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 (CH4, 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***,*

Author Index

Bold page numbers indicate presenter