Science and Technology of MBE
Room Swan A & Sandpiper - Session ST-MoP
Science and Technology of MBE Poster Session

ST-MoP-1 Cryo-MBE: Ultra Low (<20k) Growth Temperatures for High Quality Metal Epitaxy*, Nils-Eike Weber,* Scienta Omicron, Germany*; D. Beaton,* Scienta Omicron*; M. Heiss,* Scienta Omicron, Germany

Superconductor-semiconductor nanowires enable the route to quantum information devices, like topological qubits [1]. Such hybrid nanowires can be grown in a bottom-up approach by Molecular Beam Epitaxy (MBE). Low-temperature evaporation of the superconductor was demonstrated to promote a continuous and flat film morphology growth and thereby assist the fabrication of disorder-free hardgap superconductor/semiconductor epitaxial hybrids [2]. As pristine surfaces and interfaces are key, eliminating post-growth etch processes by the employment of “shadow epitaxy” is seen as a promising approach [3].

We present a new MBE system that combines an ultra-low temperature manipulator with optimized chamber geometry for shadow epitaxy which enables exploration of so far uncharted growth parameters. The closed-cycle ULT manipulator with base temperature of < 20 K can be precisely positioned in the azimuthal and polar rotation axis allowing defined growth of half-shell or full-shell structures.

Our system and manipulator geometry allows to reach grazing incidence as well as normal incidence for an up to 2” sample cryogenic sample with respect to any of the 10 source ports (including e-beam sources needed for some promising material combinations). This allows to speed up the research of a wide range of possible epitaxial hybrid material systems for a full range of low temperature nucleation conditions. We demonstrate experimental data of the sample temperature at standby as well as when exposed to a hot effusion cell surface as a proof of the excellent manipulator cooling performance.

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ST-MoP-2 Vertical Cation Segregation in During $A_xB_{1-x}N$ Epitaxy*, Christopher M. Matthews,* *Z. Engel, W. Doolittle,* Georgia Institute of Technology

III-nitrides represent the possibility to realize high efficiency electronics in many different areas, from power electronics to light emitters to photovoltaics and more. However, many optoelectronic devices are limited by indium gallium nitride’s (InGaN) tendency to phase separate. Phase separation is one of the key challenges preventing further progress in III-nitride electronics, but the driving mechanisms for this phenomenon are not fully understood. Based on experimental success in limiting phase separation in AlInN and InGaN, we suggest that surface kinetics drive this phase separation during growth, rather than a bulk diffusion mechanism that has traditionally been credited as the cause. We propose that vertical cation segregation (VCS), lateral cation separation (LCS), and thermal decomposition and desorption are the main drivers of phase separation. In this work, we present a comprehensive dynamic growth model to examine the role of VCS in phase separation of ternary III-nitrides, and we compare modeled and experimental films.

A critical dose of excess metal exists for InGaN [1] and AlGaN [2], beyond which diffusion of the larger cation away from the growth surface occurs – a process defined as VCS. Metal-modulated epitaxy (MME) can be used to eliminate VCS or to alter the way VCS manifests in thin films (as compared to metal-rich MBE). VCS can result in self-assembled super lattices (SASL), which are used to evaluate the model presented here. MME’s low temperatures and high growth rates can be used to inhibit thermal effects and LCS, respectively, leaving VCS as the lone phase separation driver.

We have built a dynamic growth model to describe the accumulation and consumption of metal adatoms during epitaxy of III-nitrides. These processes are modeled by a system of coupled differential equations that use growth parameters extracted from state-of-the-art III-nitride epitaxy to calculate rates of growth, exchange, decomposition and more. This model is solved numerically to compute the time-evolution of each surface adlayer and a composition profile of the resultant crystalline film. We matched measured XRD to simulated diffraction patterns and composition profiles to TEM for experimental and simulated AlGaN SASLs. The general nature of this dynamic model makes it applicable to most variants of MBE.

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ST-MoP-3 Non-amphoteric N-type Doping with Sn of GaAs(631) Layers Grown by Molecular Beam Epitaxy*, Alan Cano Rico,* Facultad de Ciencias, Universidad Autónoma de San Luis Potosí (UASLP), Mexico*; L. Espiinosa Vega ,* Facultad de Ciencias, Universidad Autónoma de San Luis Potosí (UASLP). Center for the Innovation and Application of Science and technology, UASLP, Mexico*; I. Cortes Mestizo,* CONACYT-Center for the Innovation and Application of Science and technology, UASLP, Mexico*; R. Pinson Ortega ,* Facultad de Ciencias, Universidad Autónoma de San Luis Potosí (UASLP), Mexico*; F. Perea Parrales,* Center for the Innovation and Application of Science and technology, UASLP, Mexico*; P. Olvera Enríquez,* Center for the Innovation and Application of Science and technology, UASLP, Mexico*; M. Villareal Faz,* Facultad de Ciencias, Universidad Autónoma de San Luis Potosí (UASLP), Mexico*; L. Hernandéz Gaytán , A. Belio Manzano,* Center for the Innovation and Application of Science and technology, UASLP, Mexico*; V. Méndez García ,* Center for the Innovation and Application of Science and technology, UASLP. Facultad de Ciencias, Universidad Autónoma de San Luis Potosí (UASLP), Mexico

The molecular beam epitaxial (MBE) growth and doping of III-V semiconductor compounds on high-index crystallographic orientations (HICO) opens a vast number of possibilities to investigate new physical properties and to develop optoelectronic devices that overcome the currently technology. The peculiar HICO surface anisotropy can conduce to a natural arrangement of unidimensional nanostructures under appropriated growth conditions. Recently, the formation of self-assembled corrugation on GaAs(631) conducted to the formation of 1D multi-quantum well heterostructures, and the modulation of the confined state eigenstates has been achieved, attaining quasi-one-dimensional or fractional dimension eigenstates [1]. Further applications in electrical and optoelectronic devices demand of the realization doped layers preserving the 1D order. Although Si is widely used as an n-type dopant for GaAs (100) the growth of Si doped GaAs on (631)A surfaces results in amphoteric behavior, p-type and n-type conduction depending on the growth parameters [2]. In this work the Sn doping effects on the electronic conduction and optical properties of GaAs(631)A layers grown by MBE are investigated. We found that the conduction type conversion is avoided when Sn-doping is implemented instead. The maximum carrier concentration was $2x10^{19}$ cm^{-3}, which is an order of magnitude higher than previously reported for Si, and it is within the same order of magnitude as compared with the growth of GaAs(100). The electron mobility was $4x10^3$ cm^2/Vs ($1x10^3 cm^2/Vs$) for carrier concentration of $1x10^{17}$ cm^{-3} ($1x10^{19}$ cm^{-3}), suitable for many optoelectronic applications. Raman spectroscopy (RS) of highly Sn-doped (100) samples showed that the TO mode completely dominates the spectrum, indicating low crystalline quality. Conversely, the selection rules for the (631) indicate that the TO mode is allowed, and according to the experimental data it was found to increase with Sn-doping. In general, the incorporation of Sn in HICO-GaAs follows a completely different process as in singular (100)-planes, which was also supported by HRXRD and AFM measurements on the films.

[1] J. Appl. Phys. 128, 244302 (2020); https://doi.org/10.1063/5.0029103

[2] Journal of Crystal Growth 347 (2012) 77–81; https://doi.org/10.1016/j.jcrysgro.2012.03.008

ST-MoP-4 Uniformity: A Phenomenon That Arises from Anisotropy and De-Relaxation During Growth*, Felipe Perea Parrales, C. Mercado Ornelas, A. Belio Manzano,*

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Recently, the set of advantages of assembling quasi-one dimensional quantum wire (QWR) heterostructures by molecular beam epitaxy (MBE) over high-indexcrystallographicorientations(HICO)has been exhibited. Some of them include the wave function's in-plane symmetry break, allowing transitions that, in principle, must be forbidden and the induction of blue shifts or red shifts to theQWR energy spectrumdepending on the lateral(L_p)and vertical(H_p) QWRperiodicities(see the inset of Figure 1.(a)). Overall, merging the benefits of both integer-dimension extremes while ruling out their flaws [1], (Figure 1.(a)) and exhibiting the presence of a lateral confinement system(Figure 1.(b)). Although the growth processes over HICO are far from being fully understood, the GaAs (631) has proven to be an ideal substrate to grow QWR heterostructures before, owing to its unparalleled uniformity length [2]. One can assert that until now, there has been scarceor nonexistent *in situ* characterization that could bring us to grasp an overview of the real-time growth process performed over HICOs. This work expands the basis of the GaAs (631) faceting uniformity in terms of the anisotropic diffusion dynamics (Figure 2.(a)) and surface (1x1) buckling-like reconstruction (Figure 2.(b)) together with their dependence on the macroscopic constraints ∏=As/Ga BEP relation and growth temperature. The discussion is supported by experimental results, kinetic Monte Carlo simulations, a proposed inverse W-RHEED method and a thorough reciprocal space analysis. A new perspective for the free energy surface minimization apparatus is introduced.

[1] J. Appl. Phys. 128, 244302 (2020); https://doi.org/10.1063/5.0029103

[2] Applied Physics Letters 101, 073112 (2012); doi: 10.1063/1.4746423

ST-MoP-5 Feature-Independent Molecular Beam Epitaxy Selective Area Regrowth Towards Embedding High Aspect Ratio Microstructures*, **Ashlee Garcia**, A. Skipper, D. Ironside, S. Bank,*

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A molecular beam epitaxy (MBE) approach to selective area epitaxy (SAE) of III-V semiconductors has the potential to advance optoelectronic structures through seamless integration of metals, dielectrics and high-quality crystalline semiconductors. While SAE by metal organic chemical vapor deposition has been widely successful due to its high deposition selectivity, an all-MBE method could enable access to non-equilibrium growth conditions and high layer precision[1,2].

SAE is difficult to achieve with conventional MBE due to III-V nucleation on the amorphous mask. As a result, Allegretti et al. developed periodic supply epitaxy (PSE), a method to inhibit polycrystal deposition by cycling group III deposition under a constant group V flux[2-4]. While an all-MBE approach has enabled the embedding of features 2µm wide and 300nm tall, applications requiring high aspect ratio microstructures such as mid- and long-wave infrared high-contrast photonics[5-7] and aspect ratio trapping of threading dislocations for metamorphic growth[8], are challenging to selectively regrow due to low adatom surface diffusion[1,3].

To expand the accessible applications, a numerical 1D model was developed to describe PSE selectivity and determine selective growth regimes by fitting adsorption, desorption, and diffusion constants to GaAs growth on SiO_2 films at 600˚C [9-12]. The model identified a desorption-limited growth regime under an 18% PSE cycle, in which only thermal desorption off the mask is required to achieve selectivity. The selective growth regime was verified experimentally by observing no polycrystal formation on the mask surface after 100nm of 10% PSE GaAs growth (Ga open 6s, closed 54s) on a SiO_2 film and patterned gratings varying from 1 to 10µm wide, indicating the ability overgrow any arbitrary set of SiO_2 features and motivating its use for embedding high aspect ratio microstructures.

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