Workshop on Epitaxial Growth of Infrared Materials
Room Cummings Ballroom - Session WEG-SaM

Workshop on Epitaxial Growth of Infrared Materials: Industry Perspectives

Moderator: Chadwick Canedy, Naval Research Laboratory

9:45am **WEG-SaM-1 Welcome & Sponsor Thank Yous***,*

10:00am **WEG-SaM-2 Antimonide-based Infrared Materials: Needs, Challenges and Recent Progress***, **Minh Nguyen**,* HRL Laboratories **INVITED**

Antimonide-based III-V semiconductors form an unique group of narrow bandgap materials as they are relatively mature to yield high-quality devices and are fab-compatible at industry foundries, yet still have many unanswered fundamental and scientific questions to investigate. Their small energy gap (<0.3 eV) corresponds to optical transitions in the infrared and terahertz regime which have tremendous potential in applications such as detectors, lasers, photovoltaic cells, spectroscopy, etc. In parallel, these narrow-gap compound semiconductors, comprised of large constituent atoms with intrinsically large spin orbit coupling, offer a great deal of advantages in semiconductor-based qubit technologies and spintronics.

In the field of infrared detection and imaging, antimonide-based materials have emerged as a serious alternative to the incumbent state-of-the-art Mercury Cadmium Telluride due to its superior "–ility" advantages: uniformity, stability, scalability, manufacturability, affordability. Another key advantage of this technology is the ability to leverage III-V foundries for material growth and device fabrication, which allow for rapid development of this small but diverse ecosystem. In this talk, we will provide an overview of recent progress, needs and challenges of infrared detector technology, from an industrial point of view.

10:30am **WEG-SaM-4 MBE Growth of GaSb- and InP-based Infrared Epitaxial Structures at IQE***, **Amy Liu**, J. Fastenau, D. Lubyshev, S. Nelson, M. Fetters, S. Cramb, W. Black,* IQE Inc. **INVITED**

The GaSb-based family of materials and heterostructures provides rich bandgap engineering possibilities for myriad infrared (IR) applications, and molecular beam epitaxy (MBE) is the primary growth technology for this material system.[1-4]There has been tremendous progress in GaSb-based IR photodetector (Sb-IRPD) technology in the last 10 years, and the transition from research and development to volume manufacturing is well underway with adoption of this technology by several US DoD programs of record and for many other commercial and defense applications.[4,5]

The MBE process for Sb-IRPD structures we originally developed on 2" diameter substrates using a research tool has been transferred to large-volume, multi–wafer production platforms, with 4" and 5" wafers now the industry standard for IR focal-plane array (FPA) applications.[6-9] The increase in production volume has also enabled us to apply statistical process control techniques to improve command over critical parameters, and thereby improve the yield and throughput of our MBE process. The robustness of our epitaxial process is further proven by the ability to not only readily reproduce Sb-IRPD material characteristics across multiple tools at the same production site, but across multiple tools at different production sites.[7]

There is also growing interest recently in exploring the metamorphic growth of Sb–IRPD structures on non-native, large-diameter substrates for large–format FPA and radiation-hard applications. We have demonstrated the feasibility of growing mid–wave Sb-IRPD structures on ≥6" GaAs, Ge and Si substrates.[8]

In this work, we will provide an update on the status of our Sb-IRPD epiwafer production with different absorber designs and on different substrates. Representative material characterization and large-area diode test data will be discussed.

In additional to IR detector structures, we also support development and production of IR emitter structures.[9] We will briefly discuss our MBE efforts for growing GaSb-based interband cascade laser and InP-based quantum cascade laser structures.

1. D. L. Smith and C. Mailhiot, J. Appl. Phys. **62**, 2545–2548 (1987).
2. S. Maimon and G. W. Wicks, Appl. Phys. Lett. **89**, 151109 (2006).
3. A. Soibel *et al*., App. Phys. Letts. **105**, 023512 (2014).
4. P. C. Klipstein *et al*., Proc. SPIE **12107**, 121070Q (2022).
5. D. A. Reago, SPIE DCS Conf., Orlando, FL, 2021, 11741-403.
6. D. Lubyshev *et al*., Proc. SPIE **7660**, 76601J (2010).
7. J. M. Fastenau *et al*., Proc. SPIE **12107**, 121070Z (2022).
8. J. M. Fastenau *et al*., J. Vac. Sci. Technol. B, **37**, 031216 (2019).
9. A. W. K. Liu *et al*., Proc. SPIE **PC12009**, PC120091 (2022).

11:00am **WEG-SaM-6 MBE HgCdTe: The Material Leading to High Performance Infrared Imaging Sensors***, **Aristo Yulius**,* Teledyne Imaging Sensors **INVITED**

Teledyne Imaging Sensors (TIS) is the leading supplier of Infrared Imaging Sensors for high performance applications, producing arrays with the lowest reported dark currents and near unity quantum efficiency over a broad range of cutoff wavelengths and operating temperatures. TIS infrared focal plane arrays are used for both ground- and space-based astronomy applications, including high profile missions like the Hubble Space Telescope (HST), the James Webb Space Telescope (JWST), and the Euclid Space Telescope to investigate the Dark Matter and Dark Energy. TIS HgCdTe device architecture is based on Molecular Beam Epitaxy (MBE)-grown HgCdTe grown on near lattice-matched bulk CdZnTe substrates.

TIS presents an overview of the HgCdTe detector technology by MBE. MBE is the ideal epitaxial growth method to achieve high performance HgCdTe epi-layers. MBE HgCdTe is grown on (211)B-oriented bulk CdZnTe substrates. The primary surface defects that are observed during MBE growth of HgCdTe are addressed. The limitations of CdZnTe substrate are examined. The quality of MBE-grown HgCdTe ultimately depends on the quality of the starting CdZnTe substrate. The properties of CdZnTe substrate such as Te precipitate size and density, Etch Pit Density (EPD), p-type impurity such as copper, and the Zn concentration and its uniformity across the substrate play significant roles in determining the characteristics of HgCdTe. The purity along with the quality of the starting substrate is also critical for "ultra-low" doping control during MBE growth of HgCdTe. The composition and "bandgap engineering" controls of MBE-grown HgCdTe are discussed. TIS backside-illuminated p-on-n device architecture is described, including discussion of the TIS activation and vacancy filling anneal of implanted HgCdTe devices. Similarly, TIS' CdZnTe substrate removal process to extend the wavelength range of the spectral response from the infrared to the ultraviolet (UV) is shown. TIS infrared detector performance is reviewed, including discussion of the widely recognized "Rule 07" dark current Figure of Merit (FOM) and update to "Rule 07" ("Rule 22"). Examples of TIS infrared detector imagery are presented.

11:30am **WEG-SaM-8 Status of Production MBE Capabilities for Infrared Applications at IntelliEPI***, **Paul Pinsukanjana**, J. Li, E. Fraser, J. Shao, S. Hill, M. Debnath, J. Middlebrooks, C. Chen, W. Li, K. Vargason, P. Chin, Y. Kao,* Intelligent Epitaxy Technology, Inc. **INVITED**

To support the growing needs for high-performance infrared (IR) epitaxy materials, IntelliEPI has established production MBE capabilities to produce advanced III-V epi wafers based on GaAs, InP and GaSb material systems. Some of the optoelectronic applications include Focal Plane Array (FPA) for IR imaging; APD for telecom/datacom & automotive LIDAR; Laser & LED for gas sensing; and components for SOA, EAM and detector for high-speed optical fiber network. Strategy/philosophy of how IntelliEPI approaches setting up production MBE for commercial manufacturing will be discussed.

Author Index

Bold page numbers indicate presenter