Saturday Morning, August 23, 2025

Workshop on MBE for Emerging Emitter Technologies
Room Tamaya ABC - Session WME1-SaM

Photonic-Crystal Surface-Emitting Lasers (PCSELs)
Moderator: Ricky Gibson, Air Force Research Laboratory

8:00am **WME1-SaM-1 Welcome & Opening Remarks**, ***Ganesh Balakrishnan,*** University of New Mexico

8:15am **WME1-SaM-2 Passively Coupled Coherent PCSEL Arrays**, *Mingsen Pan,* University of Texas at Arlington; *Chhabindra Gautam,* Semergytech, Inc.; *Thomas Rotter, Ganesh Balakrishnan,* University of New Mexico; *Shanhui Fan,* Stanford University; ***Weidong Zhou,*** University of Texas at Arlington **INVITED**

As a novel design of surface-emitting semiconductor lasers, photonic crystal surface-emitting lasers (PCSELs) feature in-plane optical feedback from photonic crystal (PC) modulation and vertical coupling with active region and emitted beams. For surface-normal emission, cavity mode in a PCSEL cavity is designed to operate at the Γ point in the momentum space. Such a cavity mode, originating from the guided resonances in PC, is coupled to radiation channels in the upward and downward directions. Thus, a surface-normal laser beam can be directed with low beam divergence which is, in theory, near the diffraction limit. One advantage of designing low divergence light source is its superior brightness in applications such as free-space optical communications and material processing [1]. The low beam divergence of a PCSEL device makes it hundreds of times brighter than the vertical cavity surface-emitting lasers (VCSELs) without collimation lens.

Monolithic PCSELs, also single PCSELs, have been demonstrated to possess high-power exceeding 50 W in continuous-wave (CW) operation and brightness of over 1 GW cm^{-2} sr^{-1} from a 3 mm diameter device aperture [2]. By designing the PC cavities, even higher output power can be achieved with larger cavity sizes. However, as the cavity size becomes larger, laser performance degrades due to the complex thermo-optical and electro-optical effects. At higher injection currents, the spatial hole burning effects create non-uniform gain distribution, thus reducing the lasing efficiency and distorting the mode profiles. High injection current induced thermal effects due to the produced high photon density at the cavity center also bring negative impacts and complexities for compensation design. On the other hand, semiconductor laser arrays are important to the applications of power scaling, which can be a promising solution to overcome the challenges in high-power PCSELs. PCSEL cavities are realized by the two-dimensional (2D) in-plane optical feedback by the PC modulation. Thus, the lateral coupling control between two PCSELs is achievable and such coupled PCSELs have been implemented by applying a waveguide connection in between for active coupling control using its optical gain/loss switching. [3]

In this paper, we investigate a compact design of coherent PCSEL arrays by placing PCSELs with suitable spacing to implement passive couplings. [4][5] The PCSEL arrays are designed on an InGaAs/GaAs multiple quantum well (MQW) platform for lasing wavelength of 1040 nm. We fabricated single PCSELs and up to 5x5 PCSEL arrays under the same processing parameters and conditions for comparison. To test the coherent operation of PCSEL arrays, we characterize the spectral linewidth properties and measure the coherency in emitted laser beam by self-interference experiments. Linewidth of 0.22 nm from a 2-by-2 PCSEL array and 0.08 nm from a single PCSEL was observed, indicating feasible coherent beam combining with narrow peak wavelength splitting from different PCSELs. The self-interference experiments test the visibility of the interference fringes, showing strong coherency of the emitted beam from the PCSEL array that is similar with a single PCSEL.

The authors acknowledge the support from JDETO and ARO.

References

[1] W. Zhou and M. Pan, "The future of photonic crystal surface-emitting lasers," *Appl. Phys. Lett.* 123, 140501, 2023.

[2] M. Yoshida, S. Katsuno, T. Inoue, J. Gelleta, K. Izumi, M. De Zoysa*, et al.*, "High-brightness scalable continuous-wave single-mode photonic-crystal laser," *Nature,* vol. 618, pp. 727-732, 2023/06/01 2023.

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[4] C. Gautam, M. Pan, Y. Chen, T. J. Rotter, G. Balakrishnan, and W. Zhou, "Laterally coupled photonic crystal surface emitting laser arrays," *Journal of Applied Physics,* vol. 135, 2024.

[5] M. Pan, C. Gautam, Y. Chen, T. Rotter, G. Balakrishnan, and W. Zhou, "Recent Advances in Photonic Crystal Surface Emitting Lasers," *IEEE J Select. Topic. Quant. Electron.* 31, pp. 1-8, 2025.

8:45am **WME1-SaM-4 GaSb-Based Photonic Crystal Surface Emitting Diode Lasers**, ***Leon Shterengas,*** *Gela Kipshidze,* SUNY at Stony Brook; *Aaron Stein, Dmitri Zakharov, Kim Kisslinger,* Brookhaven National Laboratory; *Gregory Belenky,* SUNY at Stony Brook **INVITED**

The development of the epitaxially regrown photonic crystal surface emitting lasers (PCSELs) based on various material systems and active region architectures is actively explored to enable device operation in wide range from visible to infrared. Our research group at Stony Brook University is involved in design and development of the GaSb-based PCSELs targeting operation at wavelength range from 2 to 4 µm. We have demonstrated air-pocket retaining epitaxial regrowth within antimonide material system and reported on diode and cascade diode PCSELs operating near 2 and 2.8 µm respectively. The first continuous wave (CW) room temperature operation of the monolithic epitaxially regrown III-V-Sb PCSELs emitting near 2 µm was reported in year 2023 and device output power was further enhanced in year 2024.The key technological capability required for development of the efficient PCSELs is a capacity to seamlessly integrate high index contrast photonic crystal layer into laser heterostructure. Approach selected by our research group for the GaSb-based monolithic PCSELs fabrication, was in many aspects like the one developed by Kyoto University group for fabrication of their record-breaking GaAs-based PCSELs. The process we adopted starts with the molecular beam epitaxial (MBE) growth of the n-cladding layer and n-side waveguide core layer, followed by the growth of the quantum well (QW) active region, which gets capped by p-side waveguide core layer. Then the incomplete laser heterostructure is removed from growth reactor, the square lattice of holes is etched in the p-side waveguide core layer, and nanopatterned incomplete laser heterostructure is reloaded back to MBE for regrowth of the p-cladding and p-contact layers. The regrowth regimes are optimized to form highly uniform array of buried voids. Increase of the PCSEL operating wavelength requites proportional increase of the period of the buried photonic crystal. However, the volume of the buried voids cannot be scaled up easily since it is affected by aspect ratio of the etched holes. Decrease of the relative size of the buried voids with respect to period of the photonic crystal (decrease of the void area fill-factor) can lead to reduction of the coupling coefficients controlling the strengths of in-plane feedback and surface emission. To obtain adequate area fill-factor of the void in the unit cell of the buried photonic crystal designed to operate at longer wavelength, several voids per unit cell can be used. The GaSb-based PCSELs based on four-voids unit cell design demonstrated the highest CW power level so far.

9:15am **WME1-SaM-6 III-V/Si Bound States in Continuum Lasers with Quantum Well (QW) and Quantum Dot (QD) Gain**, ***Ashok Kodigala,*** Sandia National Laboratories **INVITED**

We demonstrate the integration of quantum well and quantum dot gain with a silicon photonic crystal (PhC) at telecommunication wavelengths near 1550nm resulting in optically pumped laser emission from symmetry-protected bound states in the continuum (BIC).

9:45am **WME1-SaM-8 Panel Discussion**,

Workshop on MBE for Emerging Emitter Technologies
Room Tamaya ABC - Session WME2-SaM

Emerging Materials and Growth Technologies
Moderator: Carolina Adamo, Northrop Grumman

10:30am **WME2-SaM-11 Clean Oxides at High Temperatures**, ***Joseph Falson,*** California Institute of Technology **INVITED**

In this presentation I will discuss recent developments in the epitaxy of ultra-pure ZnO as a platform for emerging emitters. Using clean homoepitaxial layers we have investigated a range of extrinsic defects as well as implanted ions inside ZnO as the host lattice. I will provide an outlook on the current status of developing method for in-situ incorporation of the most promising varieties of defects, as well as approaches to improving their quantum lifetimes through dilution of the nuclear spin bath. If time permits, I will also discuss other novel oxides which can be grown using similar techniques to very high purity.

11:00am **WME2-SaM-13 Dislocation-Tolerant Quantum Dot Light Emitters: From Growth on Silicon to Remote Epitaxy***, Minjoo Larry Lee,* University of Illinois at Urbana-Champaign **INVITED**

InAs quantum dots (QDs) grown on GaAs/Si have emerged as a compelling active region for reliable monolithically integrated lasers on Si with emission around 1200-1300 nm. In 2020, my group demonstrated that InP QDs also show promise as dislocation-tolerant light emitters with tunable emission in the red visible wavelength range. Since then, we have demonstrated InP QD visible lasers on both GaP/Si templates and patterned photonic integrated circuit (PIC) templates. More recently, we have demonstrated InP QD visible light-emitting diodes on GaAs templates grown by remote epitaxy, which can also exhibit escalated dislocation densities. In this talk, I will review these directions and also describe new results from my group on InAsP QDs, which promise tunable emission in the near-infrared spectral range from 750-1200 nm. The potential to grow dislocation-tolerant InAsP light emitters spanning from 650-1300 nm could open a range of new applications, ranging from sensing to quantum technology.

11:30am **WME2-SaM-15 Thermal Laser Epitaxy for Emerging Emitter Materials***, Brendan Faeth,* epiray **INVITED**

As the scope of both technological demand and known material systems continues to expand, the need for greater variety and control of constituent sources has begun to strain the capabilities of conventional deposition techniques.Here, we demonstrate a new thin-film deposition technique, Thermal Laser Epitaxy (TLE), which combines IR laser heating of elemental sources with direct CO_2 laser heating of substrates.This approach allows for the evaporation of practically all elements of the periodic table in the same setup, while maintaining even extremely corrosive process gas environments up to pressures as high as 10^{-1} mbar, and at extremely high substrate temperatures. Here, I will introduce and discuss the advantages of TLE for epitaxy, with a focus on applications for emerging emitter materials across a wide range of materials families including oxides, nitrides, and other more exotic opportunities not accessible by conventional MBE approaches.

12:00pm **WME2-SaM-17 Panel Discussion***,*

Workshop on MBE for Emerging Emitter Technologies
Room Tamaya ABC - Session WME1-SaA

Emitters on Silicon

Moderator: Ganesh Balakrishnan, University of New Mexico

1:30pm **WME1-SaA-1 MBE Growth of Interband Antimonide Lasers on Silicon***, **Laurent Cerutti**, Maëva Fagot, Daniel Díaz-Thomas, Andres Remis,* IES, University of Montpellier, CNRS, France*; Audrey Gilbert,* University of Montpellier, France*; Yves Rouillard, Jean-Baptiste Rodriguez, Eric Tournié,* IES, University of Montpellier, CNRS, France **INVITED**

The evolution towards smart, compact, low power and affordable optical gas sensors to monitor our environment requires the integration of III-V optoelectronic devices with a silicon photonics-based platform. Although two approaches, bonding and direct epitaxy, are possible, the latter appears to be the most promising long-term solution. The antimonide-based compound semiconductors (ABCS), which are particularly suitable for the development of mid-infrared optoelectronics (2-5 µm), where the absorption of pollutants (CH_4, CO, HF, ...) is very strong, make them the best candidate for the realisation of monolithically integrated mid-IR lasers on silicon substrates. However, differences in crystal structure, lattice constants, thermal expansion coefficients have made this topic extremely challenging. In this presentation we will review the recent results on mid-IR interband lasers grown on (001) Si substrates and compare their performance with those grown on their native substrate. For the 2-3 µm wavelength range, the properties of GaInAsSb/AlGaAsSb type-I quantum well (QW) lasers will be presented [1, 2], while for the 3-5 µm wavelength range, the properties of type-II interband cascade lasers with high threading dislocation density will be discussed [3, 4].

These two approaches will allow to cover the whole wavelength range between 2 and 5 µm and will show that Sb-based lasers pave the way for the future epitaxial integration of III-Vs on Si.

[1] M. Rio-Calvo *et al,* Optica, **7**, 263 (2020)

[2] A. Remis *et al,* Journal of Applied Physics **133**, 093103 (2023)

[3] L. Cerutti *et al,* Optica, **8**, 1397 (2021)

[4] M. Fagot *et al,* Optics Express, **32**, 11057 (2024)

This work was partially funded by France 2030 program (EquipEx EXTRA and HYBAT, ANR-11-EQPX-0016, ANR-21-ESRE-0026), the French Occitanie Region (LASIDO project), the French Agency for Defense and Innovation (AID-DGA) and the Banque Publique d'Investissement (Hyquality Project DOS0188007/00).

2:00pm **WME1-SaA-3 Molecular Beam Epitaxy of III-V Infrared Emitters on Silicon***, **Stephanie Tomasulo**,* U.S. Naval Research Laboratory **INVITED**

Combining high-performance III-V emitters with Si substrates enables their incorporation into photonic integrated circuits, as well as novel device architectures that can improve cost effectiveness and thermal management. However, the InAs/GaSb/AlSb family of materials that is suitable for emission in the midwave infrared has a typical lattice constant (a) near 6.1 Å, resulting in a 12% lattice mismatch with silicon at a=5.43 Å. Additional differences, such as thermal and polar/non-polar mismatches, also occur when the two material systems are epitaxially combined. While these introduce significant challenges, our successful growth of interband cascade light emitting diodes on Si has produced CW output powers comparable to those of control devices grown on GaSb. This presentation will cover the challenges of III V growth on silicon, as well as the current status of mitigation techniques that enable high performance to be observed nonetheless.

2:30pm **WME1-SaA-5 High-Quality Epitaxy of SiSn, GeSn, and SiGeSn Alloys Using MBE for Si-Based Optoelectronic Applications***, **Shui-Qing Yu**, Diandian Zhang, Nirosh Eldose, Dinesh Baral, Hryhorii Stanchu, Fernando Oliveira, Wei Du, Gregory Salamo,* University of Arkansas **INVITED**

Group IV semiconductor alloys GeSn, SiSn, and SiGeSn, are promising for next-generation electronic and optoelectronic applications due to their tunable band structures and CMOS compatibility. While significant progress has been made in SiGeSn/GeSn-based lasers and photodetectors via chemical vapor deposition (CVD), achieving high-quality epitaxial growth via molecular beam epitaxy (MBE) remains challenging due to phase separation, strain relaxation, and defect formation, which limit optoelectronic performance.

In this workshop, we discuss the MBE growth of GeSn, SiSn, and SiGeSn alloys, focusing on overcoming key challenges such as Sn incorporation, surface segregation, and defect suppression. We systematically investigated growth temperatures from 100°C to 200°C, optimizing crystalline quality confirmed by high-resolution X-ray diffraction (HR-XRD) and atomic force microscopy (AFM). A major breakthrough includes the first reported direct bandgap photoluminescence (PL) emission from MBE-grown GeSn on Si (100) substrates without post-annealing, marking a critical step toward Si-based GeSn optoelectronic integration.

For SiSn, we achieved the growth of SiSn alloys with Sn content up to 5.5% on Si substrates. XRD and reciprocal space mapping (RSM) confirm successful epitaxial growth of pseudomorphic SiSn layers (3.2%–5.5% Sn) on Si (100), with full strain retention preventing defect-induced relaxation. This stability is crucial for bandgap engineering, advancing Si-compatible infrared photonic and electronic applications. Additionally, the study enables further exploration of short-range ordering phenomena in group-IV semiconductor alloys.

Further discussions cover lattice-matched Si0.42GeSn0.10 bulk materials and Si0.25GeSn0.09/Ge superlattices (SLs). XRD confirms strain-free growth on Ge substrates, while secondary ion mass spectrometry (SIMS) verifies high Si and Sn compositions. PL measurements reveal a strong emission peak at ~1850 nm in Ge/SiGeSn SLs, demonstrating potential as a mid-infrared group-IV light source.

In conclusion we will have discussed the ways in which this study lays a strong foundation for the high-quality epitaxial growth of SiSn, SiGeSn, and GeSn alloys, confirming their potential for future Si-compatible electronic and photonic applications. These findings offer valuable insights into group-IV semiconductor alloy growth, addressing key challenges in material stability and performance. Furthermore, this work paves the way for the development of advanced photonic and quantum devices, expanding the possibilities for next-generation semiconductor technologies.

3:00pm **WME1-SaA-7 Quantum Dot Lasers – Old Dog, New Trick, Niche Production to High–Volume Manufacturing***, **Andrew Clark**, Kathryn E. Sautter, Amy Liu,* IQE Inc. **INVITED**

As the amount of AI-driven data continues to surge, data centers have to deal with ever increasing power consumption, creating a financial and an environmental burden. One solution is to run the entire data center at a higher ambient temperature which will improve both operational and cost efficiencies. Operating temperature is a key metric for compound semiconductor photonic devices as it impacts device performance and reliability. The incumbent laser for many of today's data centers is an InP-based O-band laser mounted on a cooler to maintain the operating temperature at <60°C. End-users now request laser modules that can tolerate >85°C, and eventually >100°C. GaAs-based quantum dot lasers (QDL) have demonstrated that they can meet these demanding specifications.

Other QDL attributes include the obviation of optical isolator and thermoelectric coolers, leading to a simpler bill of materials and improved wall-plug efficiency. Its largest attribute is perhaps its ability to support mode-locked or comb laser fabrication which could lead to significant performance efficiency when it comes to massive data transfer. A QDL comb on a single chip can have a wide range of output wavelength lines, each capable of carrying many GB of data.

Discrete transceivers incorporating QDLs have been around for 15+ years, but the current re–emergence is fueled by the interplay of QDLs with silicon photonics (SiPh) including heterogeneous III-V epitaxy directly on a photonic integrated circuit (PIC) wafer. To deliver on all these opportunities and provide a path to high–volume manufacturing of QDL epiwafers requires a comprehensive foundry approach for epitaxy which must focus on the consolidation of QD performance, wafer scaling, and end-user device fabrication needs such as the integration with silicon photonics.

While epitaxial growth of QDL structures on GaAs substrates is not new, shifting from niche production to a high-volume manufacturing platform requires that epiwafer foundries adapt and develop existing and new production processes. In this work, we will review IQE's QDL epiwafer production process. Our benchmark process is based on multi-150mm growths on GaAs substrates, but the process is scalable from 75 mm to 200 mm with comparable results. For CMOS fabs interested in the SiPh market space where the use of native GaAs substrates is not feasible, our epi foundry solution is to offer QDL structures grown on Ge and Si substrates which can be scalable up to 300 mm. We will discuss the MBE challenges of growing on non-native substrates and will present material characterization and device performance of QDL structures grown directly on 300mm PIC wafers.

3:30pm **WME1-SaA-9 Panel Discussion***,*

Workshop on MBE for Emerging Emitter Technologies
Room Tamaya ABC - Session WME2-SaA

AI/ML Techniques for MBE
Moderator: Kurt Eyink, Air Force Research Labs

4:15pm **WME2-SaA-12 Invited Paper***,* ***Remi Dingreville,*** Sandia National Laboratories **INVITED**

4:45pm **WME2-SaA-14 Machine Learning Methods for MBE Growth Optimization***, Mingyu Yu,* University of Delaware*; Isaiah Moses,* Pennsylvania State University, United States Minor Outlying Islands (the)*; Ryan Trice, Wesley Reinhart,* ***Stephanie Law,*** Pennsylvania State University **INVITED**

Machine learning models hold the potential to explore parameter space autonomously, quickly establish process-performance relationships, and diagnose material synthesis in real time. This reduces reliance on manual intervention in parameter space exploration, enabling more precise and efficient mechanistic control. For molecular beam epitaxy (MBE), despite its breakthroughs in materials synthesis, its stringent growth conditions and complex epitaxial mechanisms make the process of optimizing growth process time-consuming and expensive. Therefore, leveraging machine learning to develop autonomous MBE growth platforms presents a highly promising prospect. In this talk, I will discuss efforts to synthesize two material systems using machine learning and Bayesian optimization. We begin with a comprehensive high-quality dataset of GaSe thin films grown on GaAs (111)B substrates. GaSe is an emerging two-dimensional semiconductor material with intriguing properties, including thickness-tunable bandgaps, nonlinear optical behaviors, and intrinsic p-type conductivity. We were interested in leveraging machine learning to analyze the relationships between growth conditions (Ga flux, Se:Ga flux ratio, and substrate temperature) and the resulting sample quality, as well as the correlations among various characterization results including in situ RHEED patterns and ex situ x-ray diffraction rocking curve full-width at half maximum (FWHM) and atomic force microscopy (AFM) root mean square (RMS) roughness. In this talk, I will discuss how unsupervised learning, mutual information analysis, and supervised learning can be used to understand the influence of different growth parameters on GaSe film quality. I will then move on to discussing our efforts to use Bayesian optimization along with machine learning to quickly find optimal growth parameters for the various polytypes of In2Se3. The techniques and code can be easily adapted to other materials and other MBE systems, making this approach broadly applicable to a wide range of problems.

Workshop on MBE for Emerging Emitter Technologies
Room Tamaya ABC - Session WME1-SuM

Quantum-Dot based Single Photon Emitters I
Moderator: Richard Mirin, National Institute of Standards and Technology

8:00am **WME1-SuM-1 Welcome & Opening Remarks***,*

8:15am **WME1-SuM-2 Invited Paper***, **Edo Waks**,* University of Maryland **INVITED**

8:45am **WME1-SuM-4 Low Noise Epitaxial Quantum Dots for Photonic Quantum Technologies***, **Alisa Javadi**,* University of Oklahoma **INVITED**

Efficient generation and detection of coherent single photons are key to advances in photonic quantum technologies such as quantum computation, quantum simulation, and quantum communication. Among many quantum emitters, semiconductor quantum dots are promising due to their deterministic and high-rate single-photon emission and the possibility of integration into nanostructures. However, poor quantum coherence between single photons created by independent emitters poses a major roadblock. I will discuss our recent work on achieving near-unity two-photon interference visibilities from two separate GaAs quantum dots [1,2]. This high visibility (~93%) is achieved under rigorous conditions: there is no Purcell enhancement, no temporal post-selection, no narrow spectral-filtering, nor frequency stabilization. One key component is the heterostructure, an n-i-p diode using material of excellent quality. The quantum dot charge is locked via Coulomb blockade; within a charging plateau, the exact emission frequency can be tuned via the bias applied to the gate; the charge noise is very low. A second key component is the quantum dot itself: the relatively large size confers multiple benefits such as larger oscillator strength and lower susceptibility to spin noise. This level of interference visibility from independent GaAs QDs is a first of its kind and matches the performance achieved in trapped ions and cold atoms, the seemingly most identical emitters. These results highlight the advantage of high-quality epitaxial quantum dots as a versatile choice for generating identical photons from multiple emitters.

[1] L. Zhai *et al.*, Nature Nanotechnology **17**, 829 (2022).

[2] L. Zhai *et al.*, Nature Communications **11**, 4745 (2020).

9:15am **WME1-SuM-6 Growth and Characterization of Epitaxial InAs Quantum Dots for Efficient and Pure Single Photon Sources***, **Kevin Silverman**,* NIST - Boulder **INVITED**

Epitaxial quantum dots (QDs) grown by molecular beam epitaxy (MBE) currently serve as the backbone of the world's best performing single photon sources. Therefore, they are poised to play an important role in emerging quantum information systems, and in particular, quantum networking applications. To meet metrics of photon purity, indistinguishability, and efficiency excellent crystal quality, careful design, and precise control of QD density and shape is necessary. In this presentation, we will discuss the optical and electrical characterization needed to prove that an epitaxial QD device can meet these demands. In contrast to conventional optoelectronic devices, photoluminescence characterization (even at cryogenic temperatures) is insufficient for this purpose. We will explain the need for precision, cryogenic, resonant measurements and how results can directly feedback to improvements in growth conditions and device design. Depending on the intended application, charge noise and/or spin noise could be the major factor effecting performance. These two concerns can be separated with different spectroscopic methods and have different physical mechanisms. We will then discuss some of our latest research into improving InAs epitaxial single photon sources including the addition of Phosphorus based materials and monolithic microcavities for enhancing collection efficiency into a single mode fiber.

Workshop on MBE for Emerging Emitter Technologies
Room Tamaya ABC - Session WME2-SuM

Quantum-Dot based Single Photon Emitters II
Moderator: Richard Mirin, National Institute of Standards and Technology

10:15am **WME2-SuM-10 Quantum Dots Obtained by Droplet Etching Epitaxy for Quantum Science and Technology***, **Armando Rastelli**,* Institute of Semiconductor and Solid State Physics, Johannes Kepler University (JKU) Linz, Austria **INVITED**

Entanglement is one of the most peculiar phenomena in quantum science and a key resource for quantum technologies. More than two decades after the initial proposal [1], semiconductor quantum dots (QDs) are now beginning to outperform other light sources for the generation of entangled photon pairs.

Among different material systems, QDs in the (Al)GaAs material platform have demonstrated the highest degree of polarization entanglement to date together with other appealing features for quantum science and technology [2–4]. These QDs are obtained by GaAs overgrowth of an AlGaAs surface with nanoholes and are characterized by small inhomogeneous broadening, high oscillator strengths, shape with high in-plane symmetry, and high optical quality, especially when embedded in charge-tunable diode structures. In this talk, we will discuss the properties of GaAs QDs obtained by the droplet etching method [5] and present recent results relevant to their application in quantum communication, such as entanglement-based quantum key distribution [6], as well as open challenges [7].

[1] O. Benson, C. Santori, M. Pelton and Y. Yamamoto, Phys. Rev. Lett. 84, 2513–2516 (2000).

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[4] L. Zaporski, N. Shofer, J. H. Bodey, S. Manna, G. Gillard, M. H. Appel, C. Schimpf, S. F. Covre da Silva, J. Jarman, G. Delamare, G. Park, U. Haeusler, E. A. Chekhovich, A. Rastelli, D. A. Gangloff, M. Atatüre and C. Le Gall, Nat. Nanotechnol. 18, 257–263 (2023).

[5] C. Heyn, A. Stemmann, T. Köppen, C. Strelow, T. Kipp, M. Grave, S. Mendach and W. Hansen, Appl. Phys. Lett. 94, 183113 (2009).

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[7] B. U. Lehner, T. Seidelmann, G. Undeutsch, C. Schimpf, S. Manna, M. Gawełczyk, S. F. Covre da Silva, X. Yuan, S. Stroj, D. E. Reiter, V. M. Axt and A. Rastelli, Nano Lett. 23, 1409–1415 (2023).

10:45am **WME2-SuM-12 Toward a Scalable Single Photon Platform***, **Chen Shang**,* University of California Santa Barbara*; Sahil Patel, Zihang Wang, Sean Doan, Dirk Bouwmeester, Galan Moody, John Bowers,* University California Santa Barbara **INVITED**

The lack of scalable photon sources has been a major roadblock for quantum photonics to realize their full potential. Self-assembled InAs QDs currently hold the best all-around single photon emitter performance as a solid-state source, offering advantages of CMOS-compatible fabrication, highly tunable optical properties, and deterministic emission. The key challenge for deploying the InAs QD single photon source at large scale is the spatial and spectral randomness of each dot due to the self-assembling process on planar substrates. The prevalent method to combat this involves manipulating substrates to create preferential nucleation sites, either grooves or mesas. However, these "site-controlled" QDs typically exhibit inferior optical qualities and less repeatable charge tunability compared to their randomly situated counterparts on planar substrates. Such substrate alternations also limit the integrability with other devices. In this work, we utilize the intrinsic material properties, especially the coefficient of thermal expansion (CTE) mismatch between the GaAs substrate and the oxide layers and the asymmetric surface diffusion of indium adatoms, to develop site-controlled InAs QD single photon emitters nucleated on compartmentalized finite surfaces that will solve both issues simultaneously at wafer scale.

The growth template was fabricated first by oxide deposition on (001) GaAs. To ensure the "epi-ready" surface quality, the hexagonal pockets in two different orientations with respect to the III-V crystal were finished HF wet etching to remove the remaining post-dry etching oxide. The InAs QD material was then deposited in a Veeco Gen II molecular beam epitaxy chamber at elevated temperatures. Due to the CTE mismatch between the GaAs substate and the oxide layers, the substrate was under a global biaxial compression at the QD deposition temperature of 500 ℃. The oxide patterns introduce local non-uniform profile with higher strain at the vertices of the hexagon and the strain level lowers toward the center of the pocket. The slow diffusion axis in the [1 1 0] orientation shows as “ridges” on the calculated potential energy profile. As the vertices are being filled, the energy penalty for adding more atoms increases and would generate new local and central potential energy minimums on either side of the slow diffusion axis. Thus, additional indium atoms are funneled toward the newly defined energy minimums. Hyperspectral images were taken under cryogenic temperatures of the as-grown InAs QDs embedded in GaAs.Emission from a single QD within one of the central minimums was observed in the pocket in the preferred orientation.

11:15am **WME2-SuM-14 Invited Paper*, Matthew Doty,*** University of Delaware **INVITED**

11:45am **WME2-SuM-16 Panel Discussion***,*

12:15pm **WME2-SuM-18 Closing Remarks***,*

Author Index

Bold page numbers indicate presenter