NAMBE
Room Cummings Ballroom - Session NAMBE1-WeA
Heterogeneous Integration

Moderators: Rafael Jaramillo, Massachusetts Institute of Technology, **John McElearney**, Tufts University

1:30pm **NAMBE1-WeA-1 Enhanced Performance of High-Density GaAsSb Nanowire Ensemble Photodetectors with NIP Axial-Core Shell Structure on Graphene for Near-Infrared Detection**, ***Hirandeep Reddy Kuchorr****, Y. Deshmukh,* North Carolina A&T State University, India

In this work, we present the molecular beam epitaxy (MBE) growth of high-density, self-assisted n-i-p core-shell (C-S) GaAs1-xSbx nanowires (NWs) on surface-functionalized monolayer graphene. We explored the effects oxygen plasma treatment duration, and critical growth parameters such as substrate temperatures and V/III ratio, on the vertical yield of core GaAs1-xSbx NWs. Employing the optimized parameters, we developed both traditional (TCS) and hybrid n-i-p C-S (HCS) architectures. The HCS architecture has a novel design with axial n-core Sb gradient, which includes an intrinsic GaAs1-xSbx segment over the n-core to enhance absorption. The optical properties of the HCS design were examined using low-temperature photoluminescence (PL) with 4K-PL emissions. Comparative electrical I-V analysis of devices from both architectures showed the HCS design's superiority, with higher responsivity (>103 A/W) and detectivity (>1014 Jones), and an extended spectral response beyond 1.5 µm on graphene, making it ideal for short-wave infrared applications. Further, temperature-dependent C-V and low-frequency noise measurements showed the HCS photodetector's remarkable thermal stability, characterized by constant positive capacitance and a low cut-off frequency under varying temperatures. These results underscore the significant potential of graphene substrates in photodetector applications and pave the way for future flexible devices.

Acknowledgement:

This research work was funded through the US Army Grant Number W911NF-22-1-0114.

1:45pm **NAMBE1-WeA-2 Superconducting (001) and (111) Metal Nitrides on GaN**, ***Brelon May****, Z. Cresswell, S. Regmi, V. Buturlim, K. Vallejo, K. Gofryk, D. Hurley,* Idaho National Laboratory

Group III-Nitride materials have found applications in optoelectronic, photonic, and high power devices due to many factors, including the large variation in bandgap spanning from the infrared to the deep ultraviolet. Recent research has pursued the combination of this well-established material system with transition-metal nitrides for the creation of complex heterostructures which possess interesting optical, magnetic, or superconducting functionality. While GaN research has been primarily focused on the hexagonal allotrope, the metastable zincblende phase has a direct bandgap of 3.2 eV and providing an attractive option as a wide bandgap cubic material. Many transition metal nitrides have a stable cubic rocksalt structure. This includes ZrN, NbN, and TaN which are also well-known superconductors with relatively low lattice mismatch to GaN. This work will use molecular beam epitaxy for the epitaxial integration of these metal nitrides with hexagonal (c-plane) and cubic (001) GaN and will discuss the effect of growth parameters, including growth direction, on the structural and electrical quality of the metal nitrides. Reflection high energy electron diffraction, X-ray diffraction, and transmission electron microscopy reveal the epitaxial quality of single layer films and superlattices. Temperature dependent resistivity measurements show the superconducting critical temperature is strongly dependent on the growth conditions. These results open the door for new epitaxial superconductor-semiconductor systems and provide a platform for integration with other cubic materials to enable complex heterostructures. Such atomically precise hierarchical matter could be used for metamaterials or quantum science.

2:00pm **NAMBE1-WeA-3 Epitaxial Growth of (111) $BaTiO_3$ Thin Films on AlGaN/GaN Heterostructures**, ***Eric Jin***, Naval Research Laboratory*; J. Hart,* NOVA Research*; A. Lang, M. Hardy, N. Nepal, D. Katzer, V. Wheeler,* Naval Research Laboratory

Development of GaN-based high electron mobility transistors (HEMTs) has led to significant performance improvements in solid-state power switching and RF electronics, owing to the wider bandgap and larger breakdown field strength of GaN compared to semiconductors such as Si and GaAs. Despite these enhanced material properties, GaN HEMT performance is limited by non-uniform peak electric fields that can cause premature breakdown. One field management strategy recently demonstrated leverages the high dielectric constant (κ) of a gate material such as $BaTiO_3$ (BTO) to both control the electrostatics and reduce the peak electric field in the gate-drain region of the HEMT [1]. These BTO dielectric layers are typically sputtered, leading to either poor crystal quality or polycrystalline films, which have lower dielectric constants than bulk or crystalline materials (κ > 1000 for bulk BTO).

In this work, we demonstrate epitaxial (111)-oriented BTO thin films grown on AlGaN/GaN HEMT heterostructures by oxide and nitride molecular beam epitaxy. Key in this approach is the use of a thin $SrTiO_3$ (STO)/TiO_2 bilayer in between the BTO and AlGaN to both grade the lattice mismatch between the oxide and nitride layers and to orient the BTO film. In previous work, we showed that a 1-nm TiO_2 buffer layer greatly improves crystallinity when cubic STO films are deposited on wurtzite AlGaN [2]. However, BTO has a tetragonal structure and a slightly larger unit cell volume than STO. Consequently, BTO films deposited on TiO_2-buffered AlGaN exhibit lower crystallinity compared to films with an additional STO buffer layer.

We determine the growth window of BTO/AlGaN films across substrate growth temperature, oxygen flow, and Ba/Ti flux, and characterize the crystal phase and structural properties with x-ray diffraction, atomic force microscopy, and reflection high-energy electron diffraction. We investigate the atomic microstructure with scanning transmission electron microscopy (STEM), which confirms the epitaxial relationship as (111)[1-10] BTO || (0001)[11-20] AlGaN, which is similar to the observed STO/AlGaN epitaxial relationship [2]. Additionally, the STEM imaging reveals that the BTO film is highly textured, with crystallites approximately 10 nm in size, and that the buffer layers are rougher than the BTO film. Finally, we show through van der Pauw Hall effect measurements that the electrical properties of the GaN channel are robustly maintained, with no appreciable degradation of sheet resistance, electron mobility, or charge density.

[1] N. K. Kalarickal et al., *IEEE Trans. Electron Devices* (2021)
[2] E. N. Jin et al., *APL Mater.* (2020)

2:15pm **NAMBE1-WeA-4 Selective Area Growth for Monolithically Integrated Quantum Dot Lasers**, ***Alec Skipper****, K. Feng,* University of California at Santa Barbara*; G. Leake, J. Herman,* SUNY Poly*; C. Shang, R. Koscica,* University of California at Santa Barbara*; D. Harame,* SUNY Poly*; J. Bowers,* University of California at Santa Barbara

While research on the direct growth of InAs quantum dot lasers on silicon has progressed rapidly in recent years, silicon photonic integrated circuits with heteroepitaxially-integrated lasers have not achieved the same level of success as heterogeneous wafer-bonded integration techniques. On-chip coupling between the silicon photonics passives and embedded heteroepitaxial III-V lasers has proven to be a significant challenge in the practical application of this technology with the best reported devices showing insertion losses of 7.35 dB. Heteroepitaxial integration has the potential to offer a significant manufacturing cost and throughput advantage over heterogeneous integration by allowing 300 mm wafer processing without the use of expensive III-V substrates. However, the coupling problem must be addressed for the technology to be competitive in device performance.

The large coupling losses in heteroepitaxially integrated lasers arise primarily from the air gap between the etched facets of the lasers and silicon photonics waveguides. Lasers are fabricated by first etching a pocket in a conventionally fabricated silicon photonics wafer, with the III-V laser material subsequently grown in the pocket to allow butt coupling between the active and passive regions. However, the growth at the edges of the pockets must be etched away to reduce the non-uniformity and to produce adequate facet mirrors for the III-V lasers. This results in a ~10 µm air gap between the laser facet and the waveguides that severely degrades coupling. In molecular beam epitaxy, these non-uniformities at the pocket edges are the result of polycrystalline III-V deposition on the silicon dioxide sidewalls. Selective area growth can reduce or eliminate this air gap by preventing the formation of polycrystalline III-V material on the sidewalls. However, selective area MBE growth is not practical for aluminum-containing alloys due to aluminum's low volatility.

We report the growth and fabrication of III-V lasers heteroepitaxially integrated with silicon photonic integrated circuits using a partial selective area growth method to reduce the coupling gap. The use of a highly selective GaAs buffer layer and non-selective laser stack mitigates the formation of polycrystalline III-V material, reducing the effective coupling gap from 11 µm to 6 µm while maintaining previously reported growth conditions in the active region. Fabricated ridge lasers exhibit scattered light output powers as high as 20 mW continuous wave with thresholds as low as 205 mA. Coupling loss measurements are in progress and will be reported at the conference.

2:30pm **NAMBE1-WeA-5 Influence of Number of Graphene Layers on Epitaxy of GdAuGe on /6H-SiC***, **Taehwan Jung**,* University of Wisconsin - Madison, Republic of Korea*; N. Hagopian,* University of Wisconsin - Madison*; C. Dong, J. Robinson,* Penn State University*; P. Voyles, J. Kawasaki,* University of Wisconsin - Madison

We investigate the dependence of the number of graphene layers on the strain and epitaxial orientation of GdAuGe films, grown on graphene / 6H-SiC (0001). Whereas GdAuGe films growth directly on SiC or on few layer epitaxial graphene on SiC forms a hexagon on hexagon epitaxial alignment (GdAuGe [10-10] // SiC [10-10]), GdAuGe films grown on buffer layer graphene on SiC are rotated 30 degrees with respect to the underlying substrate. These results cannot be explained by a “remote” epitaxy mechanism, but instead may result from the highly buckled structure of buffer graphene which has strong covalent bonding to the underlying SiC. We will present a detailed analysis of the structure and strain by cross sectional STEM and reciprocal space mapping, and the impacts on magnetism in GdAuGe.

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