NAMBE
Room Tamaya ABC - Session NAMBE2-TuA
Low Dimensional Nanostructures
Moderator: Kunal Mukherjee, Stanford University

3:30pm **NAMBE2-TuA-9 Optical and Structural Investigations of Antimonide-Exposed InAs/GaAs Quantum Dots in an InGaAs Quantum Well Matrix for 1380 nm Photoluminescent Emission**, ***Bhavya Kondapavuluri**, Kai-Yang Hsu, Pin-Chih Liu,* Yuan Ze University, Taiwan; *Wei-Sheng Liu,* Yuan Ye University, Taiwan; *Ba Laji,* Yuan Ze University, Taiwan; *Jen-Inn Chyi,* National Central University, Taiwan

The increasing demand for high-speed optical communication has driven research beyond the conventional C (1530–1565 nm) and L (1565–1625 nm) bands, focusing on photon sources that emit in the O (1260–1360 nm), E (1360–1460 nm), and S (1460–1530 nm) bands, which remain compatible with existing optical infrastructure. Concurrently, advancements in facial recognition technology necessitate cost-effective and efficient photon sources operating at wavelengths of 1380 nm and beyond, ensuring enhanced safety for human-eye interactions. To address these technological needs, we investigate the extension of quantum dot (QD) emission wavelengths on GaAs substrates, which offer superior structural robustness and a more cost-effective alternative to InP-based vertical cavity surface-emitting lasers (VCSELs). In this study, high-quality InAs/InGaAs quantum dot-in-a-well (DWELL) heterostructures were fabricated using molecular beam epitaxy (MBE), achieving room-temperature photoluminescence (PL) emission at 1380 nm. The incorporation of an $\mathbf{In_xGa_{1-x}As}$ matrix (x = 14%) facilitated strain relaxation, enhancing In adatom surface diffusion and leading to the formation of QDs with an average diameter of 50 nm and a height of 7.6 nm. These uniform QDs exhibited a strong PL emission at 1310 nm with a narrow full width at half maximum (FWHM) of 29 meV.

To further redshift the emission wavelength, a 15-second antimony (Sb) exposure was applied immediately after QD deposition, leveraging its surfactant effect. This treatment promoted QD ripening, increasing the average QD diameter to 70 nm and the height to 8.2 nm, while reducing dot density. The structural enlargement is attributed to the alleviation of elastic strain, supported by the InGaAs strain-balancing layer, which facilitated Sb incorporation into the QD top layer. As a result, the emission wavelength was successfully extended to 1380 nm. However, the Sb surfactant effect also introduced inhomogeneous broadening, increasing the FWHM to 33 meV.

Temperature-dependent PL analysis revealed that Sb exposure induced bandgap shrinkage and enhanced hole confinement, as evidenced by an increase in activation energy from 254 meV (untreated QDs) to 294 meV. Power-dependent PL measurements further confirmed the retention of type-I band alignment following Sb exposure. However, excessive Sb soaking (25 seconds) led to degraded optical properties and reduced QD uniformity.

These findings provide crucial insights into optimizing Sb exposure for InAs DWELL heterostructures grown on GaAs, advancing the development of long-wavelength photon sources for next-generation optoelectronic applications.

3:45pm **NAMBE2-TuA-10 Low Temperature Growth of Ultra-Thin CdSe/ZnSe Quantum Wells**, *Yang A. Vázquez-Soto, Jorge Pérez-Saavedra, Frantisek Sutara,* ***Isaac Hernández-Calderón,*** CINVESTAV, Mexico

CdSe has demonstrated great capabilities for the elaboration of light emitting nanostructures such as quantum dots and ultra-thin quantum wells (UTQWs). In fully strained CdSe/ZnSe ultra-thin quantum wells grown on GaAs (001) substrates CdSe is under large biaxial compressive stress resulting in a critical thickness of around 3.5 monolayers (MLs). We grow the CdSe by means of atomic layer epitaxy (ALE). During each Cd-Se ALE cycle a nominal coverage of 0.5 ML is obtained due to the surface reconstruction properties of Cd. We have observed that in the 260 – 290 °C range higher substrate temperatures (T_s) produce a lower Cd content of the UTQWs, as indicated by the blue-shifted UTQW excitonic emission [1]. This is attributed to the thermally activated substitution of Cd atoms by Zn during the first stages of ZnSe growth on top of the CdSe layer due to the chemical interaction of Zn atoms with underlaying Cd atoms which are removed from the UTQW layer and reevaporated or mixed with the Zn atoms of the growing ZnSe barrier. Then, the resulting Cd content of the UTQW is slightly lower than 100%. One could expect that lowering T_s below 260 °C will allow us to reach 100% Cd content quantum well layers, which would be evident by the red shift of the excitonic emission as the Cd content increases. With the purpose of investigating the structural and excitonic properties of CdSe UTQWs grown at lower temperatures we elaborated heterostructures containing nominally 1 and 3 ML CdSe UTQWs at T_s = 230 and 250 °C. Deoxidized GaAs(001) semi-insulating substrates covered by a 500 nm thick buffer layer of ZnSe grown by molecular beam epitaxy at 275 °C were employed for the growth. After the ZnSe buffer layer was finished, a careful procedure was used to set the desired T_s. We obtained photoluminescence spectra using a typical setup with an HeCd laser as excitation. The low and room temperature excitonic spectra of the heterostructures showed larger than expected red shifts and broadening of the peaks and reduced excitonic emissions. These results strongly suggest that, besides the Cd content increase, the low T_s produce significant roughness of the CdSe layers due to reduced surface diffusion and the characteristics of the growth mode. The observed exciton emission energies are compared with theoretical calculations considering several configurations of the QW roughness.

1. I. Hernández-Calderón, J.C. Salcedo Reyes, A. Alfaro-Martínez, M. García Rocha, Microelectronics J. 36, 985 (2005).

4:00pm **NAMBE2-TuA-11 Spatial and Spectral Control Over MBE Grown InAs/GaAs Quantum Dots for Device Platforms**, ***Nazifa Tasnim Arony,*** University of Delaware; *Lauren N. McCabe,* University of Delaware (Now working at Yale University); *Joshya Rajagopal, Lan Mai, Lottie Murray, Prashant Ramesh, Matthew Doty, Joshua Zide,* University of Delaware

Over the past few decades, InAs quantum dots (QDs) grown epitaxially on GaAs substrates have attracted significant attention due to their promising applications as single-photon emitters and as potential qubits. Additionally, the compatibility of GaAs platform with existing semiconductor manufacturing techniques offers a path toward building practical, large-scale quantum devices with applications in quantum sensing, computing and information processing. To create fully functional epitaxial quantum devices, it is essential to achieve uniformity in spatial, spectral, and structural properties, along with ensuring scalability. Recent work from our group has shown a method for site-controlled QD growth, where InAs/GaAs QDs are grown on nanofabricated substrates containing site-templated arrays of nano-pits. [1] Despite these advancements, one of the major challenges is maintaining high-quality optical emission from these QDs, as impurities introduced during the fabrication processes can affect their performance. In this work, we investigate the use of quantum dot columns (QDCs) as a buffer layer for the topmost QD arrays. This approach helps "bury" defects beneath the QDCs, effectively improving the optical quality of the QDs. Additionally, we present initial photoluminescence (PL) data demonstrating the spectral control of InAs/GaAs QDs using the 'cap and flush' technique, which further explores the possibility of tuning the emission properties of these quantum dots.

[1] J. Vac. Sci. Technol. B 38, 022803 (2020)

4:15pm **NAMBE2-TuA-12 2D-Assisted Nanoscale Nucleation for Selective III-V on Silicon Heteroepitaxy**, ***Corey White,*** University of Illinois Urbana-Champaign; *Yiteng Wang,* University of Illinois at Urbana-Champaign; *Archishman Saha, Soo Ho Choi,* University of Illinois Urbana-Champaign; *Kuangye Lu, Ne Myo Han,* Massachusetts Institute of Technology; *Ze-Wei Chen,* University of Illinois Urbana-Champaign; *Doa Kwon, Jeehwan Kim,* Massachusetts Institute of Technology; *Hyunseok Kim,* University of Illinois at Urbana-Champaign; *Minjoo Larry Lee,* University of Illinois Urbana-Champaign

Selective area growth (SAG) presents an opportunity to monolithically integrate dissimilar materials during growth. Historically, SAG has relied only on conventional dielectric mask materials,[1,2] ultimately limiting the potential of the technique. Recently, two-dimensional (2D) masks, which are ultra-thin, flexible, and possess "slippery" sp^2 bonds, have been employed in SAG by both MOCVD[3] and MBE.[4] Such masks have the potential to enable long adatom diffusion lengths and reduced dislocations in lattice mismatched III-V heteroepitaxy. By applying this growth technique to III-V on Si heteroepitaxy, we predict the formation of dislocations and anti-phase boundaries can be mitigated due to the strain-accommodating nature of graphene. Here, we present the first selective MBE-nucleation of templated GaAs and GaP grown in nanoscale openings in an amorphous graphene (a-Gr) mask on Si.

A selective growth regime was identified on a-Gr at a slow growth rate of 0.15 Å/s, a relatively high V/III flux ratio, and a substrate temperature of 605˚C. Under these conditions, growth of GaAs and GaP was performed in nanoholes (diameters ≤ 100 nm) etched in an a-Gr mask on Si. Structural

characterization was performed by atomic force microscopy, scanning electron microscopy (SEM), and high-resolution transmission electron microscopy (HR-TEM).

GaAs nanoseeds grown in ~100 nm diameter holes were ~30 nm tall and ~100 nm in diameter with most of the nuclei showing clear faceting in planview SEM. Unsurprisingly, HR-TEM revealed that the majority of the nuclei were relaxed and single-crystalline with misfit dislocations visible along the GaAs/Si interface. Furthermore, energy dispersive X-ray spectroscopy showed no signs of oxide present at the interface indicating successful deoxidation. Recently, fabrication optimization has enabled nanoholes as small as 20 nm in diameter with templated growth of both GaAs and GaP resulting in nanoseeds as small as ~25 nm in diameter or less and ~10 nm tall, on the order of a conventional self-assembled quantum dot. HR-TEM investigations of these smaller nuclei are underway and the effects of nuclei size and lattice mismatch on dislocation formation and strain accumulation will be presented at the conference.

Here, we have demonstrated the first 2D-assisted SAG of GaAs and GaP on Si via a nanopatterned a-Gr mask. Such templated growth has the potential to unlock new III-V on silicon templates for (opto)electronics applications.

[1]S. Lee et. al., *J. Appl. Phys.* **92** (2002).

[2]D. Ironside et. al., *Prog. Quantum Electron.* **77** (2021).

[3]H. Kim et. al., *Nature Nanotechnology*, **17** (2022).

[4]S. Manzo et. al., *ACS Appl. Mater. Interfaces*, **15** (2023).

Author Index

Bold page numbers indicate presenter

— A —
Arony, Nazifa Tasnim: NAMBE2-TuA-11, **1**
— C —
Chen, Ze-Wei: NAMBE2-TuA-12, 1
Choi, Soo Ho: NAMBE2-TuA-12, 1
Chyi, Jen-Inn: NAMBE2-TuA-9, 1
— D —
Doty, Matthew: NAMBE2-TuA-11, 1
— H —
Han, Ne Myo: NAMBE2-TuA-12, 1
Hernández-Calderón, Isaac: NAMBE2-TuA-10, **1**
Hsu, Kai-Yang: NAMBE2-TuA-9, 1
— K —
Kim, Hyunseok: NAMBE2-TuA-12, 1
Kim, Jeehwan: NAMBE2-TuA-12, 1
Kondapavuluri, Bhavya: NAMBE2-TuA-9, **1**
Kwon, Doa: NAMBE2-TuA-12, 1
— L —
Laji, Ba: NAMBE2-TuA-9, 1
Lee, Minjoo Larry: NAMBE2-TuA-12, 1
Liu, Pin-Chih: NAMBE2-TuA-9, 1
Liu, Wei-Sheng: NAMBE2-TuA-9, 1
Lu, Kuangye: NAMBE2-TuA-12, 1
— M —
Mai, Lan: NAMBE2-TuA-11, 1
McCabe, Lauren N.: NAMBE2-TuA-11, 1
Murray, Lottie: NAMBE2-TuA-11, 1
— P —
Pérez-Saavedra, Jorge: NAMBE2-TuA-10, 1
— R —
Rajagopal, Joshya: NAMBE2-TuA-11, 1
Ramesh, Prashant: NAMBE2-TuA-11, 1
— S —
Saha, Archishman: NAMBE2-TuA-12, 1
Sutara, Frantisek: NAMBE2-TuA-10, 1
— V —
Vázquez-Soto, Yang A.: NAMBE2-TuA-10, 1
— W —
Wang, Yiteng: NAMBE2-TuA-12, 1
White, Corey: NAMBE2-TuA-12, **1**
— Z —
Zide, Joshua: NAMBE2-TuA-11, 1