Mid-IR Optoelectronics: Materials and Devices
Room Lecture Hall, Nielsen Hall - Session MIOMD-ThM1

Detectors I

Moderator: **Robert Weih**, nanoplus Advanced Photonics Gerbrunn GmbH, Germany

8:20am **MIOMD-ThM1-1 Progress in Antimonide Unipolar Barrier Infrared Detectors**, ***David Ting**, S. Rafol, C. Hill, A. Khoshakhlagh, B. Pepper, A. Soibel, A. Fisher, S. Keo, Y. Maruyama, t. wenger, S. Gunapala,* NASA Jet Propulsion Laboratory **INVITED**

The unipolar barrier device architecture introduced by the nBn [1] and XBn [2] has led to significantly improved performance in III-V semiconductor infrared detectors. In particular,the combination of the unipolar barrier device architecture and antimonide absorbers, including the InAsSb and the GaInAsSb bulk alloys, the InAs/GaSb type-II superlattice (T2SL), and the InAs/InAsSbtype-II strained-layer superlattice (T2SLS), has enabled a new generation of high-performance infrared detectors that can provide continuous cutoff wavelengths coverage in the short-, mid-, and long-wavelength range. Notably, focal plane arrays (FPAs) based on the mid-wavelength Ga-free InAs/InAsSb T2SLS unipolar barrier infrared detector have demonstrated a 40 – 50 K higher operating temperature than the InSb FPA, while retaining the same III-V semiconductor manufacturability and affordability benefits [3]. We will provide an overview of the progress and challenges [4] in the development of antimonide unipolar barrier infrared detectors, as well as some of their applications for NASA infrared spectral imaging needs.

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

[1] S. Maimon and G. W. Wicks, *Appl. Phys. Lett*. **89**(15), 151109 (2006).

[2] P. C. Klipstein, *Proc. SPIE***6940**, 6940–2U (2008).

[3] D. Z. Ting, A. Soibel, A. Khoshakhlagh, S. B. Rafol, S. A. Keo, L. Höglund, A. M. Fisher, E. M. Luong, and S. D. Gunapala, *Appl. Phys. Lett*. **113**, 021101 (2018).

[4] D. Z. Ting, A. Khoshakhlagh, A. Soibel, and S. D. Gunapala, *J. Elec Materi***49**, 6936 (2020).

8:50am **MIOMD-ThM1-4 MWIR Resonant Cavity Infrared Detectors (RCIDs) with High Quantum Efficiency and High Frequency Response**, *C. Canedy, E. Jackson, R. Espinola, C. Kim, E. Aifer, I. Vurgaftman,* Naval Research Laboratory*; V. Jayaraman, B. Kolasa,* Praevium Research*; R. Marsland, B. Knipfer,* Intraband, LLC*; M. Turville-Heitz, J. Ryu, L. Mawst, D. Botez,* University of Wisconsin*; **Jerry Meyer**,* Naval Research Laboratory

NRL recently demonstrated the first MWIR resonant cavity IR detectors (RCIDs) to exhibit high performance [1]. At resonance wavelength λ_{res} = 4.0 µm, devices with a grown GaSb/AlAsSb bottom mirror, dielectric top mirror, and absorber thickness of only 50 nm attained external quantum efficiency EQE = 34%, with linewidth 46 nm. U. Lancaster subsequently reported RCIDs with InAs absorber displaying λ_{res}» 3.3 mm and 52% EQE [2].

Here we report devices for which an *nBn* detector chip with 20 InAs/InAsSb active quantum wells and total absorber thickness 103 nm was bonded to a GaAs/AlGaAs mirror with reflectivity > 99%. The GaSb substrate was then removed, and mesas processed from the backside of the as-grown detector epitaxy. The RCID's very thin absorber allows rapid extraction of the photoexcited carriers for high frequency response. For a device with small diameter (d = 21 µm) for reduced capacitance, the optical heterodyne data illustrated in Fig. 1 (taken before the top dielectric mirror was deposited) confirm a 3dB response of 5.9 GHz. The EQE spectrum for a larger RCID (d =105 µm) was measured with an FTIR by fitting the ratio of photocurrent to measured blackbody flux through a calibrated narrowband filter (blue curve in Fig. 2). This yielded peak EQE =57% at λ_{res}= 4.618 µm,with FWHM = 31 nm. EQEs for the same device were also characterized from the photocurrent induced by excitation from a quantum cascade laser (QCL) with calibrated incident power, in independent measurements at NRL (blue points) and Intraband, LLC (red points).

9:10am **MIOMD-ThM1-6 Growth and Development of Antimony-Based III-V Detector Materials for the Regime from eSWIR to LWIR**, ***Volker Daumer**, L. Kirste, R. Müller, J. Niemasz, M. Wobrock, A. Wörl, Q. Yang, R. Rehm,* Fraunhofer Institute for Applied Solid State Physics IAF, Germany

The family of the 6.1 Å-materials (InAs, GaSb, AlSb), their ternary and quaternary alloys, and the corresponding type-II superlattices (T2SLs) permit wavelength tuning over a wide spectral range in the infrared (IR). The flexibility in detector design that these materials provide, allows for sophisticated device concepts and high-performance bandgap engineered IR technology for various applications. Grown lattice matched on GaSb substrate by molecular beam epitaxy (MBE), these materials can be combined to address the requested requirements. At Fraunhofer IAF, we utilize these materials to develop IR detectors and arrays for the extended shortwave infrared (eSWIR), the mid-wavelength infrared (MWIR), the long-wavelength infrared (LWIR) and combinations thereof. For the eSWIR region from 1.7 up to 3.0 µm, where InGaAs on InP substrates suffers from a high dislocation density resulting in limited performance, InGaAsSb on GaSb is currently

under investigation for room temperature operation employing a heterojunction approach. This talk will report on fundamental material study as well as electro-optical characterization results of heterojunction diodes. For the thermal infrared in the range from 3 up to 12 µm covering MWIR to LWIR, T2SLs based on InAs/GaSb and InAs/InAsSb are developed. The activities range from basic studies up to pilot line production with detectors at TRL9. Recent advances aiming at high operating temperatures (HOT) for MWIR, enhanced quantum efficiency for LWIR and extended sensitivity combining MWIR and LWIR diodes will be presented.

9:30am **MIOMD-ThM1-8 Optically-Addressed Monolithically-Integrated Triple-Band Photodetectors Using Type-II Superlattice Materials**, *Z. Ju, **Allison McMinn**, X. Qi,* Arizona State University*; S. Schaefer,* National Renewable Energy Laboratory*; T. McCarthy, Y. Zhang,* Arizona State University

Multiband photodetectors are desired in various applications, including thermal imaging, environmental resources surveying, and chemical sensing. When implementing multiband photodetectors into an FPA, reducing the number of terminals on the photodetector is necessary since an increase in terminal count reduces the detector's active area and complicates ROIC and FPA layout and device processing [1]. This talk reports the demonstration of two-terminal multiband monolithically integrated optically addressed photodetectors using InAs/InAsSb type-II superlattice (T2SL) to cover SWIR, MWIR, and LWIR, as shown by the device structure in Figure 1.

The operating principle of the optical-addressing design is to use multiple optical biases on a stack of photodiodes (PDs) connected in series to switch detection bands, as shown in Figure 1 schematically. The detecting PD becomes the current-limiting device and determines the spectral response. Our preliminary results show that the MBE-grown InAs/InAsSb T2SLs as MWIR and LWIR photodetectors are nearly perfectly strain-balanced onto GaSb, showing distinct satellite peaks and a perfect overlap of the 0 order SL peak with the substrate peak, as plotted in Figure 2. Additionally, an analytical model has been established to analyze the noise characteristics and cross-talk between bands of the optically-addressed multiband detectors.

[1] E. H. Steenbergen, Appl. Phys. Lett. **97**, 161111-161114 (2010).

9:50am **MIOMD-ThM1-10 Optimizing the Design of Type-II InAs/InAsSb Superlattices for the Incorporation of Unintentional Sb in the Tensile Electron Well**, ***Marko Milosavljevic**,* Arizona State University*; P. Webster,* Air Force Research Laboratory, USA*; S. Johnson,* Arizona State University

Several strain-balanced 5.3 µm midwave and 12.0 µm longwave InAs/InAsSb superlattices are grown on (100) GaSb substrates by molecular beam epitaxy and examined using X-ray diffraction and temperature-dependent photoluminescence. A significant amount of surface Sb incorporates into the tensile InAs layer that subsequently affects the design and performance. For a given wavelength design the presence of unintentional Sb in the InAs layer i) increases the tensile electron well thickness, thereby increasing electron confinement and decreasing electron wavefunction intensity, ii) decreases hole well depth, thereby decreasing hole well width and hole confinement, and as a result iii) decreases the absorption coefficient by 8% for midwave and 11% for longwave. This is presented in Figure 1 in terms of total wavefunction overlap and that within the tensile and compressive layers for structures with and without unintentional Sb as a function of the compressive layer Sb mole fraction. The solid curves show the case with unintentional Sb and the dashed curves show the case without unintentional Sb, with the compressive layer in red, the tensile layer in black, and the total (sum of red and black) in blue. The values for the grown superlattices are shown as open circles. The measurements and calculations are for an operating temperature of 77 K.

The grown superlattice tetragonal distortion ranges from -0.019% to 0.020% with a -0.001% average for midwave and from 0.021% to 0.039% with a 0.027% average for longwave. A combination of X-ray diffraction and photoluminescence is utilized to determine that the unintentional Sb mole fraction in the tensile layer is 1.9% for midwave and 1.2% for longwave.

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