Workshop on Epitaxial Growth of Infrared Materials
Room Cummings Lobby - Session WEG-SaP

Workshop on Epitaxial Growth of Infrared Materials Poster Session

WEG-SaP-1 Thermoradiative Diodes: A Novel Application of Mid-Infrared Materials*, **Stephen Bremner**, M. Zlatinov, M. Nielsen, M. Sazzad, P. Reece, N. Ekin-Daukes,* UNSW Sydney, Australia

Photovoltaic (PV) power generation is a familiar and important process that exploits a large temperature difference between a source (the sun) and a converter (a solar cell) in order to produce electrical power [1]. There is, however, a not so well-known symmetric counterpart to the photovoltaic process, in which a warm converter radiates light to a cold environment, enabling the generation of electrical power [2,3]. Thermodynamic analysis in the radiative limit (only radiative recombination present) reveals that power densities of 54.8 W/m^2 and more [4], offering applications in waste heat recovery [5] and terrestrial night sky power generation [6]. Whilst the concept of thermoradiative power generation has been proven [7] in HgCdTe photodiodes, the generated power is orders lower than theoretical limits. This is due to non-radiative recombination processes like Auger and SRH recombination/generation. So high radiative efficiencies is a critical requirement to unlock the potential of thermoradiative power generation. The first goal aligns well with research in mid-infrared photodetectors and light emitting diodes, where such non-radiative processes are also detrimental to performance, leading to materials development and numerous design approaches to mitigate their impact [8].

Related to the ability to generate thermoradiative power is the presence of so-called negative luminescence [9], a process in which the application of a reverse bias sees net radiative emission drop below that for thermal equilibrium. Negative luminescence is an indicator of being able to generate thermoradiative power, so the search for TRD materials can build on previous work on negative luminescence in III-V materials systems such as InAs/GaSb [10]. The final presentation will discuss thermoradiative power generation and the requirements of materials for thermoradiatvie diodes (TRDs), building on previous work on mid-infrared materials. This search will be focused on III-V materials, but the requirements would drive a search in any materials system.

[1] De Vos et al., J. Appl. Phys., 74(6), 3631-3637, 1993.

[2] S. J. Byrnes et al., Proc. Natl. Acad. Sci. USA,

vol. 111, 3927, 2014.

[3] R. Strandberg, J. Appl. Phys., 118, 215102, 2015.

[4] S. Buddhiraju et al., Proc. Natl. Acad. Sci. USA, vol. 115, E3609, 2018.

[5] J. Wang et al., AIAA Propuls. Energy Forum Expo., 3977, 2019.

[6] E. J. Tervo et al., Cell Reports Phys. Sci., 1, 100258, 2020.

[7] A. Rogalski, Sensors, 20,7047, 2020. [8] M. P. Nielsen et al., ACS Photonics, 9(5), 1535-1540, 2022.

[9] T. Ashley et al., Infrared Phys. Technol., 38, 145-151,1997.

[10] L. J. Olafsen et al., Appl. Phys. Lett., 74, 2681-2683, 1999.

WEG-SaP-2 Low-temperature Epitaxial Growth of ZnTe and CdTe for Passivation of MWIR and LWIR Detectors*, **Oleg Maksimov**, H. Bhandari,* Radiation Monitoring Devices

Surface leakage current is one of the main factors limiting the performance of mid-wave infrared and long-wave infrared (MWIR and LWIR) $Hg_xCd_{1-x}Te$ and InAs/GaSb focal plane arrays (FPAs). A stable surface passivation layer is needed to overcome this problem. II-VI semiconductors, such as CdTe and ZnTe, are particularly promising due to the wide bandgap and close lattice match to the underlying structure. These are usually epitaxially grown by Molecular Beam Epitaxy (MBE) at 250 ^{o}C or higher e [1, 2, 3]. Unfortunately, high growth temperature can cause Hg diffusion in $Hg_xCd_{1-x}Te$ and Zn diffusion into InAs/GaSb degrading device performance.

Here, we report on the use of Atomic Layer Deposition (ALD) to grow ZnTe and CdTe at temperatures as low as 85 ˚C. Epitaxial growth is achieved at closely lattice-matched substrates, such as GaSb and InAs. In addition, unlike MBE, ALD allows to grow CdTe and ZnTe conformally, as was established at Si wafers with the trenches with aspect ratio as high as 10:1. This should significantly improve passivation and encapsulation of pixelated surfaces of FPAs.

[1] Zhang, J., Westerhout, R. J., Tsen, G. K. O., Antoszewski, J., Yang, Y., Dell, J. M., & Faraone, L. (2008, July). Sidewall effects of MBE grown CdTe for MWIR HgCdTe photoconductors. In *2008 COMMAD* (pp. 82-85). IEEE.

[2] Plis, E., Kutty, M. N., Myers, S., Krishna, S., Chen, C., & Phillips, J. D. (2014, June). Passivation of long-wave infrared InAs/GaSb superlattice detectors with epitaxially grown ZnTe. In *Infrared Technol. Appl. XL* (Vol. 9070, pp. 289-296). SPIE.

[3] Haakenaasen, R., Selvig, E., Heier, A. C., Lorentzen, T., & Trosdahl-Iversen, L. (2019). Improved passivation effect due to controlled smoothing of the CdTe-HgCdTe interface gradient by thermal annealing. *J. Electron. Mater.*, *48*(10), 6099-6107.

WEG-SaP-3 CdTe/InSb(211) Virtual Substrates for IR Detector Application*, **Tyler McCarthy**, Z. Ju, A. McMinn,* Arizona State University*; R. Kodama, F. Aqariden, P. Liao, P. Mitra,* Leonardo DRS*; Y. zhang,* Arizona State University

CdTe as a virtual substrate for HgCdTe IR detectors are grown by MBE on InSb(211) substrates. The advantages of such a virtual substrate to those grown on Si(211) or bulk CdZnTe substrates are: i) large, low-cost (compared to CdZnTe) substrate up to 6” available for detector arrays; ii) improved crystal quality and low In out-diffusion in CdTe layers grown on lattice-matched InSb substrates; iii) expected improved crystal quality in HgCdTe (compared to HgCdTe/CdTe/Si) and thus low dark current in IR detectors. The MBE growth of CdTe traditionally is done under Te-rich condition by employing a compound CdTe effusion cell and a supplementary Te cell. This work uses separate Te and Cd cells to achieve high-quality CdTe films grown under Cd-rich conditions, and compares different conditions for growth of CdTe on (100) and (211)B InSb substrates. Further Cd-rich CdTe(211) results will be discussed at the workshop.

Our experimental study has revealed the following: i) a Te soak of the InSb surface results in poor CdTe epilayer crystalline quality, indicated by an XRD linewidth above 100 arcsec; ii) SIMS analysis showed there was a high amount of out-diffused In present throughout the CdTe epilayer grown on InSb under Te-rich conditions; iii) in contrast, the In out-diffusion is quickly suppressed to below SIMS detection limit within the first 100 nm CdTe grown on InSb substrate by utilizing a Cd soak of the InSb surface prior to the initiation of Cd-rich growth. Up to 3 µm thick CdTe layers were successfully grown on InSb(211)B with: twin-free, streaky RHEED pattern; low haze; surface defect densities below 0.3 and 5 cm^{-2} for macro defects larger than 100 and 50 µm, respectively; and an XRD rocking curve linewidth below 30 arcsec.

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