ST7/02200.

**Keywords:** interband cascade detectors, infrared detectors, superlattice, T2SL, detectivity, matched absorbers, ICIP
Noise and Gain Characterization of Long-Wavelength Interband Cascade Infrared Photodetectors

Abstract
Interband cascade infrared photodetectors (ICIPs) have shown potential for high operating temperature (HOT) applications. The ICIP architecture allows the absorber region to be broken up among multiple stages. This allows each absorber section to be shorter than or comparable to the carrier diffusion length to maintain a high probability that photo-generated carriers will diffuse out of the absorber section and be collected. By building multiple stages into the device, each with an absorber region, the total absorber thickness can be made sufficiently large to ensure the majority of incident light is absorbed. Increasing the total absorber thickness by adding additional stages theoretically increases the internal quantum efficiency proportionally to the number of stages while simultaneously reducing the photoconductive gain by the same factor. Thus, for some ICIPs, adding additional stages should not affect the signal. The benefit of additional stages arises from the theory that the noise gain is also inversely proportional to the number of stages such that additional stages increase the sensitivity by maintaining the signal while reducing noise. In this work, the dark-current and quantum efficiency performance of long-wavelength (7.5 to 11.5 μm) ICIPs with 1, 4, 6, and 8 stages is presented for 80 K to 300 K. Noise spectra are also presented for the devices as a function of varying bias, temperature, and irradiance. The actual noise currents are compared to theoretical predictions and are used to calculate photoconductive and noise gain, revealing the effect of additional stages.

Keywords: infrared detector, interband cascade photodetector, high operating temperature

Study of infrared photodetectors with wavelength extension mechanism

Abstract
The III-V semiconductor heterostructure-based photodetectors have been studied extensively for infrared detection, near-infrared (NIR) to far-infrared (FIR) region. Due to mature material system, GaAs/AlxGa1-xAs heterostructures are attractive options for development of infrared detectors. The conventional rule of photodetection, \( \lambda_{\text{t}} = \frac{hc}{\Delta} \) determines the wavelength threshold of spectral photoresponse, where \( \Delta \) is the minimum energy gap of the material, or the interfacial energy gap of the heterostructure. In recent studies on the non-symmetrical p-GaAs/AlxGa1-xAs heterostructures, spectral threshold limit due to \( \Delta \) has been overcome owing to a detection mechanism arising from the hot-carrier effect. It has been experimentally observed that a detector with a conventional spectral threshold of \( \sim 3.1 \mu m \) shows an extended wavelength threshold of up to \( \sim 68 \mu m \). An important advantage of the wavelength extension mechanism is a lower dark current, which is determined by the standard \( \Delta \). Dark current fittings obtained from a 3D carrier drift model closely agree with experimentally measured dark current. A barrier energy offset (\( \delta E \)) between AlxGa1-xAs barriers is found to be necessary for the spectral extension mechanism. Further study with a variation in \( \delta E \) and gradient of the AlxGa1-xAs barrier is expected to shed more light on the underlying mechanism, and work is in progress in this direction.

Supported in part by the U.S. Army Research Office (W911 NF-15-1-0018) and in part by National Science Foundation (ECCS-1232184).

Keywords: infrared photodetector, wavelength extension, GaAs/AlGaAs heterostructure
Presentation Title
Utilizing the Chiral Induced Spin Selective Effect (CISS) to Realize Simple Spintronics Devices

Abstract
With the increasing demand for miniaturization, nanostructures are likely to become the primary components of future integrated circuits. Different approaches are being pursued towards achieving efficient electronics, among which are spin electronics devices (spintronics) [1]. In principle, the application of spintronics should result in reducing the power consumption of electronic devices.

A new, promising, effective approach for spintronics has emerged using spin selection in electron transport through chiral molecules, termed Chiral-Induced Spin Selectivity (CISS) [2]. Recently, by utilizing this effect we demonstrated a magnet-less magnetic memory [3, 4]. Also we achieve local spin-based magnetization generated optically at ambient temperatures [5, 6]. The locality is realized by selective adsorption of the organic molecules and the nano particles [7]. Lastly we have been able to show chiral proximate induced magnetization on the surface of ferromagnetic and superconducting materials. The magnetization is generated without driving current or optically exciting the system [8, 9].

In the talk I will give a short introduction about spintronics and the CISS effect. Then I will present ways to achieve simple spintronics devices utilizing the effect.

References

Keywords: nanowires, intersubband transitions, infrared photodetectors, photonic crystals

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Presentation Title  
SWIR to Visible Integrated Infrared Up-Conversion Imaging Device Using Nano-Spheres and Nano-Columns as the Photo-sensitive Layer

Abstract  
We present the progress in the development of an up-conversion integrated high-sensitivity short-wavelength infrared (SWIR: λ=1300-1800nm) to visible imaging device that directly converts the SWIR image into visible image. The device composed of very thin quantum structure based infrared absorption layer and visible photo-emissive layer. We demonstrate two types of quantum structure absorber layers grown by Chemical Bath Deposition (CBD) technique: PbSe in a nano-column (NC) morphology and PbS in a nano-sphere (NS) morphology. The motivation in growing nano-columns is to achieve high vertical mobility of the photo excited charge carriers, which also minimize lateral diffusion, and thus improve the image integrity of the up-conversion device. PL measurements confirmed the blue shift due to the quantum confinement of the nano-structure. Current voltage (I-V) analysis carried out in vertical geometry on different mesa sizes (250-2000 μm in diameter) revealed a densely packed films with no apparent pinholes or shunts, confirming the high quality of the deposition. A proper integration of these thin absorbing layers with an Organic Light Emitting Diode (OLED) is undergoing and is achieved by an impedance matching of the device as will be presented.

Figure 1: The detector dark and SWIR illuminated J-V measurements and OLED J-V curves showing the device dynamic range (left). Up-converted image 3 bars target (a) in dark and (b) under SWIR illumination (right).

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Presentation Title  
Highly Sensitive Tunable Room Temperature Infrared Hybrid Organic-Nanocrystals Detector

Abstract  
The integration of nanostructures in electronic detectors utilize their unique advantages of controlled quantum properties. Using self-assembled organic monolayers with nano-crystals (NCs), together with bottom up components was proven as appropriate approach for future electronic devices. In our work, we present a wavelength tunable near-infrared room temperature detector based on NCs acting as an optical gate on top of a high-mobility shallow two-dimensional electron gas channel. (1) Using shallow and very narrow channel, the device’s quantum efficiency can go as high as 10^-6 V/W at room temperature, with a signal-to-noise ratio (SNR) that enables sensitivity for very low photon power. (2) Further improvement of light detection is achieved by applying horizontal electrical filed resulting narrower the conductive channel. This approach, enhance the detector response and the SNR at different operation conditions. Using AC modulation, the detectivity at room temperature is 10^12 Jones for 980nm wavelength of, and 10^11 Jones at the QD absorption peak of 1500nm. To further improve SNR, a new concept of AC electrical filed modulation of the side gate will be presented and compared to DC measurements by analyzing response, SNR and noise behavior. (3) Lastly, expanding to a non-binary logical device is achievable due to the detector wavelength tunability.

Influence of radiative recombination on performance of p-i-n HOT long wavelength infrared HgCdTe photodiodes

Abstract
An enhanced computer program has been applied to explain in detail the influence of different recombination mechanisms (Auger, radiative and Shockley-Read-Hall) on the performance of high operation temperature long wavelength infrared p-i-n HgCdTe heterojunction photodiodes. It is shown that photon recycling effect drastically limits the influence of radiative recombination on the performance of small pixel HgCdTe photodiodes. The computer program is based on a solution of the carrier transport equations, as well as the photon transport equations for semiconductor heterostructures. We distinguish photons in different energy ranges with unequal band gaps. As a result, both the distribution of thermal carrier generation and recombination rates and spatial photon density distribution in photodiode structures have been obtained. In comparison with two previously published papers in Journal of Electronics Materials (Lee et al., DOI: 10.1007/s11664-016-4566-6 and Schuster et al., DOI: 10.1007/s11664-017-5736-x) our paper indicates an additional insight on ultimate performance of LWIR HOT HgCdTe arrays with pixel densities that are fully consistent with background- and diffraction-limited performance due to system optics.

Keywords: HgCdTe HOT photodiodes, radiative process, photon recycling, small pixels

Material developments for longwave and very-longwave InAs/GaSb superlattice barrier structures infrared photodetectors

Abstract
InAs/GaSb Type II Superlattice (T2SL) is an attractive material system for developing infrared photodetectors in longwave and very longwave infrared spectral domains thanks to its tailorable band-gap energy, providing cut-off wavelengths up to 25 µm, to the III-V semiconductor technology maturity and the availability of large format (up to 5”) highly uniform low-defect GaSb substrates.

In this communication, we report on material developments of InAs/GaSb T2SL infrared barrier structures and detectors grown by molecular beam epitaxy (MBE) on GaSb substrate, showing cut-off wavelengths at 11.5, 14.5 and 16.5 µm at 77 K. Experimental measurements on samples were made by high-resolution X-ray diffraction (HRXRD), atomic force microscopy (AFM) and Photoluminescence (PL). Additionally, capacitance-voltage (C-V) measurement was used in order to extract residual and intentional carrier concentrations of absorbing and barrier layers. Analysis of these characterizations allowed us to improve the MBE growth procedure of T2SL barrier structures.

This work was partially funded by the French “Investment for the Future” program (EquipEx EXTRA, ANR 11-EQPX-0016) and ESA contract n° 4000116260/16/NL/BJ.

Keywords: InAs/GaSb T2SL, MBE growth, barrier structure, LWIR, VLWIR
Effect of Substrate Miscut on Sb-based MWIR Photodetector Performance

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Presentation Title
Effect of Substrate Miscut on Sb-based MWIR Photodetector Performance

Abstract
Effect of substrate orientation and surface polarity on performance of MWIR photodetectors (PD) were evaluated by comparing devices fabricated on <100>, <211>A and B, and <311>A and B oriented substrates. Two types of PDs were evaluated: bulk InAsSb barrier PD with PL wavelength ~4 µm, and type-II strained layer superlattice (T2SL) PD with PL wavelength 5.5 µm. Epitaxial structures were grown by solid source molecular beam epitaxy (MBE) on various miscut substrates side-by-side in the same growth run. Material performance was evaluated by AFM, Nomarski microscopy, 78 K PL, and PD J-V and spectral testing. All wafers demonstrated reasonable surface morphology, with some variability in roughness. Bulk nBn devices fabricated on the miscut substrates show a blue shift up to 0.15 µm for both 78 K PL and spectral cut-off λ compared to the same structure on the (100) substrate. The substrate orientation and polarity variations also showed moderate reduction of QE and a variable change in dark current, Jd. The most significant Jd reduction by a factor of ~3 and ~6 was obtained for <311>A and <211>A oriented structures. Substrate orientation induces more variation in the SLS PDs, especially in Jd and QE. Also, the <211>B orientation demonstrates a red shift of the PL and cut-off λ by about 1.0 µm. The SL performance variations may be related to QW thickness undulations, modulation of the SL interfaces, or piezoelectric field shifts. The unique combinations of results make miscut surfaces potential candidates to improve PDs characteristics.

Keywords: MWIR, MBE, GaSb, Photodetectors

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Presentation Title
Growth and characterization of pseudomorphically strained InAs/GaInSb superlattices

Growth and characterization of pseudomorphically strained InAs/GaInSb superlattices

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Presentation Title
Growth and characterization of pseudomorphically strained InAs/GaInSb superlattices

Abstract
We report on the growth and characterization of strained-layer InAs/Ga1-xInxSb superlattices (SLs) with an alloy fraction x<0.4 and a lattice mismatch strain (aGaSb-aGaInSb)/aGaInSb of ~2%. The biaxial compressive strain and tetragonal distortion of the SLs crystal lattice allowed to extend the absorption cut-off beyond the VLWIR spectral range even in thin-layer InAs/ GaInSb SLs with a period of less then 8nm. In the LWIR and VLWIR range the absorption coefficient was comparatively larger than the reported values in InAs/GaSb counterparts. The InAs/GaInSb SLs were grown pseudomorphic on GaSb(100) substrates following the approach descried previously [1]. A post-growth characterization aimed to confirm the compositional nature of the strain in the SLs, determine the composition x of the ternary alloy and to evaluate the optical properties. The samples were characterized by XRD and reciprocal space mapping, scanning transmission electron micro copy (STEM), energy-dispersive X-ray spectroscopy (EDX) and Rutherford backscattering spectroscopy (RBS). Optical absorption properties were evaluated from the transmittance and reflectance spectra measured by Fourier transform spectroscopy (FTIR) and have been compared with the results of theoretical modeling using the multiband k-p method.

**Presentation Title**

Material and device characterizations of Type-II InAs/GaSb superlattice infrared detectors

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**Abstract**

In this communication, we investigated the growth by molecular beam epitaxy (MBE) of Type-II InAs/GaSb superlattice (T2SL) addressing the mid and long infrared spectral domain. The key challenge of the T2SL growth lies in the strain caused by the InAs layer on the GaSb substrate. To compensate for this strain, we studied the influence of different MBE shutter-sequences at both interfaces (IF), namely the InAs-on-GaSb and GaSb-on-InAs IFs, on the surface morphology and the structural and optical properties by performing routine material characterizations such as atomic force microscopy, x-ray diffraction and photoluminescence spectroscopy.

Firstly, we investigated the use of different Sb-soak times ("InSb-like" IF) at the GaSb-on-InAs IF with and without an As-soak ("GaAs-like" IF) at the InAs-on-GaSb IF. Secondly, we explored the Migration Enhanced Epitaxy (MEE) growth method to form an "InSb-like" IF at both interfaces. Both growth methods are then compared in terms of structural and optical properties. Finally, p-i-n photodiodes have been fabricated using the optimised growth method and their electrical performances evaluated.

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**Keywords:** InAs/GaSb superlattice, molecular beam epitaxy, infrared detector

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**Presentation Title**

Midwave infrared InAs/InAsSb type-II superlattice detector grown by molecular beam epitaxy on Si substrate

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**Abstract**

The recent demonstration of Sb-based laser devices grown by molecular beam epitaxy (MBE) on Si substrates [1] opens the way to exploring the growth on Si of III-Sb type-II superlattice (T2SL) infrared photodetectors, compatible with Si readout integrated circuits. However, due to the large material differences between Si and T2SL structures (designed to be lattice-matched to GaSb substrates), achieving high-performance IR detectors is a serious challenge. We have grown by MBE a Ga-free InAs/InAsSb MWIR T2SL barrier detector on an on-axis (001)-Si substrate. Prior to T2SL growth, the Si substrate was prepared in situ in a MOVPE reactor and a 800-nm thick GaSb buffer layer was grown by MOVPE [2]. We will present the structural and optical properties of the Si-grown T2SL, deduced from X-ray diffraction, AFM and photoluminescence spectroscopy and compare them to those of the same structure grown on GaSb. Next, we will report on the electrical and electro-optical measurements performed on photo-diodes. We will show that our results pave the way to monolithic growth of III-Sb T2SL infrared photodetectors on Si substrates.

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This work was partially funded by the French “Investment for the Future” program (EquipEx EXTRA, ANR 11-EQPX-0016).


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**Keywords:** Ga-free InAs/InAsSb T2SL, barrier detector, MWIR, Si substrate
Minority carrier lifetime and diffusion length in type II superlattice barrier devices

Abstract
The minority carrier lifetime in p-type InAs/GaSb type II superlattices (T2SLs) is quite short, typically in the region of tens of nanoseconds. In spite of this, T2SLs are becoming a viable alternative to Mercury Cadmium Telluride as the sensing material of choice for high end MWIR and LWIR infrared detectors. For example, SCD now manufactures a 640 x 512 format, 15 μm pitch LWIR focal plane array detector, with a quantum efficiency close to 50%, a pixel operability of >99%, and a dark current only about one order of magnitude larger than the state of the art Rule 07 value. A key to the very high performance of this detector is the use of an XBp barrier architecture that both suppresses the G-R current and allows stable passivation to all steps of the fabrication process. Since both the dark-current and photo-current in the XBp structure are diffusion limited, measurements of these quantities as a function of the fabrication process. Finally, comparison of the magneto-transport data prior and after substrate removal is presented which to and after substrate removal is presented which provides insight into substrate effects.

Lateral and Vertical Transport in n- and p-type InAsSb and InAs/InAsSb Type-II Strained Layer Superlattices for Infrared Detector Applications

Abstract
The InAs/InAsSb type-II strained layer superlattice (T2SLS) material system has significant potential for infrared (IR) detector applications, including space-based detection, when utilized in a unipolar barrier detector architecture (nBn). However, recent studies revealed the quantum efficiency in nBn detectors degrades significantly faster from proton-irradiation induced displacement damage as compared to HgCdTe photodiodes. Improving the quantum efficiency radiation-tolerance is theoretically possible by enhancing vertical hole mobility and thereby the vertical hole diffusion length. The vertical hole mobility of T2SLS materials differs significantly from the lateral mobility and measuring it is much less straightforward. Here, an investigation of the transport properties of n- and p-type InAsSbInAs T2SLS materials was performed in an effort to establish a relatively direct and effective methodology to measure vertical hole mobility and thereby set the stage for future studies to enhance it. The vertical transport properties of n-doped (n+n+n+) and p-doped (p+p+p+) lattice-matched InAsSb and strain-balanced InAs/InAsSb MWIR super-lattices grown on GaSb substrates using molecular beam epitaxy were determined using temperature-dependent magneto-resistivity measurements in conjunction with lateral transport measurements. Substrate-removed, metal-semiconductor-metal (MSM) devices were fabricated for vertical measurements, while standard van der Pauw structures were used for lateral measurements. AAlAs layers served as an etch-stop layer (vertical structures) and as an insulating layer (n-plane structures). To accurately determine the electronic transport properties in the presence of multiple carrier species, High Resolution Mobility Spectrum Analysis (HR-MSA) was employed. Finally, comparison of the magneto-transport data prior to and after substrate removal is presented which provides insight into substrate effects.
Development of Electron Beam Induced Current to characterize infrared detectors

Abstract

In the infrared (IR) fields, the use of high performance characterization methods is of great importance to develop and to improve the detectors. The specificities of these methods are linked to the studied IR device and can require among other to work in a specific temperature range or a particular IR spectral band. The optimization of IR detectors requires the understanding of the impact of technological processes and treatments on the material via the creation of defects within the device. To fulfill this goal, the Electron Beam Induced Current (EBIC) technique is a useful tool to determine the position of junctions, the minority-carrier diffusion length and to observe electrically active defects in the material. EBIC is particularly relevant in these IR domains as the devices are usually based on photodiodes presenting internal electric fields able to separate and collect carriers. Moreover, as EBIC is coupled to a scanning electron microscope it has a very good spatial resolution that allows minority-carrier diffusion-length estimation. This technique has already been used to study MCT photodiodes from SWIR to LWIR\(^1\)\(^-\)\(^5\) and on Type-II Superlattice (T2SL) structures such as InAs/GaSb, InAs/InAsSb and InGaAs/InAsSb\(^6\)\(^-\)\(^9\), mainly to determine the minority-carrier diffusion-length and to map electrically active defects. However, EBIC observations are more difficult for very-long wavelength MCT based photodiodes because of a drop in signal to noise ratio due to the increase of dark current and to the IR radiation of the scanning electron microscope environment, and more generally for cross-section studies due to the creation of defects during the preparation of the samples. For T2SL, EBIC studies can improve our knowledge on the effects of passivation, the influence of the composition of the devices and on the electrical properties of the structures. In this paper, thanks to multiple upgrades of a commercial equipment, we will present the benefits of the EBIC technique in IR developments applied to type-II superlattice structures and HgCdTe based photodiodes.

Keywords: EBIC, HgCdTe, T2SL, minority-carrier diffusion-length

Acknowledgments

This work has been supported by the French government through the national program “Investissement d’Avenir” of the labex PALM (ANR-10-LABX-0011-01) and by the European Union through the Horizon 2020 project “IRIS” (grant agreement 652203). The authors wish to thank J. Bacquet and M. Proust for fruitful discussions.

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References


Presentation Title

Development of Electron Beam Induced Current to characterize infrared detectors

Keywords: EBIC, HgCdTe, T2SL, minority-carrier diffusion-length

Spatial dependence of carrier localization in InAsSb/InSb digital alloy nBn detector

Abstract

Recently we have demonstrated a novel method of extending the cut-off wavelength of InAsSb nBn detectors, by incorporating a series of monolayers of InSb, which we have termed a digital alloy. In recent work [Pepper et al., Proc. SPIE 10177, 101771P (2017)] we have shown that while increasing temperature from 15 K to 40 K we observe a 19 meV blue shift of the photoluminescence peak energy and a decrease in minority carrier lifetime. We have hypothesized this effect is due to carrier localization due to fluctuations in layer thickness. Here we study the spatial variation of this effect over the surface of a sample, demonstrating significant variation with position. We discuss implications of this for the carrier localization hypothesis.

Keywords: photoluminescence, nBn, carrier localization, InAsSb, InSb

Acknowledgments

This work is supported by the French government through the national program “Investissement d’Avenir” of the labex PALM (ANR-10-LABX-0011-01) and by the European Union through the Horizon 2020 project “IRIS” (grant agreement 652203). The authors wish to thank J. Bacquet and M. Proust for fruitful discussions.

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References

Comparison study of minority carrier lifetime in type II InAs/GaSb and InAs/InAsSb superlattices

Abstract
In this work, we report the comparison study of the minority carrier lifetimes in type II InAs/GaSb and InAs/InAsSb superlattices, in which minority carrier lifetime plays an important role in photodetector performance, which has attracted considerable attention for Type-II superlattice IR sensors. Two type-II superlattice structures with 51 Å InAs/21 Å GaSb and 173 Å InAs/72 Å InAsSb0.25 were grown on GaSb substrates by solid source molecular beam epitaxy (MBE) with a RF-hydrogen-plasma added during crystal growth. The superlattice photodiodes comprise a p-i-n structure, a 1000 nm GaSb buffer layer, a contact layer doped with Be (p~2x10^{18} cm^{-3}), and a 250 Å InAs:Te (n~4x10^{18} cm^{-3}) layer for the top contact, with a total thickness of 2.5μm. In the H-plasma assisted MBE growth, the samples were exposed to H-plasma during the entire crystal growth while the H-plasma RF power was kept at a minimum. The carrier lifetime measurement was performed by time-resolved photoluminescence (PL) spectroscopy. The minority carrier lifetimes of InAs/GaSb superlattice and InAs/InAsSb superlattice were measured to be 65ns and 120ns, respectively, twice that without RF-H during crystal growth, indicating measurable improvement due to the presence of RF-Hydrogen.

Keywords: minority carrier lifetime, type-II InAs/GaSb superlattice, InAs/InAsSb

Temporal stability and correctability of a MWIR T2SL focal plane array

Abstract
Stability over time has recently become a figure of merit of major importance to compare the performances of infrared focal plane arrays (FPA) of different technologies. Indeed, this parameter dictates how often the calibration of operational electro-optical systems has to be done, and thus dictates the system availability during an operational mission. Recent studies also showed that random telegraph signal (RTS) noise, which leads to flickering pixels, can strongly affect image quality. The stability over time is generally estimated through fixed pattern noise (FPN) and residual fixed pattern noise (RFPN) measurements after a two points correction. However, each laboratory or industrial has its own protocols and criteria, such that published results cannot be easily compared.

In this paper, we describe our experimental protocol to evaluate the stability over time of a FPA and to count up / classify flickering pixels. We then present the results of two long-term measurement campaigns realized on a T2SL MWIR IDDCA provided by IRnova: the first study was dedicated to the measurement of FPN/RFPN (estimated with two different algorithms); the second study, dedicated to RTS noise, resulted in a classification of flickering pixels, based on the jump amplitude and the jump frequency. Our measurements show that the stability over time and correctability of the T2SL MWIR IDDCA are excellent.

Keywords: stability over time, FPN, RFPN, correctability, T2SL, MWIR, FPA
2-6 or 3-5’s for quantum IR imaging? Is it a simple question of columns or figures?

O. Gravrand

Presentation Title
2-6 or 3-5’s for quantum IR imaging? Is it a simple question of columns or figures?

Abstract
Since more than 30 years, HgCdTe has been the ‘king of the hill’ in IR imaging. Due to its versatility (ie the ability to address different spectral bands) as well as its extremely high performances (in QE and dark current), this 2-6 semi-conductor material has shown a remarkable resilience against the incursions of alternative material systems in the domain of high performance IR imaging, especially for the space industry. However, the exotic nature of this semiconductor material imposes the maintenance of dedicated production lines. This is often seen as a factor limiting the cost and the development lifetime of such detector arrays, or even, sometimes limiting the production yield.

Apart from QWIPs, most of those alternative solutions are also based on photodiodes but processed in 3-5 materials, which olds the reputation of a more conventional material system, meaning easier to manufacture with high yields for lower costs. Among those alternative material systems are bulk narrow gap semiconductors (such as InGaAs, InSb and now InAsSb). In those materials, the trade-off between the cost and the development lifetime of such detector arrays, or even, sometimes limiting the production yield.

However, another 3-5 player is expected to offer a versatility similar to 2-6 HgCdTe. Indeed, in the type-2 superlattice material system, the choice of superlattice stack formula allows the full design of narrow gap minibands in the whole IR spectrum. Therefore this synthetic narrow gap material is nowadays the focus of a strong interest, especially in the US which dedicated a strong research effort in the last few years to setup this technology.

This presentation intends to depict those different material systems for high performance IR imaging based on first order FOMs (such as QE, dark current or MTF) but also taking into consideration second order parameters (residual fixed pattern noise, stability and radiation hardness). Those second order FOMs being usually not perfectly known in the different material systems, this part of the tutorial will discuss those aspects based on literature data as well as considerations about the physics of the detection in each of those material systems.

Keywords: 3-5, 2-6, IR detection, FOM

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Presentation Title
Quantum Efficiency and Spatial Noise Tradeoffs for 3-V Focal Plane Arrays

Abstract
Recent advances in detector materials such as SLS have made the performance of those technologies competitive with traditional MCT and InSb detectors while offering the potential of lower unit costs. Some III-V FPAs operating in the MWIR spectral region have already achieved similar quantum efficiency performance as MCT and InSb devices and are therefore competitive for high performance applications. In the LWIR spectral region, quantum efficiency for III-V FPAs still lags MCT devices by a significant margin, but recent improvements have closed this gap. In addition, the improved spatial noise and operability typically associated with III-V devices can mitigate some of the shortfall in quantum efficiency when assessing system level performance. This paper will seek to quantify this tradeoff based on recent reported results for III-V and MCT devices in order to help focus future research. We quantify the current state of MCT and III-V (primarily SLS) FPAs in both MWIR and LWIR using a detailed literature survey to assess recent results, particularly in terms of reported quantum efficiency and residual fixed pattern noise.

This data is then used for system-level performance modeling using the US Army’s Night Vision Integrated Performance Model (NV-IPM), which calculates image contrast and spatial frequency content. The modeling analyzes various tradeoffs in quantum efficiency and spatial noise under relevant operating conditions, including scenarios with both high and low target photon fluxes, and using realistic constraints for integration time based on both frame rate and ROIC parameters. The results of this analysis are the compared to the current state of the art performance for both III-V and MCT FPAs to determine relative performance between the material systems and needed areas of improvement to meet application-specific requirements.

Keywords: Strained layer superlattice, quantum efficiency, spatial noise, infrared modeling

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Intrinsic dependence of the BLIP NEDT of SLS FPAs on pixel size

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Abstract
Since its founding nearly 14 years ago, QmagiQ has manufactured several thousand focal plane arrays, including a large number of strained-layer-superlattice (SLS) arrays hybridized to a variety of readout integrated circuits (ROICs) with different pixel pitches. In the process, we have accumulated evidence that at operating temperatures low enough for the BLIP (background-limited performance) regime to prevail and all other parameters and operating conditions being the same, the BLIP noise-equivalent difference in temperature (NEDT) of SLS focal plane arrays is intrinsically inversely proportional to the linear size of individual pixels. This conclusion holds even before invoking the traditional argument that smaller pixels entail limited well sizes, hence shorter integration times. In addition to experimental evidence supporting this claim, we also provide the theoretical background to justify the observed property. Strategies intended to circumvent this limitation will be explored.

Keywords: Strained layer superlattice, SLS, Type-II, T2SL, NEDT, focal plane array, FPA

Optics Independent Modulation Transfer Function Measurements of Mid-Wave and Long-Wave Infrared Focal Plane Arrays

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Abstract
Mid-wavelength Infrared (MWIR) and long-wavelength infrared (LWIR) antimonides type-II superlattice (T2SL) based detector arrays were hybridized to 320x256, 640x512 and 1024x1024 pixel format read out integrated circuits. Noise Equivalent Temperature Difference (NEΔT), Quantum Efficiency (η), Dark Current Density (J_D), and Modulation Transfer Function (MTF) performance of these focal plane arrays (FPAs) were measured at various operating temperatures. VGA format MWIR FPAs have given NEΔT of about 20 mK with J_D ~ 1 x10^-7 A/cm^2 and η > 50 % at 115 K operating temperature. VGA format LWIR FPAs have given about NEΔT ~ 30 mK with J_D ~ 2 x10^-5 A/cm^2 and η ~30 % at 60 K operating temperature. Some FPAs were anti-reflective coated and the measured quantum efficiency improved by 23 % in 3-5 μm spectral band for MWIR FPAs and by 10 % in 8-9.4 μm spectral band for LWIR FPAs. A novel direct one-to-one image approach is used in MTF investigations to obtain the line-spread and edge-spread functions. One-to-one imagery is produced by patterned gold films directly deposited on the substrate side of the FPAs. The direct imaged horizontal and vertical MTFs are compared with projected knife-edge edge-spread functions (ESFs) derived MTFs and initial results indicate that direct imaged MTFs are comparable to projected knife-edge ESFs derived MTFs at a Nyquist frequency. However, direct imaged MTF requires no corrections due to optics such as the lens MTF. The only relevant requirement for the direct image MTF is for the deposited pattern and substrate to be extremely thin.
Study of the MTF of a MWIR T2SL focal plane array in IDDCA configuration using Talbot effect

Abstract
Type-II InAs/GaSb superlattice (T2SL) has recently matured into a commercially available technology addressing both MWIR and LWIR spectral domains. As the prerequisites such as Quantum Efficiency (QE) and dark current were met, more advanced figures of merits related to the ElectroOptic (EO) system as a whole can now be studied to position this technology.

In this paper, we focus on modulation transfer function (MTF) measurements. Knowing the MTF of a detector is indeed of primary importance for the EO system designers, since spatial filtering affects the system range. We realized MTF measurements on a 320x256 MWIR T2SL FPA provided by IRNova, using a Continuously Self Imaging Grating (CSIG). The advantage of this experimental configuration is that no high performance projection optics is required thanks to the self-imaging property (known as Talbot effect) to project a pattern with known spatial frequencies on the photodetector. Besides, the pattern being propagation invariant, alignment is easier and the bench not does require exact knowledge of the focal plane distance to operate, opening measurement in Integrated Detector Dewar Cooler Assembly (IDDCA) configuration.

Extracted from measurements, the pixel size is 26µm for a pitch of 30µm.

Keywords: MTF, T2SL, MWIR, FPA, CSIG

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III-V detector technologies at Sofradir: dealing with image quality

Abstract
Since 2013 Sofradir Group integrates III-V detector technologies transferred from its mother companies, Thales and Safran: QWIP, InGaAs and InSb FPAs. These technologies successfully supplement Sofradir’s detector portfolio, with respect to the well implemented HgCdTe photodiode FPAs.

This technological diversity leads to rapid progresses in the understanding of the physics of our detectors, through a quite natural cross-fertilization process. We will illustrate this with an original mixture of results and analyses related to the image quality, the Holy Grail of every detector manufacturer. This polymorphic figure of merit gathers various image characteristics, ranging from Signal to Noise Ratio (SNR), uniformity / operability issues to Residual Fixed Pattern Noise (RFPN), blinking pixels and Modulation Transfer Function (MTF).

Dark current must generally be minimized in order to guarantee a satisfactory image quality. It is very sensitive to the material quality and to the surface passivation (if present). If these two aspects are insufficiently mastered, the temporal stability of the corrected image is degraded. We will illustrate this by comparing results obtained on our QWIP and InSb detectors.

For diffusion limited photodiode arrays in planar configuration the lateral collection length of the minority carriers plays on both dark current and MTF. The optimization of both parameters leads to a compromise, which can be partly relaxed by adjusting other parameters of the structure. We will give insight on these aspects and will also propose a parallel between planar diode FPAs and QWIP FPAs, which are governed by a completely different physics.

III-V detectors, QWIP, InSb, InGaAs, image quality

Keywords MTF, QWIP, InSb, InGaAs

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Presentation Title
III-V detector technologies at Sofradir: dealing with image quality

III-V detectors, QWIP, InSb, InGaAs, image quality

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High Performance Extended-Shortwave Infrared Camera

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Presentation Title
High Performance Extended-Shortwave Infrared Camera

Abstract
Imaging technology in the extended short-wave infrared (eSWIR) wavelength band, encompassing 1.7 to 3.0 μm, has seen little attention compared to the SWIR and MWIR bands despite eSWIR detection benefits. High performance eSWIR detectors have only recently been reported as bridging the gap between SWIR and MWIR detection poses materials challenges including the limited number of available III-V semiconductor substrates and lattice matching constraints. Furthermore, ensuring highest performance detection requires unipolar barrier architectures which demand more complicated heterostructures than conventional photodiodes but offer greatly reduced dark currents and detector noise. In this work, development of eSWIR detectors with cutoff wavelengths between 2.5 and 2.8 μm is discussed. Electrical characterization of molecular beam epitaxy-grown single element detectors suggests high quality, diffusion limited performance. This work culminates in the demonstration of a 640x512, 15μm pixel pitch eSWIR camera thermo-electrically cooled to 200K. Camera design tradeoffs as well as dark current and imaging results are presented.

Keywords: eSWIR, imager, infrared, FPA, unipolar barrier, camera

Ultra-Sensitive and Fast SWIR based on Nano-Photo-Transistors

Hooman Mohseni

Presentation Title
Ultra-Sensitive and Fast SWIR based on Nano-Photo-Transistors

Abstract
Short-wave infrared (SWIR) is an interesting region of the electromagnetic spectrum. It is highly suitable for imaging through biological tissue and the atmosphere, and yet immune from the background thermal photon noise. These properties have led to a rapidly growing interest in the SWIR imaging for exciting new scientific, medical, defense, and consumer applications. In this seminar, I will present our new findings for ultra-sensitive and ultra-fast SWIR cameras.

In particular, I will present a SWIR imager that is based on nano-scale phototransistors inspired by the detection mechanism in the Rod cells in the eye. We are making a very fast, and yet sensitive camera based on this new technology for the direct imaging of Earth-like exoplanets for the first time. This same detector has recently been used in a commercial medical optical tomography system, and achieved ~1000 times higher sensitivity at very low light conditions.

I will also present a new approach to add ultra-fast timing to the SWIR imaging. Using this approach we could achieve a timing accuracy of about 30 picoseconds across the images, which allows us to separate two objects that are only a fraction of centimeter apart from the difference it the time of arrival of the light rays.

Keywords: Infrared Detector, HPT, Focal Plane Array, Time of Flight, LIDAR

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**Presentation Title**

Growth of InGaAs/GaAsSb Type II Superlattice for eSWIR Photodetector using MOCVD

**Abstract**

InGaAs/GaAsSb Type II superlattice (T2SL) is a candidate for an active layer of extended short wave infrared photodetectors (eSWIR). The growth details of thin GaAsSb layer lattice matched to InP using metal organic chemical vapour deposition (MOCVD) was described in [2] and in this study we describe the growth details of 2 μm thick InGaAs/GaAsSb T2SL PN diode with cutoff close to 2.5 μm lattice matched to InP. The layers were grown at 600°C and 400 Torr using MOCVD. Thomas Swann 3x2 inch vertical reactor on N-type InP (100) substrate. TMIn, TMGa, TMSb and TBAs were used as metalorganic sources and DEZn was the P dopant sources. Xray Diffraction measurements, Photoluminescence measurements, Responsivity measurements, were carried out.

**Keywords:** (InGaAs, GaAsSb, SWIR, Photodetector)

**References:**


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**Presentation Title**

Characterization of Depleted In-Device Passivation Layer for InGaAs Photodetectors

**Abstract**

Short Wavelength Infrared (SWIR) detection is desirable for many applications such as night vision, spectroscopy and hyperspectral imaging. In SWIR band, lower dark current is an important requirement to realize high performance at night due to the small amount of photon flux. Indium Gallium Arsenide (InGaAs) is probably the most popular material for especially low cost SWIR implementations. As lower dark current levels have been achieved with planar type pixel structures in comparison with the mesa type structures so far, planar geometry is more common in the literature. However, mesa type pixel arrangement has specific usages in applications such as dual color and avalanche photodetectors. As a result, enhanced performance in mesa type designs will be highly useful. Since the main reason for the relatively high dark current is the surface leakage current due to dangling bonds, a suitable passivation method is needed for the mesa type detectors. Here, an in-device passivation technique that is based on modification of epilayer structure will be discussed in detail. In this design, a fully depleted n-type InP region surrounding InGaAs absorber layer is utilized. As there is no charge to conduct in this thin layer, isolation of pixels in mesa type arrangement is not necessary anymore. A highly doped In0.53Ga0.47As layer lattice matched to InP is also added over this fully depleted layer in order to establish a good ohmic contact.

**Keywords:** SWIR, InGaAs, In-device passivation

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The opportunity in InGaAsN/Al-GaAs quantum wells for SWIR detection

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Abstract

Incorporation of nitrogen (N) atoms into a host matrix of III-V compound semiconductors (as III-arsenides, phosphides and antimonides) leads to a strong interaction between the conduction band of the host material and energetically narrow resonant localized N states. In a framework of the band anti-crossing model (BAC [1]), the interaction between the extended conduction-band states of the matrix material and the localized N states is treated as a perturbation that leads to an eigenvalue problem. Solving the eigenvalue problem results in a split of the unperturbed conduction band of the matrix material into two new bands: a lower energy band E, that determines the reduced fundamental bandgap, and another higher energy band E+ with highly localized nature (around k=0).

The incorporation of N atoms into III-Vs results in new highly-mismatched mixed-alloy structures that are termed "dilute-nitrides" (for III-V-N). The inter-band optical transitions of N-containing InGaAs quantum wells (InGaAsN QWs) were widely explored due to their red-shifted luminescence into the optical communication bands. However, less attention has been given to inter-subband transitions (ISBT) in dilute-nitride QWs and reports on photocurrent studies are even more limited in number.

The band-offset between AlGaAs and InGaAsN is mostly in the conduction band-edge and it increases further with increasing the N content in the lattice. In our work, we have demonstrated values reaching up to approx. ~1 eV while studying the photocurrent of In GaAsN/AlGaAs quantum well infrared photodetectors (QWIPs) [2, 3]. This large conduction band offset makes these QWs suitable for short-wavelengths infrared (SWIR) detection. Here we report on our investigation on the photocurrent signal and dark current noise in InGaAsN/AlGaAs QWIPs that utilize an optical transition from a bound state in the quantum well into a localized E+ state in the continuum that is associated with localized N defect states. The localized E+ state is located far beyond the band-offset and contributes to very high photocurrent gain as a result of its long lifetime [2, 3] and demonstrates very high responsivity >10 A/W at 300 K. The photo detector’s spectral response ranges approximately between 1.1–2.1 μm (Fig. 1).


The incorporation results in a new spectral range where the detector is highly sensitive, which we demonstrate in Fig. 1. The photocurrent signal peaks at ~1.42 μm and demonstrates very high responsivity >10 A/W at 300 K. Photocurrent spectroscopy of inter-subband transitions (ISBT) in dilute-nitride QWs and reports on photocurrent studies are even more limited in number.

Fig. 1: Measured photocurrent (PC) spectral response at 300 K. The PC peaks at ~1.42 μm and demonstrates very high responsivity >10 A/W at 300 K.

Keywords: SWIR, QWIPs and QDIPS, Novel Device Concepts, Novel materials

III-V/II-VI semiconductor distributed Bragg reflectors and resonant cavities for narrow-spectral MWIR LED and photodetector applications

Yong-Hang Zhang
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Cheng-Ying Tsai

Presentation Title

III-V/II-VI semiconductor distributed Bragg reflectors and resonant cavities for narrow-spectral MWIR LED and photodetector applications

Abstract

Distributed Bragg reflector (DBR) mirrors with alternating 1/4 GaSb and ZnTe layers were designed and grown by molecular beam epitaxy (MBE) on GaSb (001) substrates with high reflectance for wavelengths between 2-5 μm. Because of the high refractive index contrast (dn = 1.1 at 3 μm) and close lattice-match (0.13%) of GaSb and ZnTe, critical thickness of the epilayers is large and suitable for DBR of wavelengths exceeding 5 μm. The MBE growths were done in a single-chamber system equipped with group-III, V, II, and VI element effusion cells to enable monolithic integration of GaSb and ZnTe layers into DBR structures and eventually resonant-cavity structures for narrow spectral Lateral and Vertical Transport in n- and p-type InAsSb and InAs/InAsSb Type-II Strained Layer Superlattices for Infrared Detector Applications and photodetectors. The reflectance of demonstrated DBRs have reached over 99% and the stop-band is increased by over 60% with layers approximately 60% thinner than the conventional GaSb/AlGaAs DBRs. High-resolution x-ray diffraction measurements reveal sharp peaks, indicating smooth heterovalent interfaces and a low density of structural defects in the epilayers. These DBRs and resonant cavities are ready for the integration with active regions such as InAsSb alloys or InAs/InAsSb type-II superlattice for resonant-cavity LEDs and photodetectors with narrow emission or response spectra.

Keywords: MBE, Heterovalent, GaSb, ZnTe, resonant-cavity, Bragg reflector

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Presentation Title
nBn Detector Designs Based on Delta Doping and Compositional Grading

Abstract
In recent studies, it has been shown that nBn type detectors can suppress Shockley-Read-Hall (SRH), trap assisted tunneling (TAT), band to band tunneling (BtBT) and surface leakage dark current mechanisms. In these detector designs, there should theoretically be no band bending under zero bias. Therefore, barrier material must be correctly chosen for blocking majority carrier and allow minority carriers to reach contacts. However, there are material restrictions and suitable barrier material may not be found for all kind of detector types leading to a valence band offset problem. Achieving zero valence band offset is the key point in order to collect photogenerated holes from the contact layer. Here, a variety of nBn type detectors including dual band implementations will be discussed. Proposed structures are constructed by removing the valence band discontinuity with the utilization of delta doping layers. It is demonstrated that nBn detectors are realizable with using high band gap undoped ternary compound materials as the barrier. The barrier is constructed by compositional grading from low bandgap absorber and contact layers. In this design, normally conduction and valence band barrier are expected to coexist meaning that majority and minority carriers are blocked simultaneously. However, if two pairs of opposite delta doped layers are placed both sides of graded layers, valence band discontinuity is shown to be eliminated by suppressing the quasi electric field created by graded layers. This technique can be applied on all the compositional gradable materials.

Keywords: Barrier detectors, dual band detectors

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Presentation Title
Self-Formed Nanojunctions for Localized Plasmonic IR Detection

Abstract
Localized Plasmonic Resonance has recently been extensively studied due to its prominent advantages: (1) confinement of the electromagnetic field, down to the nanometric scale, (2) a large field enhancement and (3) the ability to tune the resonant wavelength by controlling the geometry of the nanostructure. Combining core-shell nanostructures with a dielectric core and a metal shell enables to shift the resonance to the NIR regime.

In my talk, I will present a fabrication method for a self-formed electrical nanojunction based on unique GeSi (20:1) nanowires (NW) with a gold nanoshell cap, grown at selective locations, that can form nanojunctions. The active junction is located between the gold cap of the modified NW and a metallic counter electrode with a very small contact area owing to the geometry of the unique nanowires. The fabrication process is robust, using simple lithographic methods which enables facile scalability, and allows large-scale assembly of detector arrays.

Depending on the exact shape and size of the Au/GeOx/Ge core-shell nanostructure an electrical response was observed in the NIR regime with wavelength cut-off of 2500 nm. The electrical response of the device is due to field effect, caused by the localized field of the plasmon. In addition, the existence of hot spots, generated by the irregular shape of the NW Au cap, allows for interaction with adsorbed molecules, thus enabling detection of a Surface-Enhanced Raman Spectroscopy (SERS) signal.

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Self-Consistent Theory for Stimulated Transitions and DC-Field Driven e-h Plasma: Application to Photodetectors

Abstract

A self-consistent theory is developed for studying the strong interaction between the photo-excited electron-hole (e-h) plasma and the stimulated transitions due to absorption of an ultrashort light pulse incident on quantum wires, including ultrafast energy relaxation of hot carriers. Meanwhile, the e-h plasma is driven in momentum space by an applied DC electric field along the wires which is associated with a resistive force for momentum relaxation of drifting carriers due to intrinsic phonon and coulomb scatterings in undoped quantum wires. The applied DC field significantly modifies an optically-induced transverse polarization field, resulting from e-h plasma interacting directly with the propagating light pulse, through a localized longitudinal electromagnetic-field component. This strong-coupling theory facilitates a correlation between the local electronic response of quantum wires and the distant spatial-temporal distributions of the propagating light pulse. Moreover, this self-consistent theory reveals another correlation between the DC current from the driven e-h plasma and the localized longitudinal electromagnetic-field component due to long-lasting plasmon oscillations excited in quantum wires.
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