Thursday Afternoon, November 5, 1998

Selected Energy Epitaxy Topical Conference
Room 327 - Session SE-ThA

Seeded Supersonic Beam Epitaxial Growth

Moderator: R. Bickness-Tassius, Jet Propulsion Laboratory

2:00pm **SE-ThA1 Selected Energy Epitaxial Deposition of GaN and AlN on SiC(0001) Using Seeded Supersonic Free-Jets of NH@sub 3@ in Helium**, *V.M. Torres,* Arizona State University*; **R.B. Doak**,* Fulbright Senior Scholar, Ruhr-Universitaet-Bochum, Germany*; B.J. Wilkens, David J. Smith, I.S.T. Tsong,* Arizona State University **INVITED**

By expanding a gas mixture into vacuum through a supersonic nozzle, a heavy "seed" species in a light diluent can be aerodynamically accelerated to suprathermal translational energies, tunable by adjusting the mixture and temperature of the nozzle. Such "seeded" beams retain the high intensity, directionality, and narrow energy distribution characteristic of a supersonic free-jet. They thus offer promise in selectively promoting specific gas-surface reactions, a matter of much current interest in the growth of III-N semiconductor thin films. We report the use of 10% NH@sub 3@ in He seeded beams to grow GaN and AlN epitaxially on 6H-SiC(0001) and to grow GaN on AlN buffer layers deposited on SiC(0001). The substrate temperature was 800° C in all cases and the incident NH@sub 3@ translational energy was varied from 0.034 to 0.44 eV. Deposition was made with the beam incident at 0°, 30°, and 75° with respect to the surface normal. Ga was supplied from a simple evaporator and all growth was carried out under Ga-rich conditions. The thickness and morphology of the resulting films was characterized ex situ using RBS, Auger, TEM, and AFM. Of particular relevance to the growth of III-N compounds are the following results: (1) Selected energy epitaxial growth was observed, evidently via a direct reaction channel over a barrier of 0.3 ± 0.1 eV and mediated by the NH@sub 3@ translational energy. (2) A low energy reaction channel was also identified and ascribed to physisorption of the incoming NH@sub 3@ molecule followed by dissociative attachment of NH@sub x@ fragments. (3) Comparison of growth at 0° and 30° beam angles revealed total energy scaling, possibly due to rotational coupling of the above two reaction channels. (4) Deposition at grazing angle (75°) yielded faceting oriented towards the beam, indicating minimal mobility of the incident NH@sub 3@ and the attached NH@sub x@ fragments. The experimental evidence will be presented and the implications for III-N growth examined. Supported by ONR grant # N00014-95-1-0122

2:40pm **SE-ThA3 Homoepitaxial Growth of GaN Using Seeded Supersonic Molecular Beams**, ***H.H. Lamb,*** North Carolina State University **INVITED**

The optoelectronics applications of the Group III-nitrides have stimulated great interest in low-temperature epitaxial growth of GaN. As the quality of heteroepitaxial GaN films is limited by lattice mismatch between the film and typical substrates (e.g., sapphire and 6H-SiC), we have chosen to focus on homoepitaxial growth of epilayers on high-quality MOVPE-grown GaN substrates. Hyperthermal beams of neutral molecules (e.g., NH@sub 3@) are employed as alternatives to plasma and/or ion sources for low-temperature growth. Hyperthermal molecular beams with narrow energy distributions are generated by seeding heavy species in a supersonic expansion of a lighter gas (typically He or H@sub 2@). In this presentation, homoepitaxial growth of GaN using dual seeded supersonic molecular beams of NH@sub 3@ and triethylgallium (TEG) will be described. The results will be compared to those obtained using an NH@sub 3@-seeded supersonic molecular beam and a conventional Ga effusion cell. The influence of precursor kinetic energy on growth kinetics and film morphology will be discussed.

3:20pm **SE-ThA5 The Effect of Scaling Precursor Duty Cycles on Pulsed Supersonic Molecular Beam AlN Growth Rates**, ***V.W. Ballarotto**, M.E. Kordesch,* Ohio University

The effect of varying the precursor duty cycles for AlN grown on Si (100) at 650 °C with pulsed supersonic molecular beams is reported. The duty cycle is defined as the on-time of the valve multiplied by the driving frequency. The Al precursor was trimethylaluminum (130 meV) and the N precursor was 5 percent ammonia seeded in He (220 meV). The duty cycle was varied by changing the driving frequency. The growth rate of AlN films increases linearly (0.09 µ/h to 0.50 µ/h) with an increase in driving frequency. However, the growth rate in terms of thickness per pulse is roughly constant (1 Å/pulse). Total film thickness is on the order of 1-2 µ. A comparison of the growth rates when the duty cycle is varied by changing valve on-time will be presented. The films are predominantly oriented with the non-polar (10-0) plane parallel to the substrate plane. Preliminary results from x-ray diffraction @phi@ scans show that the films exhibit a preferred orientation that does not depend on substrate orientation or film thickness. The nucleation and growth of the non-polar (10-0) film face on polar (0001) MOCVD AlN will be discussed. Support provided by BMDO/ONR N00014-96-1-0782 and -1060.

3:40pm **SE-ThA6 In-Situ Surface Cleaning of GaN Using Hyperthermal Molecular Beams**, ***A. Michel***, North Carolina State University, US*; E. Chen,* North Carolina State University*; O. Nam, D. Thomson, R.F. Davis,* North Carolina State University, US*; H.H. Lamb,* North Carolina State University

Selected energy epitaxy (SEE) of GaN on MOVPE-grown GaN/6H-SiC substrates requires in-situ surface cleaning techniques that are effective at removing carbon and oxygen contamination without roughening or otherwise damaging the surface. Remote hydrogen plasma cleaning has been used to remove contaminants from GaN substrates prior to RF plasma-assisted MBE growth; however, the effects of hydrogen plasma exposure on surface roughness and substrate electrical properties have not been reported.@footnote 1@ Nitrogen plasma exposure can destroy surface steps on GaN/6H-SiC substrates, as evidenced by in-situ low energy electron microscopy (LEEM).@footnote 2@ Energetic beams of neutral atoms and molecules provide an alternative to plasma sources for in-situ cleaning and subsequent growth. Hyperthermal molecular beams are generated by seeding heavy species (e.g., NH@sub 3@, Kr) in a supersonic expansion of a lighter gas (e.g., He, H@sub 2@). In this work, in-situ cleaning of MOVPE-grown GaN/AlN/6H-SiC substrates using hyperthermal molecular beams was investigated. Removal of surface carbon and oxygen contaminants was achieved by heating at 730°C under a hyperthermal NH@sub 3@ beam. Oxygen is removed primarily by thermal desorption; however, carbon removal occurs only under an NH@sub 3@ flux. We infer that adsorbed H atoms produced by NH@sub 3@ decomposition react with carbonaceous species on the GaN surface to produce volatile hydrocarbons. Ex-situ atomic force microscopy (AFM) indicates that atomically smooth surfaces with regular steps are produced by NH@sub 3@ beam cleaning. In on-going work, we are investigating the use of dual hyperthermal Kr and NH@sub 3@ beams for GaN cleaning. The effects of kinetic energy on surface contamination removal and surface morphology will be discussed. @FootnoteText@ @footnote 1@W.C. Hughes, W.H. Rowland, Jr., M.A.L. Johnson, S. Fujita, J.W. Cook, Jr., J. Ren, and J.A. Edmond, J. Vac. Sci. Tech. A, 13, 1571 (1995).@footnote 2@E. Bauer, private communication.

4:20pm **SE-ThA8 Controlling Thin Film Morphology and Selectivity using Collimated Monoenergetic Molecular Beams**, ***J.R. Engstrom,*** Cornell University **INVITED**

Over the past several years we have been investigating the fundamental aspects of thin film growth using energetic neutral molecular beams produced by supersonic expansions as sources. Our focus has been on Group IV systems-- Si, Ge and Si@sub 1-x@Ge@sub x@. This work has ranged from detailed investigations of the gas-surface chemical dynamics of dissociative adsorption, to thin film deposition and growth emphasizing morphological aspects, to computer simulations of both the thin film morphology and gas-surface fluid dynamics. We will present an overview of this work, focusing on more recent developments, which will include (i) the growth of thin films at grazing angles of incidence; (ii) the selectivity of growth (e.g., Si vs. SiO@sub 2@) as a function of beam energy, beam composition and substrate temperature; and (iii) the exploration of scale-up strategies (experiment and computer simulation) for deposition over large areas.

5:00pm **SE-ThA10 Three Dimensional Modeling of Silicon Deposition Process Scale-up Employing Supersonic Jets**, *G. Chen,* ***I.D. Boyd**, J.R. Engstrom,* Cornell University

A new technique to deposit silicon thin films employing supersonic beams is examined. Our previous studies involved both experimental and numerical approaches, in which the thin films were deposited at high growth rates but over relative small areas. The current studies are focused on the process scale-up by using multiple discrete supersonic jets. 1% disilane/hydrogen mixture is heated to 350 °C and ejected through nozzles to a 700 °C substrate. Three dimensional simulations are conducted to investigate the geometrical effects of the molecular beam sources. One source configuration involving multiple jets is found to successfully deposit uniform silicon films over an area of 18 cm in diameter, with a growth rate higher than 200 @Ao@/min. The molecular beam energy obtained under these conditions is approximately 1.3eV. A configuration is also designed to increase the deposition area in a laboratory facility for experimental verification.

Author Index

Bold page numbers indicate presenter